Thesis Project Portfolio

E-SKIN RESISTIVE STRAIN SENSOR: OPTIMUM SENSOR PLACEMENT

(Technical Report)

Designing and Manufacturing Electronic Skin

and the

Effect of Risk Homeostasis on Data Breaches and Possible Solutions

(STS Research Paper)

An Undergraduate Thesis

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

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Spring, 2022

Department of Mechanical Engineering

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Overview of Technical Portion

The technical portion of this paper investigates Electronic Skin, more specifically the design and manufacturing process of a temperature/strain sensor. The goal of the project is to understand the concepts and application for thin skin-like electronics and the potential positive effects it may have in the medical field. In order to track temperature, the device must be able to detect subtle, time-dynamic changes in temperature over a very small time period. Traditional thermometers are too massive and require longer equilibrium times because of this and make them impractical for constant monitoring. A thermal sensor relies on changes of resistive, semiconducting or optical properties of a material. This paper will be dealing with what is known as a standard resistance thermometer.The design process begins with recognizing(through research) that serpentine and spiral designs are favorable in the case of the creation of a temperature or strain sensor. Initially, a 3D printed mold is created to replicate a pattern of either serpentine or spiral divots, followed then by pouring Polydimethylsiloxane on the mold which is then peeled off to reveal our design imprinted onto the PDMS. Prior to this, PDMS must be mixed in parts of PDMS-Curing Agent 10:1 in order for it to solidify/cure. It is important to note that the PDMS must cure, meaning it must be left to sit and essentially harden for a couple of hours. Multi-walled Carbon Nanotube(MWCNTs) are then scraped into the divots. This layer must also be left to cure and is typically left overnight. Upon further experimentation, laser cutting into a layer of PDMS produces an easier to work with sensor. Following this, a layer of PDMS is laser cut into in order to create a design that best allows for the measurement of strain and temperature i.e. a serpentine design. PDMS is chosen because of its advantageous properties in medical application like its flexibility, low cost and its mass producibility. MWCNTs are then scraped into the divots and wires are embedded into this layer. MWCNTs are used because of their high conductivity, which is ideal in the case of a sensor that measures temperature and strain changes through the means of measuring a change of resistance. Another layer of PDMS is then used to seal the sensor followed by testing. Testing is accomplished through the use of both a Bunsen burner for temperature variation and a tensile expander that pulls the sensor appart for strain variation. By connecting the wires previously embedded into the sensor to a Digital Multimeter, resistance changes can be found with respect to our independent variables.

Overview of STS Thesis Project

In relation to the technical portion, the STS portion of this thesis investigates risk with respect to newly introduced technology, including medical equipment like electronic skin and wearable devices. The main objective of the paper is to use Risk Homeostasis Theory(RHT) to explain security risks in the medical field. RHT is a theory that explains the relationship between "population accident rate and the level of perceived accident risk." If the accident rate increases, the population will become more cautious and the accident rate will subsequently decrease. This works both ways and can happen very suddenly and fluctuate until it reaches an equilibrium, hence "homeostasis". Although some disagree, this theory might explain a lot of the risk phenomena seen when safety tech is introduced into a society(Pless, 2016). This theory can be extended to perceived risk of any technology, including but not limited to storage system technology which is susceptible to leaks, not just safety technology. This paper looks to review past dangers predicted by this theory that occur when existing technology is not maintained and secured. One existing example of this that is very prevalent in today's society is the security of the average user's data. The goal of this thesis is to analyze how technology affects society, more specifically the everyday user. The paper discusses Packet Sniffing, a common technique used to leak data, where an individual can monitor data traveling through a network and record sensitive information. Wearable devices, The Internet of Medical Things and financial disruptions are discussed. Through each example, RHT can be used to analyze the consequence of the introduction of each.

E-Skin Resistive Strain Sensor: Optimum Sensor Placement

A Technical Report submitted to the Department of Mechanical Engineering

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Denis Chavarria Ramirez

Spring, 2022

Technical Project Team Members

Sohail Ghatnekar

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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

Lin Ma, Department of Mechanical Engineering

This project serves as an application of the cutting-edge work that has been done with transparent, elastic conductors, which are paving the way for the development of wearable devices with the ability to conform to the curved, irregular surfaces of the human body (Ray et al., 2019). E-skin sensors will be the future of wearable exercise technology, and this minimally invasive device will be a step in the direction of fully functioning continuous tracking technology. The sensor, designed in Solidworks, is a body-conforming resistive strain and temperature sensor that fits onto the anterior deltoid. While the sensor was unable to be tested on human subjects due to time and monetary restraints, it was designed, manufactured, fabricated, and tested in a mechanical setting for its temperature measuring capabilities. This report details the design considerations, and manufacture, fabrication and testing of the sensors. The sensor, made of polydimethylsiloxane (PDMS) and multi-walled carbon nanotubes (MWCNTs), was tested for the repeatability and the resistance to temperature relationship, by calculating the coefficient of temperature. The coefficient of temperature was very similar for both sensors analyzed, and indicates that the device and process could be repeated for further testing in the future. Further applications and future research could include further testing of various device iterations, as well as mechanical strain testing.

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INTRODUCTION

The purpose of this project was to create a non-invasive, e-skin resistance sensor to measure both temperature and mechanical strain on whatever part of the body it was placed. The sensor was designed to conform to the anterior deltoid, but is able to conform to multiple different parts of the body with relative ease, and accuracy. The sensor for this project has undergone multiple iterations to reach the current design. The current design uses highly accurate laser cutting capabilities, which differ from initial iterations that used 3D printing, which introduced multiple issues with accuracy and repeatability of manufacture. The design of the device is a 4x2 array meant for mechanical strain sensing. Due to time constraints, the device was changed to become a temperature sensor, but future iterations could include mechanical strain capabilities. The device was designed using the 3D CAD software, Solidworks, but was converted to a vector file, as the laser cutter was able to cut the 2D image to the necessary depth required. Polydimethylsiloxane (PDMS) was chosen as the substrate material, and multi-walled carbon nanotubes (MWCNTs) were chosen as the conductive material due to their ease of accessibility, as both materials are very cheap and have been thoroughly studied. This report gives a detailed narrative of the design, fabrication, manufacture, and testing process, with insights for further work.

DESIGN THEORY AND WORKING PRINCIPLE

Our project serves as an application of the cutting-edge work that has been done with transparent, elastic conductors, which are paving the way for the development of wearable devices with the ability to conform to the curved, irregular surfaces of the human body (Ray et al., 2019). As such, our design for a skin-like wearable temperature and potentially strain sensor was developed via the careful threefold analysis of physiological, material, and engineering factors.

PHYSIOLOGICAL CONSIDERATIONS

First and foremost, Miyamoto et al. (2017) signal the imperativeness to consider the biocompatibility of the chosen materials, as long-term psychological and physiological effects, can originate from improper electronic skin (E-skin) administration. Naturally, wearable electronics that interface with the skin should be minimally invasive, and the best results in this sense—measured in terms of the three principal factors of gas permeability, weight, and softness—are achieved with materials containing a porous, flexible structure. As such, irritation and discomfort can be reduced in long-term applications by introducing both stretchability and conformability to thin-film electronics, devices, and sensors. Planar substrates have always posed a challenge in enhancing these qualities (Miyamoto et al., 2017).

Further insight into desirable material properties can be found by evaluating the defining characteristics of human skin, namely self-reparative properties and mechanical compliance (Miyamoto et al., 2017). The latter allows skin to flex and stretch without incurring physical damage and exists as a result of it's low mechanical modulus, a key element in the organ's ability to transmit physical properties to the receptors buried under the protective epidermis layer (Miyamoto et al., 2017). In turn, the resulting complex textures and eccentric natural motions cannot be accommodated by pure bending: the ability to flex only enables effective integration across "small regions of the body or those with simple, gradual curvature" (Ray et al., 2019). Here, it is critically important to study stretchability, as defined by "linear elastic responses to large strain deformations" (Ray et al., 2019).

MATERIAL CONSIDERATIONS

Substrates have been a subject of great interest due 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 broad commercial availability and well-researched properties (Hammock et al., 2013). This popularity is largely a product of its numerous advantages, which include chemical inertness, stability over a wide range of temperatures, transparency, and variable mechanical properties (Hammock et al., 2013). E-skin applications rely heavily on PDMS's ability to define adhesive and non-adhesive regions through exposure to UV radiation, a specially important feature for bonding electronic materials to its surface (Hammock et al., 2013).

Carbon nanotube (CNT)-based active materials have likewise been remarked by preeminent researchers and engineers like Hammock et al. (2013) for their chemical stability and exceptional electronic and material properties. With proper alignment, a necessity for optimized performance, and near-ballistic transport has been achieved in defect-free tubes. From a fabrication standpoint, CNT networks are a superior choice, offering more uniform performance and better compatibility with conventional lithography and printing techniques. Moreover, stretchable conductors in both printed and photo-patterned versions have achieved excellent performance with the introduction of conductive materials like metallic spheres, flakes, and wires. The caliber of the conductor is principally determined by the relationship between this filler material and the matrix elastomer, as denoted in reports from Hammock et al. In general, large filler concentrations are typically associated with an enhanced elastic modulus and reduced strain at break. Nevertheless, anisotropic fillers have a low percolation threshold that generates strong electrical properties at lower concentrations. As such, CNTs, which are both highly conductive and highly anisotropic, have been one of the most successful fillers. That being said, controlled aggregation into conductive pathways can additionally be employed to improve stretchable conductor design by reducing the required filler loading and enhancing conductivity (Hammock et al., 2013).

Large-scale reversible elasticity is perhaps the most desirable property for potential E-skin materials, and Hammock et al. reveal that it can be achieved using discontinuous structures that can distort while retaining electrical conductivity. Importantly, the discontinuous structures can be patterned at different length scales, yet still rely on similar mechanisms. Depositing a network of discontinuous, one-dimensional conductors limits the accumulation of stress and in turn, produces similar results to thin-film cracking. At a larger scale, deliberately patterning the discontinuous structures in convoluted, typically serpentine or horseshoe-shaped pathways can further reduce network strain. In this case, a primary concern is maintaining contact during stretching, but the long nanostructures in the network bridge conductive regions, thereby retaining electrical conductivity (Hammock et al., 2013).

ENGINEERING CONSIDERATIONS

According to Ray et al., the development of stretchable electronics involves the application of synthetic materials. Bulk or laminar composites, a common synthetic material, are typically composed of active materials and dielectric elastomers such as silicones, polyurethanes, and copolymers. Internal charge transport occurs via two components: percolation pathways within a material and the collection of micro/nanostructures. The former supports the material's electronic functionality, while the latter defines its elastic mechanics and serves as a conductive filler embedded in an insulating elastomer matrix. In turn, the compositional ratio between these two components determines the percolation threshold or the point at which the bulk material becomes conductive. By definition, the compositional ratio is inversely related to the aspect ratio, surface area, and dispersion of the conductive filler (Ray et al., 2019).

Ray et al. also illustrate how foundational work with composites in the context of stretchable electronics relies on conductive, multi-walled carbon nanotubes (MWCNTs). When used as the primary conductive constituent in laminar composites, MWCNTs can offer superior electrical properties to their bulk counterparts, largely due to both their ability to support thin-film geometries and their absence of an insulating component within the active layer. The most popular fabrication approach embeds thin films of carbon nanomaterials between elastomer layers. Typically, this is implemented by either the physical transfer or direct deposition of prefabricated films onto the elastomeric membranes. Mechanically, the system relies on the reversible, nonlinear buckling of the nanomaterials, which can be predictably modeled using Newtonian mechanics (Ray et al., 2019).

Most device designs involve compromising sensitivity to improve stretchability and vice-versa. Ray et al. observe that the use of multiple optimization strategies in a single device platform can mitigate the unique trade-offs associated with any particular method. In this sense, it is essential to consider a sensor's performance in terms of gauge factor (GF), as this metric is closely linked to changes in length and cross-sectional area for geometrically-induced changes in resistance. Yet, the most critical design criterion for any wearable electronic device ultimately lies in achieving the intimate, conformal contact necessary to support interface-dependent clinically relevant measurement modalities, such as electroencephalography (EEG), electromyography (EMG), electrocardiography (ECG), precision skin thermography, arterial tonometry, arterial tonometry, and vital sign monitoring (Ray et al., 2019).

PROJECT APPLICATIONS

Drawing from the above physiological, material, and engineering considerations, the sensor is designed to capture the dynamic motions and temperature 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 is intended for placement on the anterior deltoid (shoulder). Resistive sensors in a 4x2 array are aligned to optimally measure uniaxial strain and temperature along the muscle fibers. For relative ease of manufacturability, the sensor employs an elastomeric substrate base with channels of conductors laminated to its surface. Taking into account relative commercial popularity and availability, polydimethylsiloxane (PDMS) was chosen as the substrate material, and multi-walled carbon nanotubes (MWCNTs) were chosen as the conductive material.

DESIGN AND FABRICATION

MATERIALS PREPARATION

As previously stated, the primary materials used to manufacture the temperature sensor are polydimethylsiloxane (PDMS) and multi-walled carbon nanotubes (MWCNTs). To create the PDMS solution, a 10:1 ratio of PDMS to curing agent (hexane) is mixed to promote the curing process. Once cured, the hexane is dissolved and only PDMS is left. To create an optimal layer, the area of the container was measured, and volume calculated. The PDMS mixture must be degassed in a pressurized environment to reduce imperfections in the material, and guarantee uniformity throughout the substance. Similarly, MWCNTs is mixed with a PDMS solution at a ratio of 10:1. The MWCNTs appear to be dustlike, and must be cured with a PDMS solution to conform and connect with the mold. The MWCNTs solution must also be degassed so as to ensure full uniformity within the substance. Similar to the PDMS mold, the MWCNT solution must be cured on top of the mold for at least one day to guarantee full connection between parts.

STRUCTURAL DESIGN

The structural design was developed based on previous resistive temperature sensor models, with a slightly adapted format designed to meet the needs of the particular use case. The layout was created on Solidworks, under a 4x2 strain array. The various measurements of the mold were first coded into a 3D modular form, providing for the thinnest possible mold, under the specific allowance of the 3D printer used (the printer had a tolerance of 1mm). Figure 1 on page 9 displays the manufacture sheet of the strain sensor, with specific measurements of the full device in millimeters.

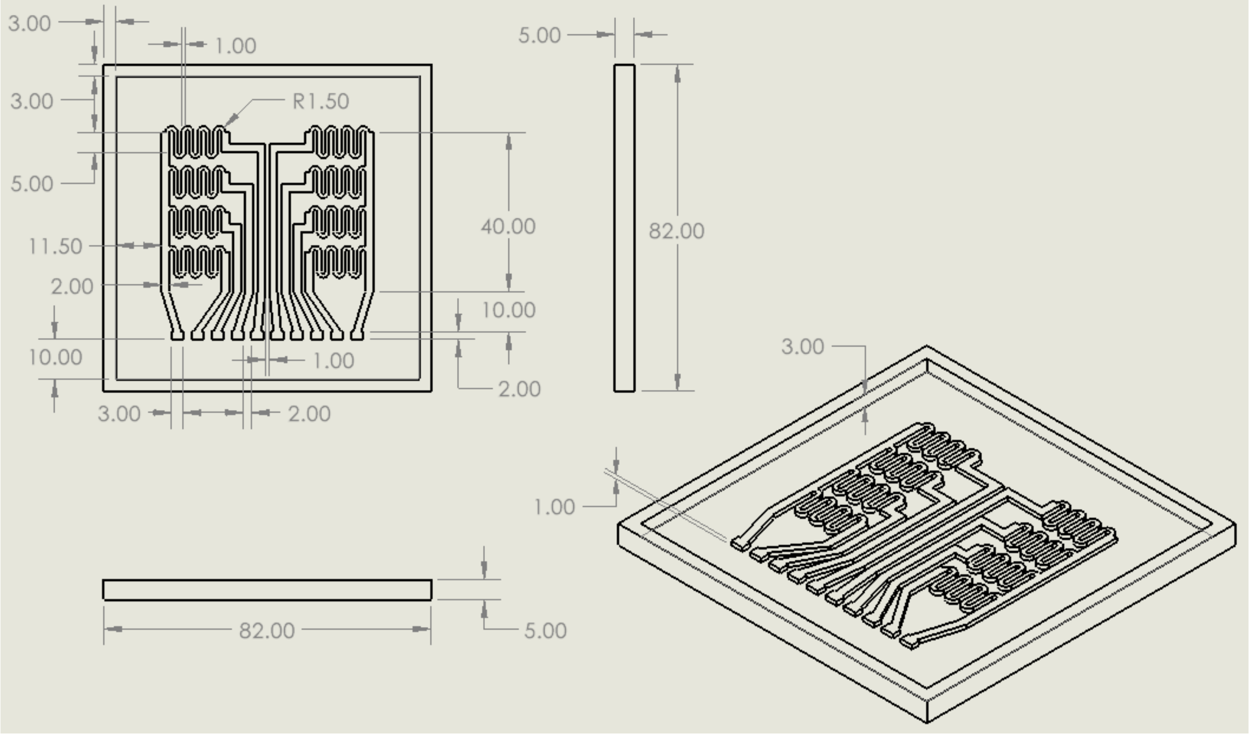

Figure 1: Sensor Mold Design with Measurements: The Solidworks part measurements and design sheet for the 3D sensor mold. (Ghatnekar et. al. 2022)

After various trials, under the specific specifications of an e-skin sensor, that must be as minimally invasive as possible, it was concluded that the mold procedure was not feasible. Due to the higher tolerance of the machine when compared to our design, a K40 Laser Cutter was discovered as a solution to the tolerance problem. Using the same design as indicated above, a 2D vector drawing was rendered. This design as seen in Figure 2 on page 10 below, was uploaded to the K40 Laser Cutter so as to implement a more precise cut directly into a layer of PDMS to minimize room for error.

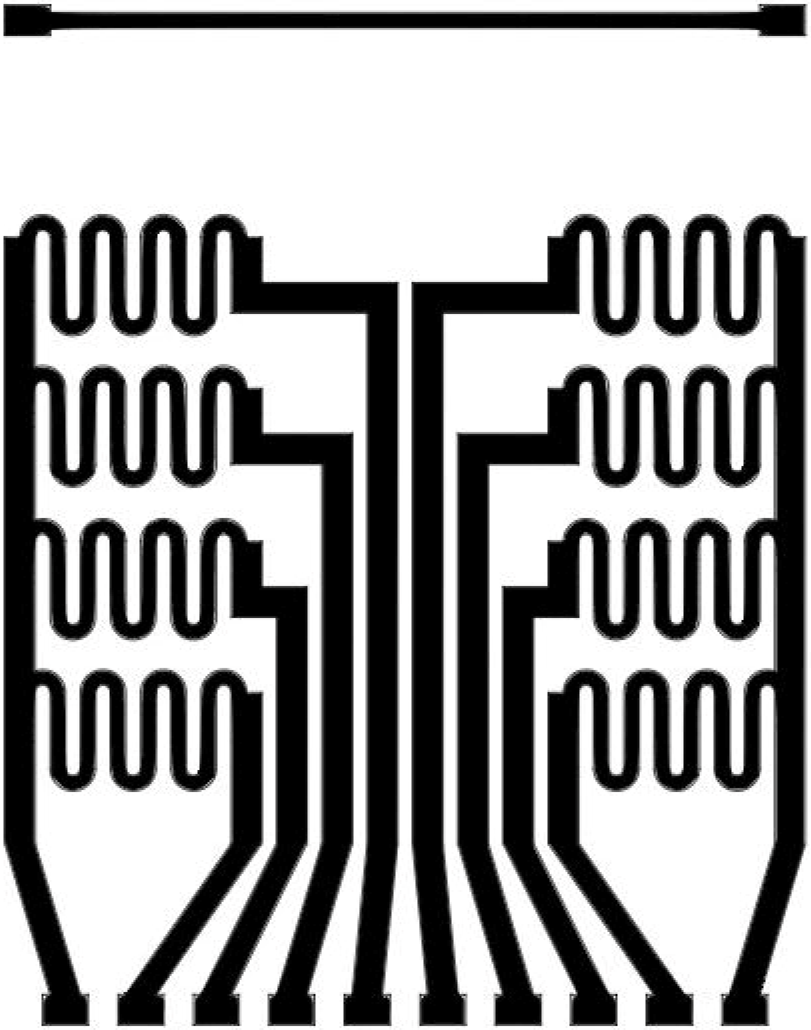

Figure 2: 2D Vector Sensor Design: The vector image of the design, used in laser cutting with the K40 Laser Cutter. (Ghatnekar et. al. 2022)

FABRICATION

Fabrication of the wearable was a multistep process. First, the area of the pietri dish where the sensor was made was measured. The dish had a radius of 7 mm, and therefore an area of about 153.9 mm^2. The volume of the pietri dish was then measured, as the PDMS solution needed to be 2 mm thick, so that the MWCNT channels could be 1 mm thick. The PDMS solution, at a 10:1 ratio, was measured using a scale and a mixing capsule. Under the assumption that the density of PDMS is 1 kg/m^3, the PDMS was measured to 31 g, and the hexane curing agent was measured to 3.1 g. The mixture was, then, mixed and degassed until there were no visible bubbles, or impurities, within the solution. Finally, the pietri dish was sprayed with a desticking spray, for ease of removal of the device once manufactured, and the device was cured overnight.

Next, the K40 Whisper software was used to cut into the PDMS solution to create a mold for the MWCNT mixture to be laid. The laser was operated at a Raster speed of 40 mm/s, operating at 9% power to engrave the cured substance as fast as possible, while not sacrificing precision, and optimizing safety. The process of laser cutting can be seen in Figure 3 below.

Figure 3: Laser Cutting of Mold: Laser cutting process of the mold, showing the intensity and precision of the cutting process. (Ghatnekar et. al. 2022)

The laser left certain byproduct behind that was not conductive, and therefore was necessary to clean off. Using an ethanol solution, as well as an air jet, the cut PDMS was washed off, so as to provide a clean surface for MWCNT solution application.

Similar to the PDMS solution process, the MWCNTs were also mixed at a 10:1 ratio. It was necessary to mix this solution at a high ratio, as the resistivity of the substance increases with higher MWCNT concentrations. The MWCNTs were mixed with the PDMS and hexane, at the same ratio as indicated above, and the solution was mixed in a UV bath to ensure full MWCNT matriculation and uniformity within the substance. After a minimum of 3 hours, the solution was removed and coated on the channels of the device. Next, the device is placed in a pressure chamber to degas again, The tedious process of coating takes multiple cycles. The first cycle completes an initial coating, but the MWCNT mixture shrinks after curing due to the evaporation of hexane from the solution during the curing stage. After multiple cycles of MWCNT coating, degassing, and curing the device looked uniform with a uniform top layer. Wires were then added at the pads of the device so that mechanical testing may be completed. Finally, the device was removed from the pietri dish, and the pietri dish was sprayed and cleaned again. A PDMS mixture at a 10:1 ratio was created, though only 15 g of PDMS solution are created, degassed, and poured into the pietri dish. The device was layed face down into the pietri dish and placed on top of the thin PDMS layer to coat and seal the device. Once cured, the device is removed, and excess PDMS is removed, finalizing the fabrication process.

RESULTS AND DISCUSSION

To test the accuracy of the device measurement, a temperature test was performed. Using a test strip from the manufactured design, as shown in Figure 4, the necessary calculations for the resistance vs. temperature relationship were measured.

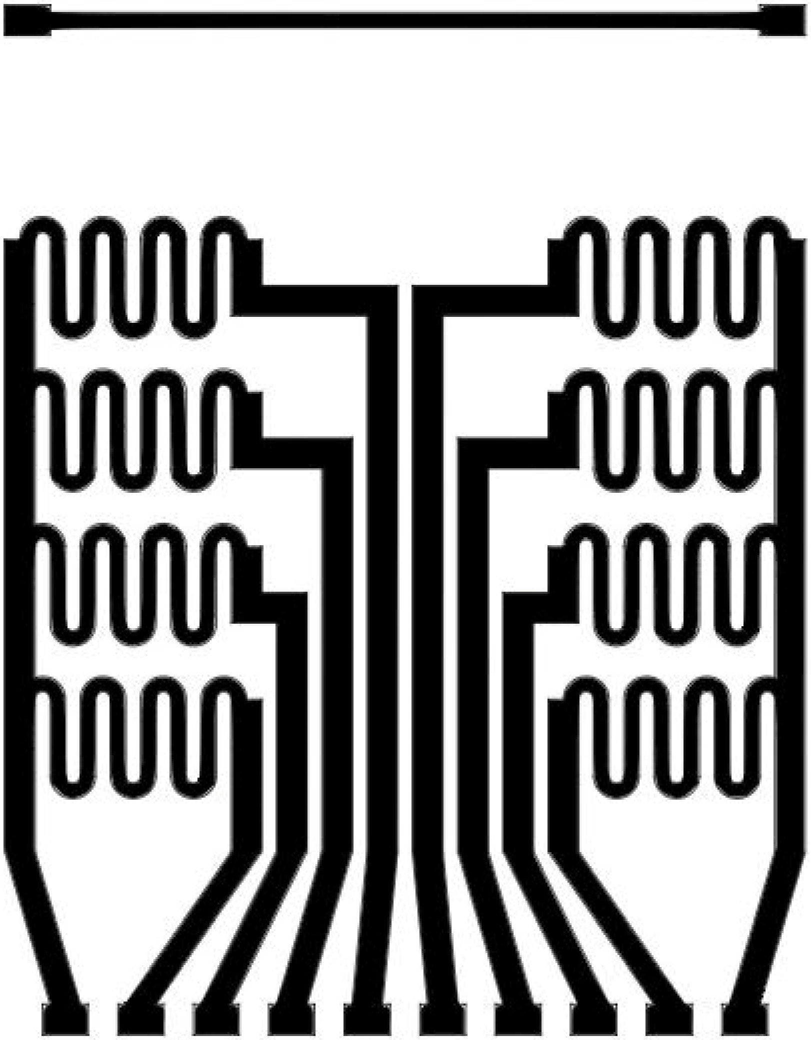

Figure 4: Testing Sensor Strip: To test the mechanical properties of the device, a smaller strip was developed using the same process that was indicative of how the full device would work. (Ghatnekar et. al. 2022)

First, the resistance of the device was measured at room temperature (25 °C). To measure the resistance, a Fluke 101 600V CAT III Multimeter was used, measuring the resistance of the sensor in kΩ. Next, the device was placed on a Thermo Scientific hot plate, and the temperature of the device was raised in increments of 5 °C until the temperature reached 45 °C. The temperatures were chosen, as they are the closest related to the range of human skin temperature. At each temperature, the device was allowed to rest for approximately 3 minutes to ensure full device uniformity in temperature. Subsequently, 3 different measurements were recorded at each temperature in 30 second intervals. The method for recording is diagramed in the schematic in Figure 5 below.

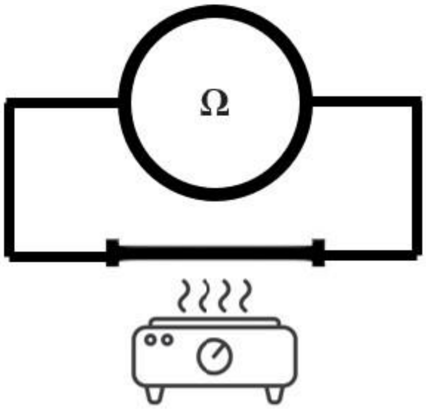

Figure 5: Schematic for Electrical Response to Temperature Testing: The method for device temperature testing, using a hot-plate, with the sensor connected to an ohmmeter, measuring the resistance of the device in kΩ. (Ghatnekar et. al. 2022)

The process was repeated in two different samples of varying thickness, one that was 3.5mm thick, and one that was 4mm thick. Once completed, the response to temperature was analyzed under the differing temperatures to analyze if the coefficient of temperature was the same for both samples, therefore confirming if the MWCNT mixture would be usable in future measurements and iterations of the study. Using the equation, $\Delta RR0=T+1$, where ΔR is the change in resistance of the sensor at varying temperatures, R_0 is the initial measured resistance of the sensor at room temperature (25 °C), α is the coefficient of temperature, and T is the measured temperature in °C. The recorded data for each sensor can be found in Appendix A.

The correct resistance ratio, ΔRR0, the temperature ratio was assumed to be the same as that of a uniform metal, meaning a purely linear measurement. As seen in Figures 6, both the 3.5 mm and 4 mm molds had a relatively linear distribution.

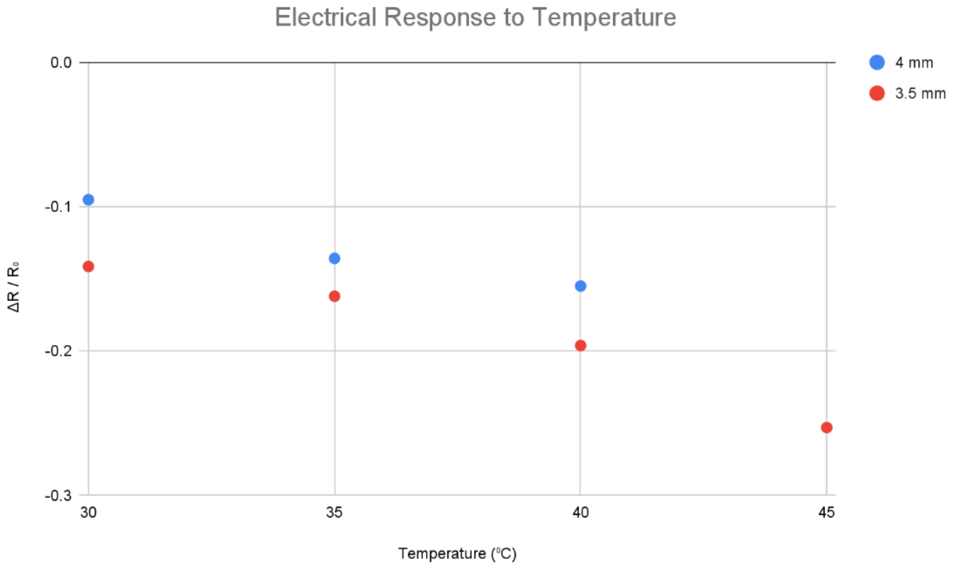

Figure 6: Electrical Response to Temperature Graph: The graph of the resistance ratio to temperature relationship for both mold thicknesses, to find the coefficient of temperature. (Ghatnekar et. al. 2022)

The measured α for the 3.5 mm mold was -0.0326 C^{-1}, while the 4 mm mold had a measurement of -0.0322 C^{-1}. While both were not exactly the same, they differed by about 1%, which is fairly accurate. It is worth noting that the data for the 4 mm mold is lacking a data point at 45 °C. It is unknown as to why the device failed to record a resistance measurement at this temperature, but can be hypothesized that the wire connection to the MWCNT channel within the sensor failed, and the sensor was broken, rendered useless. Interestingly, the measurements for resistance were all about 4% lower for the 3.5 mm compared to the 4 mm mold. This may be attributed to the random nature of the MWCNT connections and the channel, as well as the greater relative thickness of the MWCNT channels compared to the rest of the sensor thickness.

CONCLUSION

Due to time and monetary constraints, the sensor was not able to be tested on human subjects. Similarly, the device was unable to undergo mechanical strain testing, so as to be applied in a sporting/biomechanical environment. Also, for future applications of this project, the wire materials must be further analyzed, and a new method for wire implementation must be included. With the current results, further analysis of the MWCNT and temperature relationship may be conducted to analyze the relationship between the resistance ratio and temperature within this material. If possible, an exact value for the temperature coefficient would make the creation of more sensors using this method easily repeatable, scalable and feasible. While the sensor is still not able to provide use on human subjects, further research into the sensor, and further design and fabrication with the laser sensor could create a viable, exact, and precise sensor for human testing.

ACKNOWLEDGMENTS

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REFERENCES

Hammock, M. L., Chortos, A., Tee, B. C.-K., Tok, J. B.-H., & Bao, Z. (2013). 25th anniversary article: The evolution of electronic skin (E-skin): A brief history, design considerations, and recent progress. *Advanced Materials*, *25*(42), 5997-6038. https://doi.org/10.1002/adma.201302240

Miyamoto, A., Lee, S., Florence Cooray, N., Lee, S., Mori, M., Matsuhisa, N., Jin, H., Yoda, L., Yokota, T., Itoh, A., Sekino, M., Kawasaki, H., Ebihara, T., Amagai, M., & Someya, T. (2017). Inflammation-free, gas-permeable, lightweight, stretchable on-skin electronics with nanomeshes. *Nature Nanotechnology*, *12*, 907-913. https://doi.org/10.1038/nnano.2017.125

Ray, T. R., Choi, J., Bandodkar, A. J., Krishnan, S., Gutruf, P., Ghaffari, R., & Rogers, J. A. (2019). Bio-integrated wearable systems: A comprehensive review. *Chemical Reviews*, *119*(8). 5461-5533. https://pubs.acs.org/doi/10.1021/acs.chemrev.8b00573

Zardetto, V., Brown, T. M., Andrea, R., & Di Carlo, A. (2011). Substrates for flexible electronics: A practical investigation on the electrical, film flexibility, optical, temperature, and solvent resistance properties. *Journal of Polymer Science Part B: Polymer Physics*, *49*(9), 638-648. https://onlinelibrary.wiley.com/doi/10.1002/polb.22227

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Denis Chavarria Ramirez

Spring 2020

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

Lin Ma

Joshua Earle, Department of Engineering and Society

Introduction and Methods:

Risk Homeostasis is a theory coined by Gerald Wilde, a Professor Emeritus of Psychology at Queens University (Wilde, 2012). The theory explains that there is a homeostatic relationship between “population accident rate and the level of perceived accident risk.” (Wilde, 2012). If the accident rate increases, the population will become more cautious and the accident rate will subsequently decrease. This works both ways and can happen very suddenly and fluctuate until it reaches an equilibrium, hence “homeostasis.” Although some disagree, this theory might explain a lot of the risk phenomena seen when safety tech is introduced into a society (Pless, 2016). This theory can be extended to perceived risk of any technology, including but not limited to storage system technology which is susceptible to leaks, not just safety technology. In this paper, I review past dangers predicted by this theory that occur when existing technology is not maintained and secured. One existing example of this that is very prevalent in today’s society is the security of the average user's data. The goal of this thesis is to analyze how safety technology affects society, more specifically the everyday user.

In this paper, I am applying Risk Homeostasis theory to data storage safety. Risk Homeostasis Theory begins with an existing technology, user information/data. Given this technology is secure and safe, users or creators of the technology will either become more comfortable with the security of their information or ignore and/or brush aside potential issues within the system. Consequently, data or user information will leak. Maintenance will then be done and users will become more aware of how valuable their information is by becoming informed. Unfortunately this only happens after some damage has been done. Finally, the amount of data leaks will decrease (given that action is taken to secure the data in question). Predicting human behavior as a result of the effects of safety technology can be extremely useful.

It helps prevent or educate users of potential problems that may arise due to feelings of comfort produced by said technologies and the services they provide. In this paper, I analyze various other papers and increase user awareness of the security of their data and potential consequences that may occur due to user/creator apathy. The world we live in torday is data-heavy so addressing concerns around sensitive data is crucial in that it can save lives.

Gerald Wilde emphasizes the importance of the word homeostasis due to a common misconception surrounding his theory. He explains that the perceived accident rate is by no means fixed once and forever, hence the term homeostasis in the theory. It fluctuates between limits and will change if circumstances demand it. If the accident rate fluctuates, the perceived accident risk will fluctuate (Wilde, 2012). This fluctuation specifically is what allows for analysis of the issues presented in this thesis, the fluctuating nature of accident rate and risk. This fluctuation implies space for improvement, in this case the decrease in data leaks which may mean an increase in user security.

A more niche example of a technology that can be analyzed using Risk Homeostasis Theory is wearable technology. The application of Risk Homeostasis Theory can be seen more clearly through this medium. Wearable technology has become increasingly popular over the past decade, more specifically electronic skin and its effects in the medical field. Electronic skin can collect data like temperature, strain, heart rate, blood oxygen level, and cholesterol levels which are all very useful in diagnosing patients. The data it collects is valuable and personal, therefore any data leakage could be extremely sensitive and damaging.

It follows that because this technology can be useful, it carries sensitive information that is valuable to those with malicious intentions. One common way information can be leaked is through a technique called “Packet Sniffing,” where a hacker can monitor data traveling through a network and record sensitive information (Maity, 2022). This hacking technique led to a research paper written by Rudranil Maity and Rajdeep Chakraborty titled “A Progressive Approach Towards Securing Hospital Networks from Packet Sniffing using WireShark.” Packet Sniffing is used through a tool called WireShark and Maity and Chakraborty explore ways this has affected the medical field. Maity and Chakraborty also discuss how hospitals can protect themselves from cyber attacks similar to this. As can be seen, the nature of Risk Homeostasis theory predicts that because of the occurrence of hacks within the medical field, there must be a response, that response being a preventative measure like a stronger security system or an increase in monitoring of data. In the case of this paper, Maity et al. suggest the use of encryption and a Secure File Transfer Protocol (Maity, 2022)to decrease the amount of breaches in transferring data, sensitive or not. After these preventative measures are taken stakeholders will inevitably become complacent, leading to another rise in risk as malicious actors improve their techniques. The cycle between attacks and increasing security will continue until either the system is absolutely secure, or, more likely, an equilibrium is reached. The equilibrium being found between the amount of risk taken and the action taken to prevent negative consequences, in this case data leaks.

E Scott Geller talks at length about risk in an article titled “Does feeling safe make us more reckless.” He gives a perfect example of safety gear in sports and how he willingly would throw himself at others with gear on because he perceived the risk to be low. Another article writes about the pandemic and how “a mask (a perceived safety measure) makes presence in a public area (risky activity) seem less risky” (Horenstein, 2021, p. 1). Also as mentioned earlier, the data in question varies tremendously and can be exploited by both the companies that store it as well as malicious individuals. Steve Huinn lays out the different types of data stored in medical devices and each one's importance (Huinn, 2020). The four main types of data include: physiological, therapeutic, demographic information, and device status. Physiological data includes “vital signs and measurement of body functions.” Demographic information includes height, weight, age, and the like. Therapeutic data includes information about how to treat a patient and protocols for the usage of devices.

Sensation or feeling force is just one example of a vital measurement that allows an individual to properly experience the world around them. Adapting (SA) mechanoreceptors sense constant, static forces and respond continuously throughout said force. Implementing SA and FA sensors into robots can allow for a more sensitized experience, allowing them to sense pressure and force to either proceed or halt their task, depending on the situation. Robots however are also susceptible to leaks and hacks, like any piece of technology.

Temperature sensing and kinematic sensing are two other measurements that are important to keep track of for the diagnosis of a patient (Ray, 2019). Kinematic sensing deals with the monitoring of strain which, not surprisingly, deals with strain sensors that detect elongations of a material, typically through the use of electricity (Nachazel, 2020). The sensor's resistance changes as a result of elongation and this resistance can be converted to the amount of strain or elongation %. This is crucial in monitoring athletic performance in the training and recovery stages during an athlete’s career. More related to the medical field, this can be useful in diagnosing movement or neurological disorders by observing movement patterns (voluntary or involuntary) of a patient (Ray, 2019). As stated previously, temperature is a critical biomarker for human health which can indicate sickness. In order to track temperature, the device must be able to detect subtle, time-dynamic changes in temperature over a very small time period (Ray, 2019).

A 2019 paper written by Victor Chang and colleagues claims there to be 3 main issues with the introduction of wearable tech (Chang, 2019). One, “system vulnerabilities” can be found and may cause exploitation of user data. Second, the lack of accountability that may rise within big companies promoted by the discrete distribution of user data. Third, companies prioritize surface level features rather than the security of the data within the system. This is in order to attract the most people in efforts of making a profit, disregarding the solidity and security of the system they have built.

The importance of these cannot be stressed enough. Online data isn’t physically tangible, but that doesn’t make it any less real. At times it can be difficult to see how simple things like heart rate or temperature can do any harm, but by putting yourself in the position of an immunocompromised individual one will realize the true sensitivity of this information. People can and will get hurt if users and companies are not careful. Privacy and security should be everyone's priority when dealing with any personal online information. As Risk Homeostasis Theory puts it, the more neglectful we are of our security, the higher the risk we are taking which will consequently result in undesirable outcomes to say the least.

Results/Analysis:

Wearable Devices

Wearable devices track anything from calorie count to mileage and although exploitation of these types of data seem pointless, accessing this may not be the end goal for some. Back in 2016, Fitbit users were hacked, their usernames and passwords were leaked on third party sites (McGee, 2016). Once inside the account, hackers attempted to order replacement parts through the company. These data breaches can even include the erasure of important medical information and may even lead to extortion, as seen earlier this year in a hospital in Miami presented in Chang and colleagues paper on The Ethical Problems of Wearable Devices (Collier, 2019). In this example, the risk is to invest your trust into the system in place at the hospitals in question. As one can see, trust combined with poor security resulted in the hospital becoming more susceptible to cyber attacks.

Internet of Medical Things

The Internet of Medical Things (IoMT), a prime example of a widely used system used in the medical field to store, interpret and give out information based on the situation of a patient and their needs (Pirbhulal, 2019). The idea originated in the 1970s when a group of students at Carnegie Mellon connected a Coke Vending Machine to the internet (AMTELCO, 2018). It is "the collection of medical devices and applications that connect to healthcare IT systems through online computer networks" (DelVecchio, 2015). It is what allows for constant monitoring of long term patients through the communication between machines via wifi. It is essentially a large dynamic database between machines that stores information like tracking the medication needs of an individual as well as where the individual is located and much more. This type of data transfer has revolutionized the medical field and allows for more lives to be saved. Naturally, the level of security this database has will be questioned. In a 2018 article, it was reported that there will be 30 billion devices on the Internet of Things database (AMTELCO, 2018). Note this is not the Internet of Medical Things, however, according to a 2019 Forbes article titled "The Hospital will see you now", approximately 696 million of these devices will be used in the medical field (Heredia, 2021). The amount of data transferred between these devices is only exponentially increasing, making it more likely to have data leaks. This emphasizes the importance of the structural integrity of these databases and devices. Looking through the lens of Risk Homeostasis

Theory, the more the database grows, the higher the number of people will be experiencing user apathy. This trust in the system (or user apathy) will lead to an increase in accident rates, or in this case data leaks. Given Risk Homeostasis Theory, one can see that with these breaches, precaution will rise amongst the creators of the Internet of Medical Things. In this case, one potential implementation can be to install database management systems (DBMS) that detect user intrusions (Bertino, 2005). This is a good start but constant monitoring and progress must be made in an attempt to minimize potential damage to patients around the globe. At the end of the day, patient security needs to be the number one priority.

Financial Issues

Financially speaking, both hospitals and patients can suffer tremendously as a result of the misuage of data. There are three standard ways this can happen, according to Pirbhulal et al. Victims may lose money if fraudsters obtain physician services. This issue is self explanatory, the more services given to fraudsters, the less attention those who are entitled to their coverage receive. Also, Victims may be charged a large amount for drugs they did not order, or an insurance company and individual both will lose money if fraudsters unite with a devious clinic and report services that have not been done. Money would then be disbursed to both the clinic and the fraudsters by the health insurance. This can lead to financial exploitation of the true owner of the insurance. The paper then goes on to provide a potential solution in attempts to minimize the amount of fraudulent access to medical data through an encryption based system (Pirbhulal, 2019). Data breaches are also surprisingly very expensive. Each record breach in 2020 resulted in a minimum penalty of approximately five hundred dollars. On top of this, the average penalty increased a significant amount, which was originally four hundred and twenty nine dollars to five hundred (Cheng, 2017).

Reform Attempts

Briefly mentioned earlier in the paper, many attempts to redesign medical databases have been made in order to improve user security. Chiu C. Tan and colleagues focused on improving the security of data relayed between Body Network Sensors (Tan, 2009). The idea was to use multiple encryption keys. The example they used was that during different times of day, a different key would be needed in order to decrypt user information, therefore limiting the amount of people you have access to with one given key. The Prabhulal paper attempts to explore the use of biomarkers as encryption keys within the Internet of Medical Things, since every individual is different, increasing the uniqueness of each key and the security as a result. Biomarkers can include anything from blood pressure, heart rate, fingerprints and/or genetic tests of blood. More specifically, they explore an Electrocardiogram (ECG) security based framework which they claim will “provide not only stability between resource-efficiency and security, but it also increases secret key strength so an attacker should not compromise either key or medical information” (Pirbhulal, 2019). A relatively new idea in the world of data encryption, the results from these bio generated encryption keys appear to be promising. Security measures like these are critical in the reduction of the equilibrium between perceived risk and accident rate. Risk Homeostasis Theory may seem trivial in many cases but it is trivial because it perfectly describes a simple relationship that can be seen everywhere in society and emphasizes the importance of security in areas like the medical field.

Discussion

Being aware of Risk Homeostasis Theory can be very useful in predicting potential issues that can arise when new technology is implemented into society. A majority of people feel indifferent when it comes to their online data. There is a lot of talk about how companies sell personal information to advertisement companies and how it can be used to target products to an audience. One might think “If it will improve user experience then this shouldn’t be an issue.” However, thoughts like this can be seen to have dangerous consequences. In 2017, Germany banned smartwatches for kids (Filip, 2017). One of the primary motivations for this attack is how easy it was to access the location of children, therefore threatening their safety. In an ideal world, companies prioritize the user and provide cyber-attack free databases/security systems but this is impossible. Regardless of this, the reform attempts mentioned above are a step in the right direction. Understanding where and how your data is stored is key to keeping your personal information safe and secure. If you understand the system being used to store your valuable information, you are more likely to build a successful case that attempts to reform the system set in place and replace it with a safer alternative/upgrade. Change begins with awareness and knowledge of the problem at hand. Risk Homeostasis Theory should be acknowledged universally as a simple and viable way of predicting human behavior and its important role in minimizing risk in all technology, not just safety technology. Throughout this paper Risk Homeostasis Theory has been used to explain risk very broadly, but statistical analysis can be used to analyze certain situations more specifically, allowing for more impactful use of this theory and its predictive nature.

Conclusion

“There needs to be more awareness when it comes to where personal information is distributed to and how well protected that data is.” This paper has explained the kind of data present in the medical field and how it can be used maliciously if not properly secured. Risk Homeostasis theory predicts this. Risk Homeostasis Theory not only does this, but it suggests that simply being aware of how this may occur can help decrease the amount of data leaks. The paper then proceeded to analyze different studies explaining the inner workings of the medical field's main data storage system, Internet of Medical Things. Financial issues were briefly discussed in order to raise awareness of the potential harm that could be done if data security is not taken seriously. Attempts at improving certain aspects of the storage system were discussed in order to provide potential solutions. Working towards a system that prioritizes user safety is the end goal. The solution to secure data is by no means the fault of one group of people. Both user and creator need to be aware of the importance of data and implement data that can help reduce data leak issues. Although just a theory, this paper shows how useful it can be to apply an idea as simple as RHT to predict responses to certain situations.

References

AMTELCO, 1C. (2018, August 30). The internet of medical things (IOMT). The Internet Of Medical Things (IoMT). Retrieved February 7, 2022, from https://www.healthitoutcomes.com/doc/the-internet-of-medical-things-iomt-0001#:~:text=Many%20of%20us%20are%20familiar,vending%20machine%20to%20the%20internet.

Bertino, E. (2005). Intrusion detection in RBAC-administered databases. Retrieved April 15, 2022, from https://ieeexplore.ieee.org/document/1565245

Chang, V. (2019, May 2). *Ethical Problems of Smart Wearable Devices*. Teesside University. Retrieved October 27, 2021, from https://research.tees.ac.uk/ws/portalfiles/portal/9950502/Smart_wearables_accepted.pdf

Cheng, L. (2017). Enterprise data breach: Causes. Retrieved April 16, 2022, from https://wires.onlinelibrary.wiley.com/doi/pdf/10.1002/widm.1211

Collier, K. (2021, February 5). *Hackers post detailed patient medical records from two hospitals to the dark web*. NBCNews.com. Retrieved October 27, 2021, from https://www.nbcnews.com/tech/security/hackers-post-detailed-patient-medical-records-two-hospitals-dark-web-n1256887

DelVecchio, A. (2015, August 31). What is IOMT (internet of medical things) or healthcare iot? - definition from whatis.com. IoT Agenda. Retrieved February 7, 2022, from https://internetofthingsagenda.techtarget.com/definition/IoMT-Internet-of-Medical-Things

Heredia, R. (2021, August 25). 10 of the best examples of IOT in Healthcare. Zipit. Retrieved February 7, 2022, from https://www.zipitwireless.com/blog/10-of-the-best-examples-of-iot-in-healthcare

Horenstein , A., & Grabiszewski , K. (2021, October 14). *When safety measures lead to riskier behavior by more people*. The Conversation. Retrieved October 27, 2021, from https://theconversation.com/when-safety-measures-lead-to-riskier-behavior-by-more-people-133039

Huin, S. (2020, November 12). *What are the types of connected medical device data? introduction to data governance and why privacy and security are essential in telehealth*. Irdeto Insights. Retrieved February 7, 2022, from https://blog.irdeto.com/healthcare/what-are-the-types-of-connected-medical-device-data-introduction-to-data-governance-and-why-privacy-and-security-are-essential-in-telehealth/

Irwin, L. (2021, December 14). What is the cost of a healthcare data breach in the US? IT Governance USA Blog. Retrieved February 8, 2022, from https://www.itgovernanceusa.com/blog/what-is-the-cost-of-a-health-care-data-breach-in-the-us#:~:text=According%20to%20the%20US%20Department,in%20losses%20of%20%2413%20billion.&text=This%20represents%20a%2025%25%20increase,in%20the%20past%20six%20years.

Maity, R., & Chakraborty, R. (2022). *A PROGRESSIVE APPORACH TOWARDS SECURING HOSPITAL NETWORKS FROM PACKET SNIFFING USING WIRESHARK* (No. 7561). EasyChair.

McGee, M. K., & Ross, R. (2016, January 11). *Fitbit Hack: What are the lessons?* Data Breach Today. Retrieved October 27, 2021, from https://www.databreachtoday.com/fitbit-hack-what-are-lessons-a-8793

Nachazel, A. (2020, August 14). *What is a Strain Gauge and How Does it Work?* Michigan Scientific Corporation. Retrieved October 27, 2021, from https://www.michsci.com/what-is-a-strain-gauge/

Pirbhulal, S., Samuel, O. W., Wu, W., Sangaiah, A. K., & Li, G. (2019, January 18). *A joint resource-aware and Medical Data Security Framework for wearable healthcare systems*. Future Generation Computer Systems. Retrieved February 7, 2022, from https://www.sciencedirect.com/science/article/pii/S0167739X18315474

Pless, B. (2016, August 29). *Risk compensation: Revisited and rebutted*. MDPI. Retrieved October 27, 2021, from https://www.mdpi.com/2313-576X/2/3/16/htm

Ray, T. R., Choi, J., Bandodkar, A. J., Krishnan, S., Gutruf, P., Tian, L., Ghaffari, R., & Rogers, J. A. (2019). *Bio-integrated wearable systems: A comprehensive review*. ACS Publications. Retrieved October 31, 2021, from https://pubs.acs.org/doi/10.1021/acs.chemrev.8b00573

Sinclair, I. (2001). *Resistance thermometer*. Resistance Thermometer - an overview | ScienceDirect Topics. Retrieved October 31, 2021, from https://www.sciencedirect.com/topics/engineering/resistance-thermometer

Tan, C. (2009, September 29). Ibe-Lite: A lightweight identity-based cryptography for Body Sensor Networks. IEEE Xplore. Retrieved February 8, 2022, from https://ieeexplore.ieee.org/abstract/document/5272415?casa_token=9tkpdVLe2koAAAAA%3AqirXR4BR2WJAExIuyLAXLOSb1E6iEd5RllESw8FWcTTJc5e8siGMjXGrx3e_Fzn70Ou4k-zPzBs

Wilde, G. (2012, September 18). *Risk Homeostasis: A Theory about Risk Taking Behaviour*. About Risk Homeostasis. Retrieved October 27, 2021, from http://riskhomeostasis.org/about-risk-homeostasis

Designing and Manufacturing Electronic Skin

(Technical Paper)

Effect of Risk Homeostasis on Data Breaches and Possible Solutions

(STS Paper)

A Thesis Prospectus Submitted to the

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University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree

Bachelor of Science, School of Engineering

Denis Chavarria Ramirez

Fall, 2021

Technical Project Team Members

Sohail Ghatnekar

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Nick Johnson

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 __________

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Approved ____ Date __________

Baoxing Xu, Department of Mechanical Engineering

Approved ____ Date __________

Kathryn A. Neeley, Associate Professor of STS, Department of Engineering and Society

Designing and Manufacturing Electronic Skin

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In STS 4500

Presented to

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By

Denis Chavarria Ramirez

November 1, 2021

Nick Johnson, Sohail Ghatnekar , Zachary Holden

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.

ADVISORS

Adarsh Ramakrishnan, Department of Engineering and Society

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Introduction

Risk Homeostasis is a theory coined by Gerald Wilde, a Professor Emeritus of Psychology at Queens University (Wilde, 2012). The theory explains that there is a homeostatic relationship between “population accident rate and the level of perceived accident risk.” (Wilde, 2012). If the accident rate increases, the population will become more cautious and the accident rate will subsequently decrease. This works both ways and can happen very suddenly and fluctuate until it reaches an equilibrium, hence “homeostasis”. Although some disagree, this theory might explain a lot of the risk phenomena seen when safety tech is introduced into a society(Pless, 2016). This theory can be extended to perceived risk of any newly introduced technology, including wearable technology, not just safety technology. E Scott Geller talks at length about this in an article titled “Does feeling safe make us more reckless.” He gives a perfect example of safety gear in sports and how he would willingly throw himself at others with the gear on because he perceived the risk to be low. Another article writes about the pandemic and how “a mask (a perceived safety measure) makes presence in a public area (risky activity) seem less risky” (Horenstein, 2021).This paper looks to analyze potential dangers predicted by this theory that may present itself when new wearable technology is introduced into society. One existing example of this that is very prevalent in today’s society is the security of the average user's data. The goal of this thesis is to analyze how technology affects society, more specifically the everyday user.

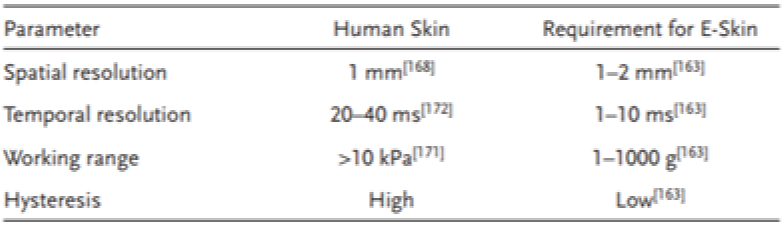
The theory begins with a newly introduced technology. People will then become careless with the way they handle their personal information. Consequently, data or user information will leak. Users will then adapt and become more aware of how valuable their information is by becoming informed. Finally, the amount of data leaks will decrease.

Predicting human behavior as a result of new technology can be extremely useful. It helps prevent or educate users of potential problems that may arise due to feelings of comfort produced by said new technologies. What will be presented are potential solutions to possible problems with wearable devices and how they can be implemented.

The technical topic is related to wearable technology, more specifically the design and manufacturing process of Electronic Skin(E-skin) whereas the STS topic deals more specifically with the data collected by wearable technology i.e. E-skin. This report will address potential problems that may arise with the increasing usage of Electronic skin and possible ways to prevent them.

The technical project, Designing and Manufacturing Electronic skin, focuses on the creation process of E-skin. The goal of the project is to understand the concepts and application for thin skin-like electronics and the potential positive effects it may have in the medical field. The project allows for an in-depth analysis on the motivation behind the improvement in E-skin, the materials used and things that still need to be worked on in the field of thin wearable technology.

Electronic skin was initially inspired by Science Fiction in the late 1900s and has since grown into a multi-billion-dollar market (Ray, 2019). A field with the highest demand for E-skin is the medical field, which would benefit by improving robots from doing well-defined and repetitive tasks to more dynamic ones. Mechanoreceptors are sensors found below our skin at different depths that allow us to sense the world around us (Hammock, 2013**).** Fast Adapting (FA) mechanoreceptors respond with intense signals and encourage high force output while Slow Adapting (SA) mechanoreceptors sense constant, static forces and respond continuously throughout said force. Implementing SA and FA sensors into robots can allow for a more sensitized experience, allowing them to sense pressure and force to either proceed or halt their task, depending on the situation. Below is a table that lays out similar minimum requirements that should be met when creating human-like electronic skin.



Parameter	Human Skin	Requirement for E-Skin
Spatial resolution	1 mm[168]	1–2 mm[163]
Temporal resolution	20–40 ms[172]	1–10 ms[163]
Working range	>10 kPa[171]	1–1000 g[163]
Hysteresis	High	Low[163]

Table 1. Summary of the Properties of human skin and corresponding requirements in E-skin (Hammock, 2013)

Some additional desirable traits of a material for electronic skin implementation include flexibility, low cost, large area coverage and mass producibility. This project includes the use of PDMS and carbon nanotubes(CNT). PDMS will create a serpentine-like mold which will allow for CNT to be placed in the crevices created. The image below is similar to the end goal of the technical portion of this report.

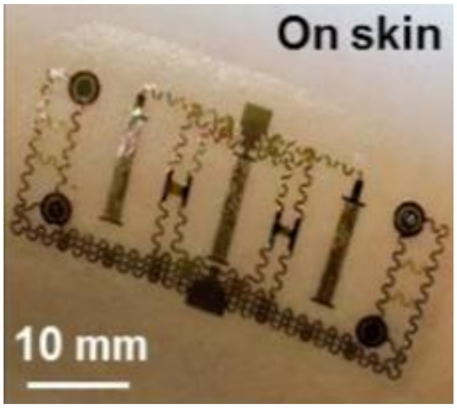


Figure 1. Electronic Skin placed on skin

PDMS or Polydimethylsiloxane is a desirable material because it is optically transparent, has good thermal stability and its surface properties can easily be changed(Gale, 2016). Carbon nanotubes are chosen largely because of their incredible sensitivity and fast response time(Zaporotskova, 2017).

Sensation or feeling force is just one example of a vital measurement that allows an individual to properly experience the world around them. Temperature sensing and kinematic sensing are two other measurements that are more relevant to this project and important to keep track of for the diagnosis of a patient(Ray, 2019). Kinematic sensing deals with the monitoring of strain which, not surprisingly, deals with strain sensors that detect elongations of a material, typically through the use of electricity(Nachazel, 2020). The sensor's resistance changes as a result of elongation and this resistance can be converted to the amount of strain or elongation %. This is crucial in monitoring athletic performance in the training and recovery stages during an athlete’s career. More related to the medical field, this can be useful in diagnosing movement or neurological disorders by observing movement patterns (voluntary or involuntary) of a patient(Ray, 2019). As stated previously, temperature is a critical biomarker for human health which can indicate sickness. In order to track temperature, the device must be able to detect subtle, time-dynamic changes in temperature over a very small time period(Ray, 2019). Traditional thermometers are too massive and require longer equilibrium times because of this and make them impractical for constant monitoring. A thermal sensor relies on changes of resistive, semiconducting or optical properties of a material. This paper will be dealing with what is known as a standard resistance thermometer. It works on the principle that as the temperature of an object increases, the resistance to the flow of electricity also increases(Sinclair, 2001). This allows for diagnosis of sickness and can even be integrated onto a human. More specifically, these sensors can be attached to an individual to allow them to regain sensation.

A majority of people feel indifferent when it comes to their online data. There is a lot of talk about how companies sell personal information to advertisement companies and how it can be used to target products to an audience. One might think “If it will improve user experience then this shouldn’t be an issue.” However, thoughts like this can be seen to have dangerous consequences. In 2017, Germany banned smartwatches for kids(Filip, 2017). One of the primary motivations for this attack is how easy it was to access the location of children, therefore threatening their safety.

Now that’s not to say that people must sacrifice their safety in order to improve the usability of a product. A good company protects its customers no matter what, but the misuse of data is inevitable in this day and age. There needs to be more awareness when it comes to where personal information is distributed to and how well protected that data is. According to the Risk Homeostasis theory, this risk awareness will lessen the chances of data leaks from occurring. Through educating users on data breaches, damage can be mitigated or prevented entirely. Other forms of data leak mitigation will be explored like location of storage of data.

Wearable devices track anything from calorie count to mileage and although exploitation of these types of data seem pointless, accessing this may not be the end goal for some. Back in 2016, Fitbit users were hacked, their usernames and passwords were leaked on third party sites (McGee, 2016). Once inside the account, hackers attempted to order replacement parts through the company. In this report, when data leaks are mentioned, this includes login information, vital patient information and anything and everything in between. These data breaches can even include the erasure of important medical information and may even lead to extortion, as seen earlier this year in a hospital in Miami presented in Chang and colleagues paper on The Ethical Problems of Wearable Devices(Collier, 2019).

This report will investigate the information gathered by wearable devices and the ethical problems with wearable devices. Potential solutions will be presented to prevent data breaches from occurring. Some questions that will be answered include: What potential threat does the implementation of new wearable technologies create? What are some ethical problems with wearable devices and how can they be addressed? How can we prevent/mitigate potential data breaches predicted by Risk Homeostasis? One example to mitigate potential data breaches can be simply to inform the consumer of the value of their data, as discussed earlier in the report.

Conclusion

Overall, there are two projects described in this report. The first is the STS paper that looks to address how data breaches can be prevented by predicting the behavior of individuals using the Risk Homeostasis Theory and providing possible solutions for prevention. Simply acknowledging the importance of an individual's information can go a long way. Becoming aware of the potential danger data breaches might cause is significant in reducing the chances of data breaches from occurring. The second project described later in the paper focuses on the design process and manufacturing of Electronic skin with temperature and/or strain sensors. The team’s final deliverables will include optical images of the final product on and not on the skin, measurement in working condition and performance data analysis of the temperature sensor created.

References

Chang, V. (2019, May 2). *Ethical Problems of Smart Wearable Devices*. Teesside University. Retrieved October 27, 2021, from https://research.tees.ac.uk/ws/portalfiles/portal/9950502/Smart_wearables_accepted.pdf

Collier, K. (2021, February 5). *Hackers post detailed patient medical records from two hospitals to the dark web*. NBCNews.com. Retrieved October 27, 2021, from https://www.nbcnews.com/tech/security/hackers-post-detailed-patient-medical-records-two-hospitals-dark-web-n1256887

Filip, (2017). *Germany Bans Smartwatches For Kids*. Retrieved from http://www.nextpowerup.com/news/39786/germanybans-smartwatches-for-kids/

Gale, B. K. (2016). *Polydimethylsiloxane*. Polydimethylsiloxane - an overview . Retrieved October 27, 2021, from https://www.sciencedirect.com/topics/chemical-engineering/polydimethylsiloxane

Geller, E. S. (2011, July 6). *Does feeling safe make us more reckless?* ISHN RSS. Retrieved October 27, 2021, from https://www.ishn.com/articles/83639-does-feeling-safe-make-us-more-reckless

Hammock, M. L., Chortos, A., Tee, B. C.-K., Tok, J. B.-H., & Bao, Z. (2013, October 22). *25th anniversary article: The Evolution of Electronic Skin (e-skin): A brief history, design considerations, and recent progress*. Wiley Online Library. Retrieved October 31, 2021, from https://onlinelibrary.wiley.com/doi/full/10.1002/adma.201302240

Horenstein , A., & Grabiszewski , K. (2021, October 14). *When safety measures lead to riskier behavior by more people*. The Conversation. Retrieved October 27, 2021, from https://theconversation.com/when-safety-measures-lead-to-riskier-behavior-by-more-people-133039

Huin, S. (2020, November 12). *What are the types of connected medical device data? introduction to data governance and why privacy and security are essential in telehealth*. Irdeto Insights. Retrieved February 7, 2022, from https://blog.irdeto.com/healthcare/what-are-the-types-of-connected-medical-device-data-introduction-to-data-governance-and-why-privacy-and-security-are-essential-in-telehealth/

McGee, M. K., & Ross, R. (2016, January 11). *Fitbit Hack: What are the lessons?* Data Breach Today. Retrieved October 27, 2021, from https://www.databreachtoday.com/fitbit-hack-what-are-lessons-a-8793

Nachazel, A. (2020, August 14). *What is a Strain Gauge and How Does it Work?* Michigan Scientific Corporation. Retrieved October 27, 2021, from https://www.michsci.com/what-is-a-strain-gauge/

Pless, B. (2016, August 29). *Risk compensation: Revisited and rebutted*. MDPI. Retrieved October 27, 2021, from https://www.mdpi.com/2313-576X/2/3/16/htm

Ray, T. R., Choi, J., Bandodkar, A. J., Krishnan, S., Gutruf, P., Tian, L., Ghaffari, R., & Rogers, J. A. (2019). *Bio-integrated wearable systems: A comprehensive review*. ACS Publications. Retrieved October 31, 2021, from https://pubs.acs.org/doi/10.1021/acs.chemrev.8b00573

Sinclair, I. (2001). *Resistance thermometer*. Resistance Thermometer - an overview | ScienceDirect Topics. Retrieved October 31, 2021, from https://www.sciencedirect.com/topics/engineering/resistance-thermometer

Wilde, G. (2012, September 18). *Risk Homeostasis: A Theory about Risk Taking Behaviour*. About Risk Homeostasis. Retrieved October 27, 2021, from http://riskhomeostasis.org/about-risk-homeostasis

Zaporotskova, I. V., Boroznina, N. P., Parkhomenko, Y. N., & Kozhitov, L. V. (2017, February 10). *Carbon nanotubes: Sensor properties. A Review*. Modern Electronic Materials. Retrieved October 27, 2021, from https://www.sciencedirect.com/science/article/pii/S2452177917300178#:~:text=As%20a%20nanotube%20is%20a,concentrated%20in%20its%20surface%20layers.&text=The%20use%20of%20CNT%20in,as%20fast%20response%20and%20recovery