Engineering Capstone Project (OENG1167)
Investigation of Materials to Develop a Wearable Stress Monitoring Device

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2 Introduction

3 Statement of Problem

Stress is an ordinary physical response to everyday circumstances and challenges. Stress is comprised of both mental and physical components and when it arises, the human body automatically releases adrenaline and other hormones as a natural response. Stress can be quite useful when under control as it allows humans to be productive and efficient. However, stress, left unchecked, can quickly spiral into unproductivity or anxiety. Identifying and understanding periods of elevated stress could significantly increase our understanding of how stress relates to productivity and long-term health. Studies indicate that devices which monitor Heart Rate Variability (HRV), Electrodermal Activity (EDA) and Body Temperature may be useful in the analysis of stress levels. HRV (a measurement of heart rhythm over time), EDA (a measurement of the changes in skin conductance) and Body Temperature provide insights into the Autonomic Nervous System (ANS). The ANS is responsible for the sending of signals to the body which either stimulate or relax different involuntary processes (such as heart rate, sweat secretion and body temperature) (Chung, 2021). The consequences of untreated stress are vast and have a ripple effect across a person's physical and mental health. Aligned with the growing use of telehealth and telemedicine for stress management, wearable technology that both monitors the physiological indicators of stress and provides feedback to the user are becoming more widely accepted. Thus, having a wearable device that can monitor key physiological signals associated with the Autonomic Nervous System could provide key insights into the levels and effects of stress. This project will aim to investigate the materials and methods of construction for wearable devices and then verify these findings through the development of a stress monitoring wearable device. This project will require knowledge of core electronic principles including microcontrollers and sensors, as well as basic textile skills. Project success will be determined by mainly the wearability of the device and accuracy of the data.

3.1 Design and Research Questions

The design and development of a wearable continuous stress monitoring device can be broken down into two, neat categories. The first being the identification of signals and sensors that can be used to monitor stress and the second, where on the body is an optimal location to place the various components. The following research and design questions are largely based on those present in the project proposal however, this version expands further, into more detail: 1. How to identify levels of stress via physiological signals and sensors? a) Which physiological signals correlate to stress? b) Which sensors can be used to measure the identified physiological signals? i) Should Heart Rate be measured via ECG, or PPG? ii) Should skin temperature be measured from one or more locations? - How often to collect skin temperature data? iii) How to measure sweat rate? - How often to collect sweat rate data? iv) How to calibrate such sensors? c) How to visualise acquired data? i) Can off the shelf data visualisation platforms be used? ii) Can spreadsheets be used to analyse prototyping data? d) How to transmit data from the wearable device to visualisation platform? i) Should Bluetooth or Wi-Fi be used? ii) How often should data be transmitted? iii) Should data be compressed on the MCU? iv) Should the MCU do any pre-processing of data? e) Which components to be used? i) What are the optimal operating ranges (voltage, temperature, etc)?

ii) What are the associated budgets for each component? f) How to power the device? i) What battery voltage to use? ii) Where to attach the battery? iii) How to charge the battery? - Detach the battery to charge? 2. How to incorporate sensors into a wearable device? a) How to reduce and minimise obtrusiveness? i) Where on the body would this be achieved? b) Which materials would facilitate the most comfort for the user? i) For heart rate sensing would electrodes or optical sensing be more comfortable? ii) Where on the body should heart rate, skin temperature and galvanic skin response be placed? c) Where on the body would be the most effective location for the device? i) How to transmit data from sensors to microcontroller? - I2C? - SPI? ii) How would this position affect signal acquisition? iii) How would this position affect wearability?

4 Background and Literature Review

5 Methodology and Engineering Design

Table 1 outlines the ways in which the design and research questions will be answered. It also provides reasoning as to why a specified approach will be taken. Subsequently, it links to the section of this document where the results and discussion will be included.

5.1 Methods for Answering Design and Research Questions

Question	Method	Reasoning	Corresponding Section
1.a)	Literature Review	Physiological Signals and their correlation to mental stress lie externally to the project groups area of expertise.	
1.b)	Literature Review	The identification of sensors that can acquire data from specific physiological signals need not be tested, but rather identified.	
1.c)	Testing	Different methods of data analysis will be tested to identify the most appropriate method.	
1.d)	Testing	The specificities of data transfer will be understood throuh testing once data has been acquired.	
1.e)	Desktop Research	The components will be identified through the research and comparison of multiple options. The options will be compared and the most optimal chosen.	
1.f)	Testing	The most optimal power source will be identified through requirements analysis (I.e., operating voltages of other components).	
2.a)	Literature Review/Testing	The identification of the most optimal places to locate the various components will be identified through literature review and then tested in a practical setting.	

Question	Method	Reasoning	Corresponding Section
2.b)	Literature Review/Testing	A literature review of the most optimal materials will be conducted and then testing will determine the most optimal in practical environments.	
2.c)	Testing	Multiple locations will be tested and then whether all components will be placed in a localised area or spread over multiple areas will be determined.	

5.2 Overall System Architecture

The overall system architecture can be seen below in Figure 1. On the left-hand side of the diagram the on-body section of the system is illustrated. This section represents everything that will be included in the wearable component of the stress monitoring device. On the right-hand side, the off-body section is illustrated. This includes everything that will not be included in the wearable component of the device. INSERT IMAGE OF OVERALL SYSTEM ARCHITECTURE

5.3 Low-Level Design

5.4 Component Selection

5.4.1 Heart Rate Sensor

The major constraints decided upon for the heart rate sensor were the ability to be worn comfortably without impeding the sensor, the ability to communicate with common MCUs, and to be able to collect the heart rate data in real time. To this end we found seven different heart rate sensors from various suppliers and had to narrow them down further. We ended up choosing the SparkFun Pulse Sensor since it is very small and has flexibility of placement.

5.4.2 Galvanic Skin Response Sensor

We were unable to find a sensor which fit our requirements for cost and size so we are going to be building our own GSR sensor as it is a relatively simple undertaking compared to the other sensors in our project. We will however be using a Grove GSR Sensor in order to calibrate our sensor and ensure it functions properly.

5.4.3 Skin Temperature

For measuring skin temperature the main constraints for the sensor were

1. Temperature range including 20-45 Degrees Celcius
2. 3.3V Operation
3. Compact Profile
4. I2C Functionality

We looked through the sensors available at Core Electronics, DigiKey, and JayCar and found the sensor that best fit the requirements whilst being relatively cheap was the AHT20 Temperature and Humidity Sensor. We chose this one because of it's small form-factor, abundant documentation, low price, and the potential to measure sweat levels using the humidity sensor built in.

5.4.4 MCU

The MCU being the central componant of the system must have certain requirements in order to be usable with this project.

1. Small Form-Factor
2. I2C Functionality
3. Sleep Mode
4. Arduino Compatible
5. Low Power Consumption
6. WiFi/Bluetooth Functionality

The MCU we decided to use is the ESP32 due to it's extensive documentation, sleep mode, extremely small form-factor, Wifi/Bluetooth functionality which can be processed in parallel with the rest of the operations on the chip. For development we will be using the ESP32-PICO-KIT Development Board due to it's built-in programmer, Prototyping pins, and relatively small size.

6 Feasibility/Proof of Concept

7 Preliminary Findings

8 Project Management

9 Conclusions

10 References

[1] Q. H. Dang, S. J. Chen, D. D. Zhang, D. D. Kimtai, and C. Fumeaux, "Flexible substrate materials for wearable antennas," in *2020 4th Australian Microwave Symposium AMS*, 2020, pp. 1–2. DOI: 10.1109/AMS48904.2020.9059490.

[2] A. Alemaryeen and S. Noghanian, "Applications of magneto-dielectric materials in wearable antenna design," in *2017 IEEE International Symposium on Antennas and Propagation USNC/URSI National Radio Science Meeting*, 2017, pp. 515–516. DOI: 10.1109/APUSNCURSINRSM.2017.8072300.

[3] M. A. Kango and S. O. Rahurkar, "Effect of dielectric materials on uwb antenna for wearable applications," in *2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering ICPCSI*, 2017, pp. 1610–1615. DOI: 10.1109/ICPCSI.2017.8391984.

[4] H. Walter, A. Grams, M. Seckel, T. Löher, O. Wittler, and K. D. Lang, "Determination of relevant material behavior for use in stretchable electronics," in *2018 19th International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems EuroSimE*, 2018, pp. 1–5. DOI: 10.1109/EuroSimE.2018.8369902.

[5] A. Noda and H. Shinoda, "Frequency-division-multiplexed signal and power transfer for wearable devices networked via conductive embroideries on a cloth," in *2017 IEEE MTT-S International Microwave Symposium IMS*, 2017, pp. 537–540. DOI: 10.1109/MWSYM.2017.8058619.

[6] S.-H. Liu, G.-H. Cai, Y.-F. Huang, and Y.-F. Chen, "A wearable ecg apperatus for ubiquitous health care," in *2016 IEEE International Conference on Systems, Man, and Cybernetics SMC*, 2016, pp. 004 471–004 476. DOI: 10.1109/SMC.2016.7844936.

[7] R. Guo, S. Yao, X. Sun, and J. Liu, "An improved liquid metal mask printing enabled fast fabrication of wearable electronics on fabrics," in *2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society EMBC*, 2019, pp. 1761–1764. DOI: 10.1109/EMBC.2019.8857044.

[8] C. Cooper and B. Hughes, "Aerosol jet printing of electronics: An enabling technology for wearable devices," in *2020 Pan Pacific Microelectronics Symposium Pan Pacific*, 2020, pp. 1–11. DOI: 10.23919/PanPacific48324.2020.9059444.

[9] T. Healy, J. Donnelly, B. O'Neill, *et al.*, "Innovative packaging techniques for wearable applications using flexible silicon fibres," in *2004 Proceedings. 54th Electronic Components and Technology Conference IEEE Cat. No.04CH37546*, vol. 2, 2004, 1216–1219 Vol.2. DOI: 10.1109/ECTC.2004.1319066.

[10] C. Loss, R. Salvado, R. Gonçalves, and P. Pinho, "Development of a textile antenna using a continuous substrate integrating the ground plane," in *2018 IEEE International Symposium on Antennas and Propagation USNC/URSI National Radio Science Meeting*, 2018, pp. 1679–1680. DOI: 10.1109/APUSNCURSINRSM.2018.8609177.

[11] R. Vieroth, T. Loher, M. Seckel, *et al.*, "Stretchable circuit board technology and application," in *2009 International Symposium on Wearable Computers*, 2009, pp. 33–36. DOI: 10.1109/ISWC.2009.13.

[12] "Stella project." (), [Online]. Available: http://www.stella-project.de/ (visited on 03/25/2022).

[13] J. K. Sim and Y.-H. Cho, "Portable active sensors for human sweat rate monitoring," in *2015 IEEE SENSORS*, 2015, pp. 1–4. DOI: 10.1109/ICSENS.2015.7370676.

[14] V. F. Curto, N. Angelov, S. Coyle, *et al.*, "'my sweat my health': Real time sweat analysis using wearable micro-fluidic devices," in *2011 5th International Conference on Pervasive Computing Technologies for Healthcare PervasiveHealth and Workshops*, 2011, pp. 196–197.

[15] A. Steijlen, J. Bastemeijer, K. Jansen, P. French, and A. Bossche, "A novel sweat rate and conductivity sensor patch made with low-cost fabrication techniques," in *2020 IEEE SENSORS*, 2020, pp. 1–4. DOI: 10.1109/SENSORS47125.2020.9278850.

[16] P. Salvo, F. Di Francesco, D. Costanzo, C. Ferrari, M. G. Trivella, and D. De Rossi, "A wearable sensor for measuring sweat rate," *IEEE Sensors Journal*, vol. 10, no. 10, pp. 1557–1558, 2010. DOI: 10.1109/JSEN.2010.2046634.

[17] M. A. Yokus, T. Agcayazi, M. Traenkle, A. Bozkurt, and M. A. Daniele, "Wearable sweat rate sensors," in *2020 IEEE SENSORS*, 2020, pp. 1–4. DOI: 10.1109/SENSORS47125.2020.9278818.

[18] D.-R. UK, *Dht11 humidity and temperature sensor*, 2010. [Online]. Available: https://www.circuitbasics.com/wp-content/uploads/2015/11/DHT11-Datasheet.pdf.

[19] M. Sadrawi, C.-H. Lin, Y.-T. Lin, *et al.*, "Arrhythmia evaluation in wearable ecg devices," *Sensors Basel, Switzerland*, vol. 17, no. 11, pp. 2445–, 2017, ISSN: 1424-8220.

[20] C. Claisse, O. Cottencin, L. Ott, G. Berna, T. Danel, and J.-L. Nandrino, "Heart rate variability changes and emotion regulation abilities in short- and long-term abstinent alcoholic individuals," *Drug and alcohol dependence*, Drug and Alcohol Dependence, vol. 175, pp. 237–245, 2017, ISSN: 0376-8716.

[21] C. Steinberg, F. Philippon, M. Sanchez, *et al.*, "A novel wearable device for continuous ambulatory ecg recording: Proof of concept and assessment of signal quality," *Biosensors Basel*, vol. 9, no. 1, pp. 17–, 2019, ISSN: 2079-6374.

[22] S. Ramasamy and A. Balan, "Wearable sensors for ecg measurement: A review," *Sensor review*, vol. 38, no. 4, pp. 412–419, 2018, ISSN: 0260-2288.

[23] M. A. Agung and Basari, "3-lead acquisition using single channel ecg device developed on ad8232 analog front end for wireless ecg application," in *AIP conference proceedings*, vol. 1817, 2017.

[24] M. F. Ahmed, M. K. Hasan, M. Shahjalal, M. M. Alam, and Y. M. Jang, "Design and implementation of an occ-based real-time heart rate and pulse-oxygen saturation monitoring system," *IEEE access*, vol. 8, pp. 198 740–198 747, 2020, ISSN: 2169-3536.

[25] R. Martinez, A. Salazar-Ramirez, A. Arruti, E. Irigoyen, J. I. Martin, and J. Muguerza, "A self-paced relaxation response detection system based on galvanic skin response analysis," *IEEE access*, vol. 7, pp. 43 730–43 741, 2019, ISSN: 2169-3536.

[26] K. H. Hong, S. M. Lee, Y. G. Lim, and K. S. Park, "Measuring skin conductance over clothes," *Medical & biological engineering & computing*, vol. 50, no. 11, pp. 1155–1161, 2012, ISSN: 0140-0118.

[27] M. V. Villarejo, B. G. Zapirain, and A. M. Zorrilla, "A stress sensor based on galvanic skin response gsr controlled by zigbee," *Sensors Basel, Switzerland*, vol. 12, no. 5, pp. 6075–6101, 2012, ISSN: 1424-8220.

[28] N. Rani, S. L. Chu, and Q. Li, "Exploring user micro-behaviors towards five wearable device types in everyday learning-oriented scenarios," *International journal of human-computer interaction*, vol. 37, no. 20, pp. 1931–1946, 2021, ISSN: 1044-7318.

[29] T. Fernández-Caramés and P. Fraga-Lamas, "Towards the internet-of-smart-clothing: A review on iot wearables and garments for creating intelligent connected e-textiles," *Electronics Basel*, vol. 7, no. 12, pp. 405–, 2018, ISSN: 2079-9292.

[30] J. Hu, J. Wang, and H. Xie, "Wearable bracelets with variable sampling frequency for measuring multiple physiological parameter of human," *Computer communications*, vol. 161, pp. 257–265, 2020, ISSN: 0140-3664.

[31] P. Vanveerdeghem, P. Van Torre, C. Stevens, J. Knockaert, and H. Rogier, "Synchronous wearable wireless body sensor network composed of autonomous textile nodes," *Sensors Basel, Switzerland*, vol. 14, no. 10, pp. 18 583–18 610, 2014, ISSN: 1424-8220.

[32] O. V. Crowley, P. S. McKinley, M. M. Burg, *et al.*, "The interactive effect of change in perceived stress and trait anxiety on vagal recovery from cognitive challenge," *International journal of psychophysiology*, vol. 82, no. 3, pp. 225–232, 2011, ISSN: 0167-8760.

[33] O. Kofman, N. Meiran, E. Greenberg, M. Balas, and H. Cohen, "Enhanced performance on executive functions associated with examination stress: Evidence from task-switching and stroop paradigms," *Cognition and emotion*, vol. 20, no. 5, pp. 577–595, 2006, ISSN: 0269-9931.

[34] K. Kyriakou, B. Resch, G. Sagl, *et al.*, "Detecting moments of stress from measurements of wearable physiological sensors," *Sensors Basel, Switzerland*, vol. 19, no. 17, pp. 3805–, 2019, ISSN: 1424-8220.

[35] A. Sano, S. Taylor, A. W. McHill, *et al.*, "Identifying objective physiological markers and modifiable behaviors for self-reported stress and mental health status using wearable sensors and mobile phones: Observational study," *Journal of medical Internet research*, vol. 20, no. 6, e210–e210, 2018, ISSN: 1438-8871.

[36] M. Choi, G. Koo, M. Seo, and S. W. Kim, "Wearable device-based system to monitor a driver's stress, fatigue, and drowsiness," *IEEE transactions on instrumentation and measurement*, vol. 67, no. 3, pp. 634–645, 2018, ISSN: 0018-9456.

[37] R. Liu, L. He, M. Cao, Z. Sun, R. Zhu, and Y. Li, "Flexible temperature sensors," *Frontiers in chemistry*, vol. 9, pp. 539 678–539 678, 2021, ISSN: 2296-2646.

[38] M. J. Mnati, R. F. Chisab, A. M. Al-Rawi, A. H. Ali, and A. Van den Bossche, "An open-source non-contact thermometer using low-cost electronic components," *HardwareX*, vol. 9, e00183–, 2021, ISSN: 2468-0672.

[39] B. Arman Kuzubasoglu and S. Kursun Bahadir, "Flexible temperature sensors: A review," *Sensors and actuators. A. Physical.*, vol. 315, pp. 112 282–, 2020, ISSN: 0924-4247.

[40] A. Soldatov, A. Soldatov, I. Obach, A. Abouellail, and P. Sorokin, "Research of thermocouple electrical characteristics," *Materials science forum*, vol. 938, pp. 104–111, 2018, ISSN: 0255-5476.

[41] Y. Zhang and Y. Cui, "Development of flexible and wearable temperature sensors based on pedot:pss," *IEEE transactions on electron devices*, vol. 66, no. 7, pp. 3129–3133, 2019, ISSN: 0018-9383.

[42] S. Lambert, H. Lu, Z. Shreve, Y. Zhan, A. Jahangir Alam Majumder, and G. Sahin, "Low-powered wearable motion detecting system using static electric fields," *IET Cyber-Physical Systems: Theory & Applications*, vol. 5, no. 1, pp. 31–38, 2020, ISSN: 2398-3396.

[43] W. Barfield, *Fundamentals of Wearable Computers and Augmented Reality*. CRC Press, 2015, ISBN: 1482243504.

[44] A. H. Chung, R. N. Gevirtz, R. S. Gharbo, M. A. Thiam, and J. J. Ginsberg, "Pilot study on reducing symptoms of anxiety with a heart rate variability biofeedback wearable and remote stress management coach," *Applied psychophysiology and biofeedback*, vol. 46, no. 4, pp. 347–358, 2021, ISSN: 1090-0586.

[45] J. Healey, "Gsr sock: A new e-textile sensor prototype," in *2011 15th Annual International Symposium on Wearable Computers*, IEEE, 2011, pp. 113–114, ISBN: 1457707748.

[46] B. Arman Kuzubasoglu and S. Kursun Bahadir, "Flexible temperature sensors: A review," *Sensors and Actuators A: Physical*, vol. 315, p. 112 282, 2020, ISSN: 0924-4247. DOI: https://doi.org/10.1016/j.sna.2020.112282. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0924424720308116.

[47] A. Abouellail, I. Obach, A. Soldatov, P. Sorokin, and A. Soldatov, "Research of thermocouple electrical characteristics," *Materials Science Forum*, vol. 938, pp. 104–111, Nov. 2018. DOI: 10.4028/www.scientific.net/MSF.938.104.

[48] Y. Zhang and Y. Cui, "Development of flexible and wearable temperature sensors based on pedot:pss," *IEEE Transactions on Electron Devices*, vol. 66, no. 7, pp. 3129–3133, 2019. DOI: 10.1109/TED.2019.2914301.

[49] G. Sahin, "Low-powered wearable motion detecting system using static electric fields," *IET Cyber-Physical Systems: Theory & Applications*, vol. 5, 31–38(7), 1 Mar. 2020. [Online]. Available: https://digital-library.theiet.org/content/journals/10.1049/iet-cps.2018.5034.

[50] *Health records act 2001*, version 046, Aug. 27, 2020. [Online]. Available: https://content.legislation.vic.gov.au/sites/default/files/2020-08/01-2aa046%5C%20authorised.pdf (visited on 03/29/2022).

11 Appendices

11.1 Group member contribution table

Section	Person(s) responsible and percentage
Executive summary	