MONITORED COMPRESSION THERAPY: USING SMART TECHNOLOGY TO OPTIMIZE THE TREATMENT OF LOWER EXTREMITY SWELLING

By

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ABSTRACT

Chronic Venous Insufficiency (CVI) and Venous Stasis Ulcers (VSUs) are symptoms which stem from diabetes – a disease effecting over 34 million people in the United States alone as of 2020. This Thesis details the design of a pressure-sensing garment used to enhance the treatment of CVI. The garment uses small force sensors (four levels: the insole of the foot, the lower leg, the lower calf, and the upper calf) to sense the pressure applied by a compression stocking. The sensed data is transmitted wirelessly via Bluetooth to a smartphone application that was developed to display the data and interface with the electronics. The data is displayed on the smartphone application and can be monitored by the patient and/or nurse to ensure that the proper pressure gradient is applied to the leg. The gradient starts at around 30-50 mmHg at the foot and decreases linearly to about 6 mmHg just below the knee. The proper application of this pressure gradient best promotes blood flow and is predicted by medical experts to potentially cut healing time for VSUs from 6 months to as little as just 60 days.

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I would like to thank Dr. Baker for the wide variety of opportunities I have been provided in my nearly 4 years in his research group. Dr. Baker has been a role model for me as an engineer and an educator ever since I first took his *Circuits I* course in the spring of 2017. His passion for teaching, and his mastery of the subject matter which he teaches, have inspired me to challenge myself to be the best engineer that I can be–to never fear testing out ideas I may have, to embrace opportunities when they come my way, and to seek and value knowledge and gained experience in all my engineering-related endeavors. I would also like to thank Dr. Harris for always going above and beyond to help me both inside and outside of the classroom. Dr. Harris has a special, kind heart and puts her students at the top of her enormous and impressive list of priorities.

I would like to thank the rest of my advisory committee for being a part of this defense and for their time and investment in my education – Dr. Brendan Morris and Dr. Dustin Hines. A special thanks to Dr. Morris for always being available to answer questions I may have had about a class I was taking, or about the future of my education and career. I would also like to thank Dr. Todd Meyrath for the enormous impact he has had on my education in electrical engineering, and for the practical experience I gained working for him at *Vorpal.* Todd has also been incredibly

helpful in the process of applications for PhD programs and has offered priceless career advice to me in exchange for nothing.

A special thanks to my colleague and friend Francisco Mata. Francisco and I have worked as partners tirelessly on countless projects. I could not be more grateful to have worked in the same research group as someone with such impeccable work ethic. Francisco doesn't leave until the job is done, and he only knows how to give 100% effort in everything he does. His effort and his desire to learn are contagious and have rubbed off on me, both in academia and elsewhere. I would also like to thank Dr. Sachin Namboodiri from the bottom of my heart for never even hesitating to drop what he is doing to help me with a project, an assignment, or a question I may have had about any number of things. Sachin has had an immeasurable impact on my education, and I could never thank him enough for his efforts. Another special thanks to Daniel Senda for being a great colleague and a great friend. Daniel taught me how to solder surface mount components, helped me with my consulting work, and has been a great study partner throughout several courses we have taken together. I would like to thank Jazmine Boloor for her friendship and constant encouragement throughout my time in this group. Jazmine always provides me with helpful feedback on projects, presentations, and emails, and she even let me use half of her shelving at her desk to store parts for my projects for at least a year and a half. Lastly, I would like to thank the rest of the past and present members of the Baker group for guidance, support, and friendship throughout my time in the group.

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LIST OF ABBREVIATIONS/ACRONYMS

ADC	Analog-to-Digital Converter
ASCII	American Standard Code for Information Interchange
BLE	Bluetooth Low Energy
BOM	Bill of Materials
CVI	Chronic Venous Insufficiency
DAC	Digital-to-Analog Converter
DC	Direct Current
DIP	Dual In-line Package
EMI	Electromagnetic Interference
EUSART	Enhanced USART
FHSS	Frequency-Hopping Spread Spectrum
FM	Frequency Modulation
FSK	Frequency-Shift Keying
FSR	Force Sensing Resistor
FVR	Fixed Voltage Reference
GPIO	General Purpose Input/Output
GUI	Graphical User Interface
IC	Integrated Circuit
IDE	Integrated Development Environment
LED	Light Emitting Diode
LSB	Least Significant Bit
MCU	Microcontroller Unit

MD	Doctor of Medicine
MIT	Massachusetts Institute of Technology
NC	Not Connected
PC	Personal Computer
PCB	Printed Circuit Board
RN	Registered Nurse
SBC	Single Board Computer
SMD	Surface Mount Device
SMT	Surface Mount Technology
SOC	System-on-Chip
SOIC	Small-Outline IC
SPI	Serial Peripheral Interface
SPS	Switching Power Supply
SSOP	Shrink Small-Outline Package
TSSOP	Thin-Shrink Small-Outline Package
UART	Universal Asynchronous Receiver and Transmitter
UMC	University Medical Center
USART	Universal Synchronous/Asynchronous Receiver and Transmitter
USB	Universal Serial Bus
VSU	Venous Stasis Ulcer

LIST OF CONVERSION FACTORS

CURRENT

1000 mA = 1 A

1000 μA = 1 mA

VOLTAGE

1000 mV = 1 V

1000 μV = 1 mV

RESISTANCE

1000 Ω = 1 kΩ

1000000 Ω = 1 MEGΩ

PRESSURE

7500.62 mmHg = 1 N/mm^2

DATA

8 bits = 1 bytes

2^{10} bytes = 1 kilobytes (KB)

2^{20} bytes = 1 megabytes (MB)

2^{30} bytes = 1 gigabytes (GB)

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CURRICULUM VITAE

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Education

University of Nevada, Las Vegas, 2020-2021

Master of Science in Electrical and Computer Engineering

Graduating: December 2021

University of Nevada, Las Vegas, 2016-2020

Bachelor of Science in Electrical Engineering

Honors: Magna Cum Laude (GPA: 3.96/4.00)

Research

- **Graduate Research Assistant in an integrated circuit design/testing research group supervised by Dr. R. Jacob Baker at UNLV.**
    - **Publication 1:** Vikas Vinayaka, Sachin P. Namboodiri, Shadden Abdalla, Bryan Kerstetter, Francisco Mata-Carlos, Daniel Senda, **James Skelly,** Angsuman Roy, R. Jacob Baker. 2019. Monolithic 8x8 SiPM with 4-bit Current-Mode Flash ADC with Tunable Dynamic Range. In GLSVLSI '19: 2019 Great Lakes Symposium on VLSI, May 9-11, 2019, Tysons Corner, VA, USA. ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3299874.3318005
    - **Publication 2:** S. P. Namboodiri, G. Arteaga, **J. Skelly**, F. Mata-carlos, A. Roy and R. J. Baker, "A Current-Mode Photon Counting Circuit for Long- Range LiDAR Applications," *2020 IEEE 63rd International Midwest Symposium on Circuits and Systems (MWSCAS)*, 2020, pp. 146-149, doi: 10.1109/MWSCAS48704.2020.9184584.
    - **IC design, layout, tape out** using C5, AMS, TowerJazz processes in Cadence.
    - **PCB design** for ICs designed in the lab and other lab projects.
    - **Soldering** through-hole, SMD components by hand, as well as reflow soldering.
    - **Programming microcontrollers** for various embedded systems projects.

Other Work Experience

- **Electrical Engineering Intern** at Vorpal Research Systems, a laser and electro-optical system design and manufacturing company. (Spring 2019 – Fall 2020)
- **Electrical Engineering Intern** at Pololu Robotics and Electronics, design and test voltage regulators, motor drivers, controllers. (Fall 2021)
- **Intellectual Property Technical Consultant**
    - **Covington & Burling LLP (Palo Alto, CA and Washington, DC)**
        - Case 1 – Phenix (sic) Longhorn, LLC v. *Texas Instruments, Inc.*
            - Case Number - Texas, ED (Marshall) 2:18-cv-00020. Complaint filed on January 22, 2018.
            - Case Subject Matter – Circuit with non-volatile memory for gamma correction in a display screen.
            - Work Performed – Provided expert consulting services including reviewing schematics and other case materials.
        - Case 2 – Bell Semiconductor, LLC v. *Texas Instruments, Inc.*
            - Case Number – Texas, ED 2:20-cv-00048
            - Case Subject Matter – Package drawing files using cutouts to reduce parasitic capacitance on high-speed pins.
            - Work Performed – Reviewed package drawing files and categorized package designs.
    - **DLA Piper (East Palo Alto, CA)**
        - Case – Invensas Corporation and Tessera Advanced Technologies, Inc. v. *NVIDIA Corporation*
            - Case Number – Delaware, 1:19-cv-00861. Complaint filed on May 8, 2019.
            - Case Subject Matter – Reference voltage circuits (programmable bandgaps) having a substantially zero temperature coefficient using bipolar and MOS transistors.
            - Work Performed – Provided expert consulting services including reviewing schematics and other case materials.
- **Grader** for various electrical and computer engineering courses (Spring 2020 – Spring 2021)
- **Math Tutor –** tutored 6 high school and undergraduate level students in a variety of mathematics courses including (high school) algebra I, algebra II, geometry, (college) pre-calculus, calculus I, II, III. (Fall 2016 – Spring 2019)
- **Textbook Reviewer** for *CMOS Circuit Design, Layout, and Simulation, Fourth Edition* – R. Jacob Baker.

Projects

Individual

- **Bluetooth Low Energy Module Breakout Board:** Designed a breakout board for the HM-10, HM-11 BLE modules with on-board buck-boost SPS. PIC18LF26K22 MCU is used to send data serially to the BLE module and to configure settings on the module. MCU programmed in C using MPLAB. System can be connected to Android apps.
- **Force Sensing Mechanism with Amplified Output:** Designed a PCB containing a small force sensor with analog output voltage and an instrumentation amplifier. Entire unit is comprised of two PCBs connected by pogo pins for spring action.
- **Manually Operable Scoreboard:** Designed a 9" by 15" fully functional scoreboard for various sports using an ATmega328P MCU programmed in C.
- **Darkness Sensor:** Designed, programmed, and built PCB containing ATMEGA328P MCU and a photoresistor divider to sense when the undergraduate lab is dark and hit the switch turning the lights back on using DC push-type solenoids. MCU programmed in C.
- **PIC Microcontroller Breakout Board:** Designed a breakout board for the QFP44 PIC18LF46K22 microcontroller including convenient PICkit3 programming pins, female header ports for each IO pin, indicator LEDs for programming and power, and a UART port breaking out the TX and RX pins.
- **CMOS Boost Switching Power Supply:** Designed, simulated, and laid out a Boost SPS IC for varying temperature (0 to 100 degrees Celsius) and power supply voltage ($3.75V \leq VDD \leq 4.75V$) with a fixed 5V DC output reference voltage.
- **555 Timer Christmas Tree Ornament:** Designed a PCB to be used as an ornament in the shape of a Christmas tree using a 555 timer and powered by a 9V battery. The ornament has flashing and solid modes, and the flashing frequency can be adjusted by the on-board easily accessible potentiometer. No programming necessary.
- **CMOS High-Speed Transimpedance Amplifier:** Designed and simulated a transimpedance amplifier using differential amplifiers to convert light from an avalanche photodiode into a voltage output.
- **CMOS Low Voltage, High Gain Op-Amp:** Designed and simulated an op-amp with Gain Bandwidth Product over 1 MHz, capable of operating over a wide power supply range ($2V \leq VDD \leq 6V$).
- **CMOS Serial-to-Parallel Data Converter:** Designed, simulated, and laid out 8-bit Serial-to-Parallel data converter in Cadence's C5 process.
- **CMOS Low-Power Voltage Amplifier:** Designed, simulated, and tested (on breadboard) a CMOS voltage amplifier with a gain of 10 which draws less than 1mA of current from a 9V power supply.
- **CMOS Full Adder:** Designed CMOS 8-bit full adder, performed logic simulation using transient analysis of digital signals, and laid out the circuit in Cadence's C5 process.

Group

- **Wireless Data Transmission System (Thesis):** Worked in a team of 2 to design a system (confidential) to extract data from sensors, process the data and transmit processed data wirelessly to a smartphone application for analysis. System was designed using HM-10 BLE module and PIC MCU, programmed in C using MPLAB.
- **Motor-Driven Laser Alignment Station (Senior Design):** Worked in a team of 2 to design a laser lens alignment station using programmable stepper motors and ball-screw linear actuators. GUI programmed using C# and beam modeling performed in MATLAB.
- **Alignment Station 3D Modeling:** Worked in a team of 2 to model each individual component of the laser alignment station and create a final assembly in SolidWorks.
- **Freedom Photonics IC Tape-out:** Worked in a team of 5 to tape out a 152-pin, 5mm x 5mm ASIC with on-chip current and voltage DACs, op-amps, LVDS channels, and other structures for a Freedom Photonics project. Cadence TowerJazz process was used.
- **Four Function Calculator:** Led a team of 2 in design of 8-bit four-function calculator, implemented on DE2 board. Wrote code for each function using Verilog, designed schematic.
- **Test Structures IC:** Worked in a team of 3 which designed IC containing logic gates (NAND, NOR, NOT), ring oscillator, voltage divider, MOSFETs, and boost SPS circuitry. Laid out in Cadence's C5 process and fabricated for testing.
- **CMOS Audio Amplifier:** Led a team of 2 in design, simulation, and testing of a CMOS audio amplifier using ZVN3306A and ZVP3306A transistors. Input is audio signal from iPhone audio jack, output on 22-ohm speaker.

Volunteering & Service Activities

- **Reach Our City –** Travel down to the Las Vegas Strip every other Wednesday to help give out 100 free Bibles, free waters, and pray with people walking by.
- **Calvary Downtown Outreach –** Volunteer at Calvary Downtown Outreach helping to feed homeless people in the downtown Las Vegas area.
- **F.E.A.T. (Families for Effective Autism Treatment) Picnic –** Volunteer at F.E.A.T. picnic manning game stations, giving out lunch, setup, and breakdown.
- **I.K.E.D. (Introduce a Kid to Engineering Day) –** Led different age groups of 15 or more children in creating a makeshift light spectrometer using cereal boxes and CDs, answered questions about engineering and college in general.
- **Panelist** on student panel for NSF Las Vegas Scholars' Program. (Summer 2019)

Leadership

- **Former President of Tau Beta Pi, NV Beta Chapter at UNLV:** Lead chapter (containing 845 total members) by planning of service events, delegating tasks to other officers, organizing and leading initiation and orientation ceremonies.
- **Teaching Assistant:** Lead group review and study sessions as a TA, as well as office hours for several electrical and computer engineering courses, including Digital Logic Design I, Mixed-Signal Circuit Design, Digital Electronics and Digital IC Design, Digital Electronics Lab, and Memory Circuit Design. (Spring 2020 – Spring 2021)
- **IEEE Workshop Leader:** Led PCB Design, Soldering, LTSpice workshops for students at UNLV who are pursuing degrees in electrical/computer engineering.
- **Event Manager at The Plaza, Whitney Ranch:** In charge of event setup and venue management, directing and managing caterers, bartenders, barbacks, DJs, and guests for over three years. (June 2015 – September 2018)
- **UNLV Intramural Basketball Team Captain** (Spring 2018 – Spring 2019)
- **Men's Slow-pitch Softball Team Coach/Captain** (Fall 2019, Spring 2021)

Honors/Awards

- UNLV Rebel Grad Slam 3-Minute Thesis Competition **Grand Prize Winner** (Fall 2021)
- Marjorie and Victor Kunkel Scholarship (Fall 2020 – Spring 2021)
- AEE Nevada Chapter 2020 Scholarship (Fall 2020 – Spring 2021)
- **Magna Cum Laude, Bachelor of Science in Engineering** (Spring 2020)
- Wolzinger Family Engineering Scholarship (Fall 2019 – Spring 2020)
- Gilman and Bartlett Engineering Scholarship (Fall 2018 – Spring 2019)
- Earl and Hazel Wilson Scholarship (Fall 2016 – May 2020)
- Valedictorian Scholarship (Fall 2016 – May 2020)
- Millennium Scholarship (Fall 2016 – May 2020)
- Robert Mars Principal Achievement Scholarship (Fall 2016 – Spring 2017)
- Howard R. Hughes College of Engineering Dean's Honor List (Fall 2016 – May 2020)
- Named to UNLV Intramural Basketball All-Star Team (Spring 2019)
- Back-to-back UNLV Intramural 3-Point Contest Champion (Fall 2020, Spring 2021)

Professional Associations

- **Member,** IEEE (Institute of Electrical and Electronics Engineers)
- **Member,** Tau Beta Pi (Engineering Honor Society) National Chapter