DESIGN DAY VU

School *of* Engineering

MONDAY, APRIL 22, 2024

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Cover designed by Mary Alice Bernal, Finn Partners Southeast.

Preface

On behalf of the School of Engineering, we would like to share the 48 senior design engineering capstone design projects for 2024. We had capstone projects completed in partnership with sponsors including Amazon Robotics, Booz Allen Hamilton, Nissan North America, NASA Marshall Space Flight Center, Sterling Ranch Development Company in Colorado, Permobil, Vanderbilt University Medical Center, and many more. We thank all our project sponsors, advisers, and mentors for their support of our design teams and the entire program.

Senior design courses provide students with experience working on real-world projects that involve design constraints, budgets, reviews and deadlines. All the teams, sponsors, mentors, and everyone involved have experienced a year that created a challenging environment for collaborative design. They will remember the adaptability and hard work to keep working from all corners of the globe.

Students learned about professionalism, teamwork, entrepreneurship, and above all resilience. As their projects take form, student teams interact with their industry and faculty advisers, hold meetings, write formal documentation and present their work. By the end of the academic year, the teams produce design processes, systems, prototypes, simulations, or demonstrations.

This book is one of the tangible representation of Design Day, which has always been a celebration of all the lessons learned over four years of their engineering educations. As you read this book, know that those lessons were learned and demonstrated throughout all these projects.

We recognize the value of senior projects mentored and supported by external advisors—industry representatives, entrepreneurs, nonprofit mentors, as well as research and clinical faculty. This experience allows you to work with Vanderbilt engineering seniors and discover what makes our students stand out among other applicants when it comes to employment and postgraduate study. If you or your colleagues are interested in mentoring or sponsoring a project or to learn more, please contact me.

Be resilient, persevere, and work hard to make each other's world a little better each day. We are grateful for your support and guidance of our next generation of engineers and scientists.

With gratitude,

Thomas J. Withrow
Assistant Dean for Design
Professor of the Practice of Mechanical Engineering
514 Olin Hall | 615.322.3594 | thomas.j.withrow@vanderbilt.edu

Contents

Departments and Programs

APRIL 22

BIOMEDICAL ENGINEERING
BME-1

TEAM
Madison Albert, BME/Math
Katelyn Craft, BME
August Jurva, BME
Rebecca Pan, BME
Nicholas Wan, BME

ADVISER
Professor Xinqiang Yan, ECE,
Department of Radiology, VUMC

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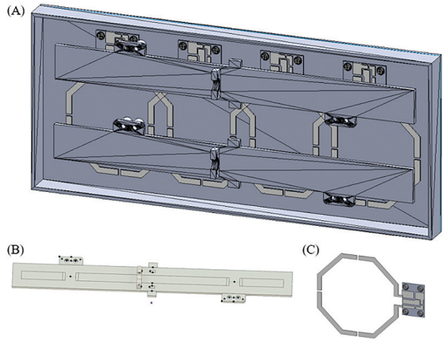
Optimizing and fabricating body coils for 7T MRI

Radiofrequency (RF) coils are essential to magnetic resonance imaging (MRI). Higher field strength MRI machines, like seven Tesla (7T) scanners, offer promising diagnostic capabilities while posing new challenges like high specific absorption rate (SAR). There are currently no FDA approved 7T RF coils for body imaging, and current research body coils have a limited field of view. Our project aims to create a safe and affordable body coil that can be used with 7T MRI machines to image the abdomen. Our design incorporates an 8-channel-transmit/32-channel-receive RF coil array. For the transmit coil, we ran simulations to optimize the placement of each dipole antenna, which emits RF signals into the body. For the receive coil, we created a wearable coil consisting of 32 loops, with each loop capturing part of the reemitted RF signal. The receive coil is placed directly on the patient's abdomen, below the transmit coil. The received signals are then sent to the MRI computer system for image reconstruction. Ultimately, the design maximizes resolution and SNR while maintaining safe SAR levels. Our coils will be used in conjunction with the 7T MRI system at VUMC to produce high resolution, cross-sectional images of internal body structures.



(A) One of eight repeated boxes that will comprise the body coil. Each box will consist of two transmit antennas and four overlapping receive loops. (B) Single transmit coil that emits RF signals into the body. (C) Single receive loop that captures reemitted RF signals from the abdomen.

VUIIS

BIOMEDICAL ENGINEERING
BME-2

TEAM
Sungmin Kwon, BME
Hari Patel, BME
Nathan Zhang, BME/Math
Joy Zou, BME

ADVISERS
Joseph Schlesinger, M.D., FCCM, Department of Anesthesiology, VUMC
Professor Joshua Shive, Tennessee State University

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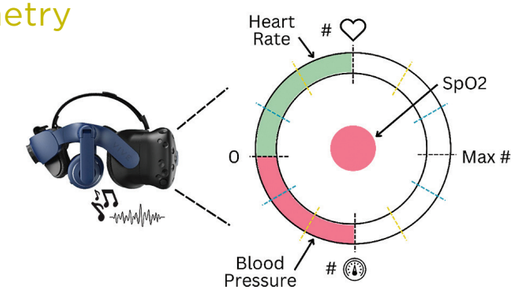
Utilizing VR eye tracking and pupillometry to improve ICU alarm systems

Our project proposes a novel ring-based visual display system that consolidates the presentation of patient health information to reduce alarm fatigue among clinicians in the Intensive Care Unit (ICU). Complemented with a previous research project's alarm sounds optimized for auditory comfort, the visual display prioritizes the integration of three patient vitals–heart rate, blood pressure and blood oxygenation (SpO2)–and their relative severity. Our visual display consists of a ring with the upper half denoting heart rate, the lower half denoting blood pressure, and the color of the center dot denoting SpO2. Markings along the ring indicate very low, low, normal, high, and very high alarm zones. Our team integrated this visual display system into a virtual reality (VR) environment using the HTC VIVE Pro Eye headset. The selected VR system, distinguished by its eye tracking and pupillometry capabilities, facilitates a multisensory alarm system while allowing complete freedom of movement for research participants. Using the eye tracking and pupillometry capabilities of the VR headset, we are testing to determine if this visual display system is more effective at decreasing clinician response time and increasing accuracy to patient emergencies compared to existing alarm systems, as well as previous years' developed visual displays.



A novel clinical visual display integrates the presentation of patient heart rate, blood pressure, and SpO2. The display is presented in a virtual clinical environment with the HTC VIVE Pro Eye headset, allowing for eye tracking and pupillometry data collection.

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TEAM
Kiara Herro, BME
Layla Reejhsinghani, BME
Marin Schiffman, BME
Max Sharp, BME

ADVISER
Professor Joseph Wiencek, PhD, DABCC, FADLM, Department of Pathology, Microbiology, and Immunology, VUMC

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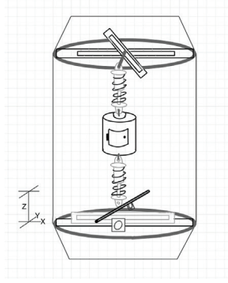
BIOMEDICAL ENGINEERING
BME-3

Protective carrier insert for specimen transport system

Thousands of blood samples are transported daily across hospitals via pneumatic tube systems (PTS). Blood samples in a PTS are subjected to high shock, g-forces, and rapid acceleration changes, causing hemolysis and erroneous test results. Currently, foam inserts are used to reduce movement of the blood sample inside a PTS carrier, but they are ineffective at reducing hemodynamic stressors. Therefore, staff resort to walking blood samples between hospital locations, taking time away from patient care. Our team developed a carrier insert to minimize forces experienced by blood samples to be below the threshold for hemolysis. The carrier features a gyroscope sensor, servo motors, an Arduino Nano microcontroller, 3D-printed tracks, a spring-dashpot system, and a 3D-printed box. The gyroscope sensor detects change in movement of the sample and communicates with servo motors to counter forces experienced in x- and y-directions; this movement occurs on 3D-printed tracks. A spring-dashpot system reduces acceleration in the z-direction. We used an Arduino Nano microcontroller to process information received by the sensor and control the servo motors accordingly. Test tubes are stored in a 3D-printed box that is vacuum-sealed with plastic to eliminate risk of specimen leakage. This solution enhances lab efficiency and accuracy by reducing hemolysis.



Our carrier features a gyroscope sensor, servo motors, an Arduino Nano microcontroller, 3D-printed tracks, a spring-dashpot system, and a 3D-printed box. Acceleration will be reduced using the gyroscope sensor and servo motor-controlled tracks in the x- and y-directions, and the spring-dashpot system in the z-direction.

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BIOMEDICAL ENGINEERING
BME-4

TEAM
Manuel Avila, BME
Quang Anh Nguyen, BME/EE
Steven Edwards, BME/ECE
Henry Chung, BME

ADVISERS
Ryan J Buckley, MD
VUMC Division of General Internal Medicine and Public Health
Health Care IDEA Studio, the Wond'ry

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Hospital hearing aid alternative

Often in a hospital environment, patients may have undiagnosed or untreated hearing loss. This can impede communication between the hospital staff and patients, disproportionately affecting elders suffering from presbycusis. To improve the patient's understanding and comfort as well as the efficiency of physician interactions, our solution comprises a custom app that simultaneously connects a Bluetooth earpiece and microphone to a smart device. The app is capable of amplifying audio from the connected microphone into the earpiece, transcribing speech to text, and translating the produced text into other languages. It is designed to have a user-friendly interface that allows the patient to amplify specific audio frequencies, akin to an equalizer, and modify text size to suit their vision needs. Our app has advantages over personal sound amplification products (PSAP) by targeting a trifecta of audio-visual signals for patients in the form of sound amplification, noise reduction and closed captioning compared to a PSAP's sole audio amplification. As a mobile application, our solution is more accessible and portable than PSAPs, particularly for lower-resource and remote settings. We anticipate that our device will significantly increase the quality of the patient's visit, increase their comprehension of the physician's diagnosis, and decrease the duration of patient-physician interactions.

Left, 3D model assembly of stand for the tablet, microphones, and earbuds. Right, Picture of physical components.

Health Care IDEA Studio

theWONDRY | VANDERBILT UNIVERSITY MEDICAL CENTER

BIOMEDICAL ENGINEERING

BME-5

TEAM

Kaelyn Fann, BME
Ryder Li, BME
John Paul Libanati, BME
Caroline Sims, BME
Stanley Vinet, BME

ADVISERS

Professor Marc Moore, BME
Danielle Hayes, MD, Dept. of Plastic Surgery, VUMC
Elizabeth Slater, MD, Dept. of Plastic Surgery, VUMC
John Summitt, MD, Dept. of Plastic Surgery, VUMC
Alexandra Capps, Sr. Lecturer of Theatre Costume Design, the Wondr'y
Garrett Thorne, Makerspace Manager, the Wondr'y

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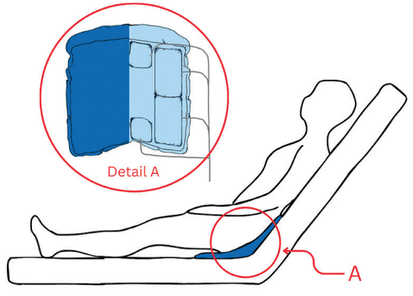
Lower cost decubitus ulcer prevention device

Decubitus ulcers, or bed sores, affect more than 2.5 million Americans annually. These ulcers form when bedridden patients are exposed to prolonged pressure, friction and moisture accumulation on bony prominences. Managing ulcers has resulted in significant health care costs and adverse patient outcomes, even death. This pathology requires proactive, preventative treatment. Dynamic pressure relief is crucial for optimally preventing ulcer formation. However, current solutions often fail to provide dynamic pressure relief; rather, they typically provide only static support. Our solution consists of a pad with a series of inflatable chambers. By alternating the inflation of these chambers, the pad minimizes pressure on bony prominences and enhances tissue oxygenation and blood perfusion. A moisture-wicking cover would wrap around the chambered pad that would rest beneath the patient to specifically offload the pressure on high-risk areas like the bony prominences of the sacrum and ischial tuberosities. The pad and its cover, which together cost under $100, are easy to apply and low maintenance. The wear time of the cover coincides with an 8-hour nursing shift which would minimize the workload of the nursing staff by requiring only one change per shift. This device offers a disposable, efficient, moisture-wicking, and cost-effective device that dynamically redistributes pressure concentrated at near bony prominences.



An inflatable device including multiple air chambers with an external moisture wicking cover. Air chambers are filled via tubes in an alternating pattern to redistribute and offset pressure. The alternating inflation and deflation of the chambers prevents prolonged pressure in one localized area for extended periods of time while patients sit on the device.

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MEDICAL CENTER

BIOMEDICAL ENGINEERING

BME-6

TEAM

Delaney Clawson, BME
Erica Guelfi, BME
Lindsey Sabo, BME
Natalie Scherr, BME

ADVISERS

Professor Marc Moore, BME
Dan Debrah, Permobil
Derek Nash, Permobil
Ben Gasser, Permobil

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Steering attachment for Permobil's SmartDrive

This project is an attachment accessory to the existing Permobil SmartDrive system, a detachable powered wheel for manual wheelchairs. Manual wheelchair use can trigger shoulder strain, causing patients to undergo surgeries and lose independence during recuperation from these injuries. The SmartDrive, an intermediary between manual and powered wheelchairs, allows users to take advantage of the motor propulsion for strenuous activities while retaining the ability to use the chair manually for everyday tasks and greater autonomy. Currently, steering is limited to traditional hand rim turning. Braking is a two-pronged approach of turning off the SmartDrive and then braking by hand. Our design aims to streamline this process, combining both steering and braking into a bicycle-style design that uses hand disc brakes and handlebars for increased control. The frame's folding mechanisms and easy-to-use attachment hardware are key components of the final design. The team anticipates that this device will provide patients with a more intuitive and simple way to direct their wheelchair when using the SmartDrive to aid independence and prevent injury.

The wheelchair attachment features ergonomic handlebars, smooth braking, and easy-to-open attachment mechanisms. The design collapses for easy storage and transport.

School of Engineering
permobil

TEAM

Davis Zakary, BME
Eva Hanson, BME
Natalie Oyenarte, BME
Olivia Rice, BME
Zeus Zohair, BME

ADVISERS

Grant Stohler, Permobil
Brian Larsen, Permobil
Mike Tersigni, Permobil

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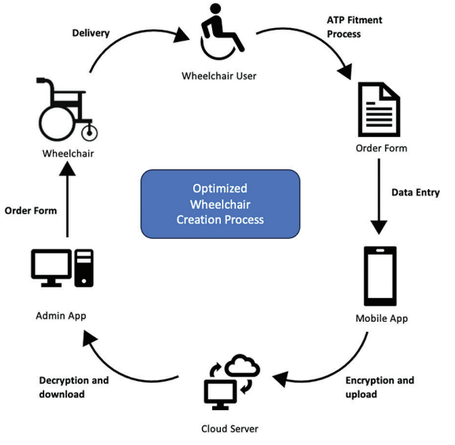
BIOMEDICAL ENGINEERING

BME-7

Mobile solution for proper wheelchair fit and measurement delivery

Ensuring a proper fit for wheelchairs is crucial for user comfort and preventing shoulder tissue damage. The project goal is to create a software solution to replace the manual transmission of wheelchair order forms and streamline the wheelchair fitting process. When a wheelchair is prescribed, a technician obtains measurements using a tape measure and translate these into a chair specification. In many cases, this chair specification is combined with various options on a paper order form, which is then faxed or emailed to the manufacturer. Data transfer is insecure and it introduces the potential for costly errors when the manufacturer manually enters the measurements into their computer system. The solution includes a mobile application, a server and a desktop application. A technician uses the mobile application to complete the order form and upload it to the server. Then the manufacturer will use the desktop application to download the order. Our solution includes industry standard RSA 4096 bit encryption to ensure protection of confidential user information. The user-friendly interface of our free mobile application simplifies measurement recording, promoting technician adoption and facilitating a faster, more reliable system for transferring measurements.



Improved wheelchair order pipeline with the additions of a mobile application, cloud server and admin application, all equipped with encryption.

permobil

BIOMEDICAL ENGINEERING

BME-8

TEAM

Janki Bava, BME
Ori Chalom, BME
Reed Cooper, BME
Anushka Iyer, BME

ADVISERS

Bryan Hartley, M.D., Department of Radiology, VUMC
Professor Marc Moore, BME

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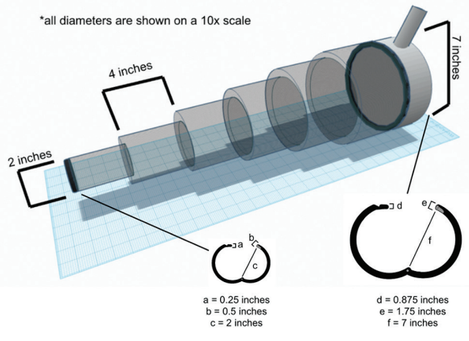
Microcatheter driving system

Our project aims to revolutionize catheterization procedures by developing a streamlined microcatheter driving system designed for single-operator use, thereby reducing costs. Typically, microcatheter procedures involve two physicians—one to drive and one to guide. While some physicians possess advanced training to operate the microcatheter independently, both methods present challenges. The telescoping microcatheter driving system, composed of six 4-inch concentric cylinders, is 3D-printed with BioMed Durable Resin using an SLA printer to ensuring sterility and reusability. The design allows flexibility by letting physicians choose the number of cylinders based on the procedure and microcatheter length. The device is attached to the hub of the base catheter with a luer lock, and a y-connecter is used to water lock the system. Here, the device can be clipped to the drapes. The distal end of the device accommodates a torque device for microcatheter guidance. The device's inner diameter ensures a smooth glide for the microcatheter during collapse, minimizing resistance and kinking of the microcatheter. This innovation offers a significant advantage over existing methods. It eliminates the need for a second physician and enhances procedural efficiency. The anticipated outcome is a reduction in procedural time and costs, empowering physicians to complete microcatheter procedures more effectively.



Telescoping microcatheter driving system, composed of six, 4-inch concentric cylinders that clip around the microcatheter (clipping mechanism shown in diagram).

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BIOMEDICAL ENGINEERING

BME-9

TEAM

Brooke Demarco, BME
Elisa Holtzman, BME
Caleb Setser, BME
Alexander Stabile, BME
Nicholas Wan, BME

ADVISERS

Kiersten Brown Espaillat, DNP, Department of Neurology, VUMC
Adam Meidinger, DPT, Vanderbilt Health

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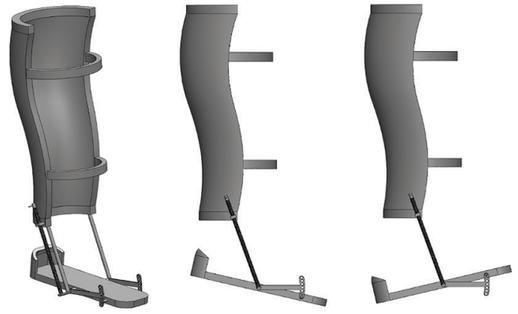
Ankle distraction and stretching boot

Current ankle injury solutions do not provide external ankle distraction and static stretching, which that can lead to complications in patient recovery and discomfort. For patients recovering from grade 2 and 3 ankle injuries, our goal is to develop a device that combines adjustable ankle distraction and static dorsiflexion/plantarflexion stretching features for at home use. The main design components include a rigid base secured to the top of the foot, a rail lengthening component on medial and lateral sides of talus, a secure calf component and a curved track to allow for dorsiflexion and plantarflexion. The external traction device would be the first that combines ankle distraction and stretching into one device, significantly reducing the manual workload of physical therapists. This device would reduce tension in the foot, prevent fluid buildup, address soft tissue contractures, alleviate pain and increase range of motion throughout the healing process.



The CAD 3D model for the distraction and stretching boot includes a rigid food plate, a form-fitting calf-sleeve, straps for adjustability, a track for flexion adjustment and a lengthening rail system for ankle distraction. Outer padding and fabric layers not shown.

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BIOMEDICAL ENGINEERING

BME-10

TEAM

Shannon Bussing, BME
Kelsey Corwen, BME
Erin Oldham, BME
Alejandra Taulet, BME

ADVISERS

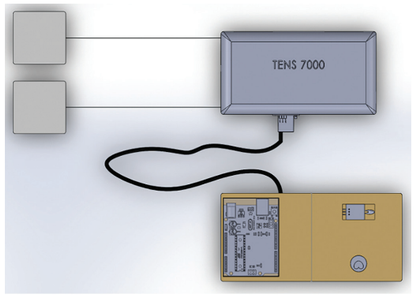
Professor Marc Moore, BME
Tamara Baynham, Ph.D., PopCheck Technologies
Erika Dillard, M.D., Ph.D., PopCheck Technologies

SPONSOR

PopCheck Technologies

Adhesive wearable device for blood clot detection

Patients undergoing procedures such as total joint arthroplasties and total joint replacements are at a higher risk of developing venous thromboembolisms (VTE), making health care associated blood clots a significant costly and potentially deadly public health issue. Traditional preventative measures like intermittent compression devices are cumbersome and restrict patients' mobility, leading to decreased compliance. Our team designed a wearable device that monitors key physiological indicators and promptly alerts both the patient and physician of potential blood clot formations, with minimal changes to patients' day-to-day life. This device is an adhesive silicone patch containing a photoplethysmography (PPG) sensor to monitor blood volume and associated hemoglobin concentration at the back of the knee. An accelerometer is incorporated to adjust for movement-related variations, ensuring data accuracy. A temperature sensor is used to detect shifts in skin temperature associated with changes in blood flow. Upon detecting any changes, the device activates a transcutaneous electrical nerve stimulation (TENS) machine, which effectively prevents blood clot progression and promotes timely intervention. This approach not only enhances patient safety and well-being but also is a significant step forward in the proactive management of VTE risks.



The skin-tone wearable patch, which includes a PPG sensor, accelerometer and temperature sensor, adheres seamlessly to the back of the patient's knee. The temperature and volume of blood at this location are constantly measured and the data is processed by an Arduino UNO microcontroller. Fluctuations in this data automatically trigger electrical stimulation from a TENS machine, enhancing patient care.

POPCHECK TECHNOLOGIES

TEAM

Amaya King, BME
Megan McKeen, BME
Peter Podar, BME
Supriyo Rana, BME

ADVISERS

Professor Marc Moore, BME
Professor Xiaoguang Dong, ME, BME

SPONSOR

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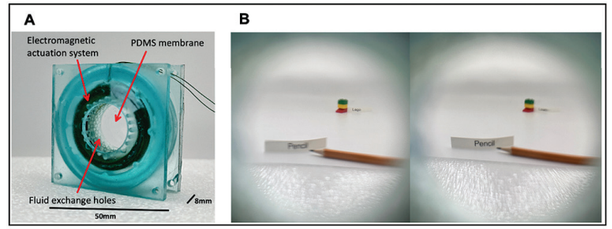
BIOMEDICAL ENGINEERING

BME-11

Ophthalmic lens with adjustable focal power

The most common eye conditions are hyperopia (farsightedness), myopia (nearsightedness), and cataracts. These conditions are typically corrected with single-vision lenses that preserve vision in one range while correcting vision in another range. There is currently no way to simultaneously improve visual acuity at ranges not visually attainable while preserving clear vision ranges for these individuals. This project's objective is to design and prototype an ophthalmic lens that can adjust focal power. It uses electromagnetic actuation to induce attraction or repulsion between a coil of wire and a permanent magnet based on varying an applied voltage, displacing the fluid under a flexible PDMS membrane. The change in fluid volume alters the lens' curvature to adjust focal power. The design team intends to allow user control of the focal power with a dial on a frame controlling current through the electromagnet. This device is advantageous in that it uses a fast and efficient actuation method never before used to correct vision and, if successful, accesses all visual ranges.



(A) Prototype testing module composed of two chambers houses the electromagnet coil, permanent ring magnet, PDMS membrane, and optical fluid.

(B) Focus test comparison of images taken through the tunable focus module demonstrating dynamic focal power. The word Lego farther in the field of view is in focus on the left, while the closer word Pencil is blurred. Focal power increase in the right image blurs Lego and focuses Pencil.

VANDERBILT School of Engineering

TEAM

Rosana Alfaro, BME
Emily Liao, BME/EE
Schyler Rowland, BME
Shreya Shrestha, BME

ADVISER

Professor Marc Moore, BME

SPONSOR

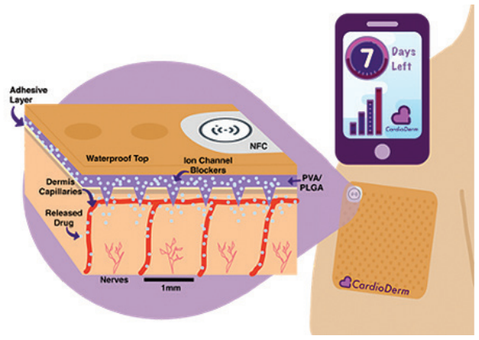
Vanderbilt University School of Engineering

BIOMEDICAL ENGINEERING

BME-12

Microneedle patch for hypertension drug delivery

Current hypertension treatments include oral medication, but outcomes depend heavily on patient adherence. As many as 50% of patients do not successfully follow their prescribed regimens. To address this challenge, our team developed a wearable microneedle patch designed to replace daily oral medication for 7 days. This patch features microneedles cast with Poly(vinyl) alcohol (PVA) and Poly(lactic-co-glycolic acid) (PLGA) crosslinked with fluorescent dye Rhodamine B as a model calcium channel blocker, based on its similar chemical properties. Our prototyping process included 3D printing microneedle-positive molds, casting negative molds with silicone, fabricating the crosslinked microneedles through high-pressure casting, and setting up an NFC chip-based tagging system. Ratios of PVA, PLGA, and Rhodamine B are fine-tuned throughout the design process to provide a physiologically relevant delivery rate throughout the 7 day period. To assess mechanical and chemical properties of the patch, we measure the tensile strength through compression testing, evaluate the penetration capabilities of the patch using parafilm layers and a light microscope, and create a degradation profile by assessing weight and cumulative release. In conjunction with the patch, an application has been developed to track patch replacement and to log heart health metrics such as daily blood pressure readings. Together, this hypertension management system provides patients and doctors with reliable medication delivery and individualized data to further tune treatment plans.



The CardioDerm microneedle patch for the transdermal delivery of chronic hypertension medication includes PVA/PLGA crosslinked microneedles infused with Rhodamine B as a model drug, an NFC chip for connection to the app, a waterproof surface to prevent damage to the patch, and an adhesive layer to secure the patch to patient skin.

VANDERBILT School of Engineering

CHEMICAL AND BIOMOLECULAR ENGINEERING
ChBE-1

TEAM
Rebecca Hedges, ChemE
Olivia Jones, ChemE/Chem
Heather Murray, ChemE/BME
Jordan Walker, ChemE

ADVISERS
Professor Russell Dunn, P.E., ChBE
Brian Babcock, Polymer Chemistry and Coatings, LLC
Karl Schnelle, PhD, Chemical Engineering Consultant

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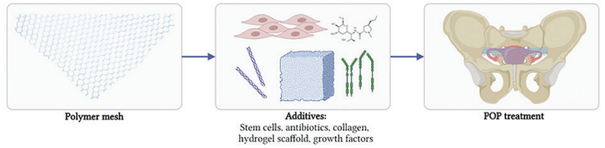
Novel polymer mesh design for enhanced pelvic organ prolapse (POP) treatment



Flowchart illustrates key components of the design process to develop a novel mesh product for POP treatment, including selection of the main polymer component of the mesh along with possible additives to enhance performance in the desired application area.

Historically, pelvic organ prolapse (POP) has been treated with surgically implanted polypropylene (PP) mesh. This treatment option led to severe failures such as erosion, shrinkage, and oxidative degradation, triggering adverse health consequences. Chronic inflammation, severe pain, and recurrence of POP in patients motivate the team's design of an alternative mesh implant to support prolapsed pelvic organs while minimizing health risks to patients. The team assessed the safety and ethicality of a currently marketed product (Gynemesh PS) through a root cause analysis and is designing a novel mesh that addresses the failures of PP mesh. The team is evaluating main polymer components and mesh additives to improve biocompatibility through a comprehensive literature review that ranks experimental outcomes based on their alignment with the team's design criteria. The recommended design enhances POP mesh treatment by incorporating a biodegradable polymer, enhancing tissue growth, and reducing infection and chronic inflammation to avoid the failures of the PP mesh and improve patient satisfaction. The final design proposal includes a detailed plan of safety testing required for the translation of the design to a clinical setting according to the medical device standards set forth by the International Standard Organization.

Polymer & Chemical Technologies, LLC

School of Engineering

CHEMICAL AND BIOMOLECULAR ENGINEERING
ChBE-2

TEAM
Maddie Espejo Karabell, ChemE
Jessica Lee, ChemE
Katrina Schwensen, ChemE
Hannah Thomas, ChemE

ADVISERS
Professor Russell Dunn, P.E., ChBE
Brian Babcock, Polymer Chemistry and Coatings, LLC
Karl Schnelle, PhD, Chemical Engineering Consultant

SPONSOR
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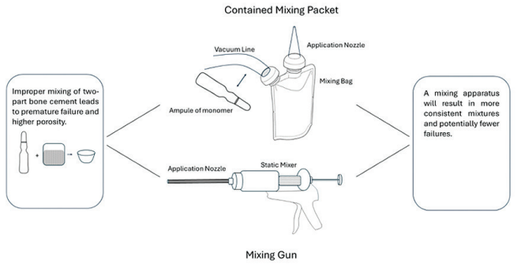
Optimizing clinical mixing of orthopedic bone cement

Bone cement is widely used for implant fixation in various common surgeries. Around 90% of all knee arthroplasties and about 60% of hip arthroplasties worldwide are fixated by bone cement. This cement consists of a volatile methyl methacrylate monomer (MMA) and powdered polymer (PMMA) that must be thoroughly and quickly mixed together within a narrow time window before application. Inadequate mixing compromises the properties of the cement, leading to fracturing and breakdown, poor long-term morbidity rates, and costly revision procedures. Additionally, prolonged interaction with MMA leads to health risks for the physicians handling the cement. To reduce the risks of using bone cement, we sought to develop a device that can reliably and safely mix the two components. The design must mitigate the inhalation of monomers, constantly incorporate the cement with minimal porosity, and must be easy to apply within the proper application time window. The team developed two prototypes—a contained mixing bag and an applicator gun with static mixer attachment. The efficacies of these prototypes are evaluated for strength and porosity with dynamic mechanical testing and SEM imaging of the resultant bone cement.



Two proposed prototype options to optimize bone cement mixing include a contained mixing bag and a static mixer attachment for a bone cement gun, each minimizing manual contact and cement porosity.

Polymer & Chemical Technologies, LLC

VANDERBILT Office of Experiential Learning and Immersion Vanderbilt

TEAM
Jacob Arquette, ChemE
Laura Bertalomi, ChemE
Aidan Fein, ChemE
Macy Noe, ChemE

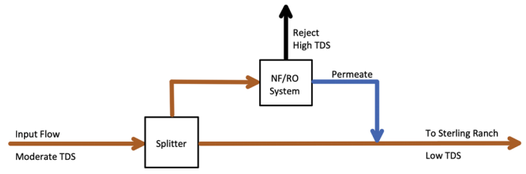
ADVISERS
Professor Russell Dunn, P.E., ChBE
Professor Bryan Beyer, ChemE
Professor Paul Laibinis, ChemE
Professor Shihong Lin, CEE, ChBE

SPONSOR
Sterling Ranch

CHEMICAL AND BIOMOLECULAR ENGINEERING
ChBE-3

Water network design software for Sterling Ranch, CO

Sterling Ranch is a community in Douglas County, Colorado, that prides itself on measures for water and energy sustainability. Through smart home water metering and onsite treatment facilities, Sterling Ranch has drastically decreased water consumption among its residents. Despite these measures, the American West is still facing an intense water crisis. We developed a software tool in Microsoft Excel that aids in selecting water purification membranes (reverse osmosis, RO, and nanofiltration, NF) that allows Sterling Ranch to improve any of the many sources from which they obtain their water. Our motivation behind this goal is due to the array of parties involved in Sterling Ranch's water system. We found it to be more effective to develop a system that may be used to solve a variety of problems, rather than one problem that may not be relevant to Sterling Ranch's current goals. To accomplish this goal, we tested several RO and NF membranes, compiled their performances, and developed the software tool that uses these performance parameters.



A flow diagram demonstrates the purification of a feed water source using a RO or NF membrane system to reduce a source TDS to a lower target TDS for Sterling Ranch.

STERLING RANCH COLORADO

School of Engineering

TEAM
Amberi Cui, ChemE
Chris Fitz, ChemE
Daniel Rau, ChemE
Samuel Ellis, ChemE

ADVISERS
Professor Russell Dunn, P.E., ChBE
David Steckler, Impact Technology Development, Inc.
Alan Crawford, Alan Crawford Consulting LLC.
Bruno Feitosa, P.E, Ascend Elements Zain Nasir, P.E., Ascend Elements Anton Popiy, Ascend Elements

SPONSORS
Ascend Elements, Inc.
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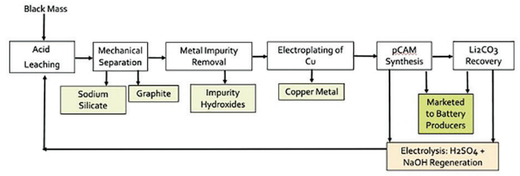
CHEMICAL AND BIOMOLECULAR ENGINEERING
ChBE-4

Hydrometallurgical NMC 811 lithium-ion battery recycling process

Our novel hydrometallurgical battery recycling process design aims to address the exponentially growing demand for critical metals used in lithium-ion batteries. The process is designed to economically recover lithium, nickel, cobalt, and manganese from otherwise discarded electric vehicle (EV) batteries. This process operates as a near closed-loop system, recycling water and heat and regenerating reagents from waste streams. The process continuously leaches a commodity-like pre-processed "black mass" to separate the insoluble anode components. Stepwise precipitation and mechanical separation are used to remove impurities before crystallizing the nickel, manganese, and cobalt in an 8:1:1 stoichiometric ratio to be later used for battery-grade cathode synthesis. Critical acidic reagents and bases are regenerated through electrolysis, while waste streams are properly treated. Our design leads to higher metal recoveries, higher product purities, and lower energy usage compared to alternative pyrometallurgical processes used in other regions of the world. The process adheres to strict environmental regulations while striving toward full circularity, reducing the overall footprint of the electric vehicle value chain. Detailed preliminary economic assessments with sensitivity analyses were conducted to identify the optimal flowsheet and operating conditions.



A mixed-metal powder containing nickel, manganese, cobalt, lithium and other components from crushed EV lithium-ion batteries is leached with an acid solution. Next, the insoluble graphite and silicon anode components are separated and upcycled into valuable co-products. The metal-rich acidic slurry's impurities are removed before being converted back into precursor cathode active material (pCAM). A battery-grade lithium product is recovered before waste treatment and reagent regeneration to achieve circularity.

ASCEND ELEMENTS

School of Engineering

CHEMICAL AND BIOMOLECULAR ENGINEERING

ChBE-5

TEAM

Olivia Black, ChemE
Mia Haschert, ChemE
Miles Sitcawich, ChemE/Math
Jonathan Wang, ChemE

ADVISERS

Professor Russell Dunn, P.E., ChBE
Professor Bryan Beyer, ChemE

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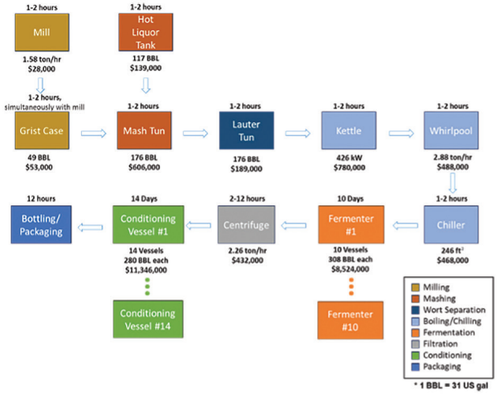
School of Engineering
Polymer & Chemical
Technologies, LLC

Plant design and economic analysis of a multi-product brewery

The word beer comes from the Latin verb bibere, meaning "to drink." The oldest evidence of beer is 5500 years old, and its invention has been argued to have fueled mankind's desire and ability to advance technologically. Although international beer production is dominated by a handful of macro breweries, the last few decades have seen a rise in the number and popularity of craft breweries in the United States. Our team was tasked with evaluating the economic feasibility of starting a craft brewery with a production rate of 100k bbl per year (1 bbl = 31 US gallons). The offerings would include IPAs, DIPAs, stouts, pilsners, lagers, and more. The two business models considered were the creation of our own facilities from scratch and contract brewing, where our products would be brewed using the equipment at a large regional brewery. By scaling up brewing recipes and designing equipment trains to accommodate them, the team has obtained preliminary estimates for raw material costs, total capital investment, and operating costs.



Process flow diagram of the plant design including process equipment, equipment capacity, equipment cost, and duration for each of the major steps of the brewing process.

Polymer & Chemical Technologies, LLC

VANDERBILT School of Engineering

CHEMICAL AND BIOMOLECULAR ENGINEERING

ChBE-6

TEAM

Anna Berger Romeu, ChemE
Patrick Gamble, ChemE
Michal Perez, ChemE/CLAS

ADVISERS

Professor Russell Dunn, P.E., ChBE
Alan Crawford, Alan Crawford Consulting LLC
David Steckler, IMPACT Technology Development Inc.

SPONSOR

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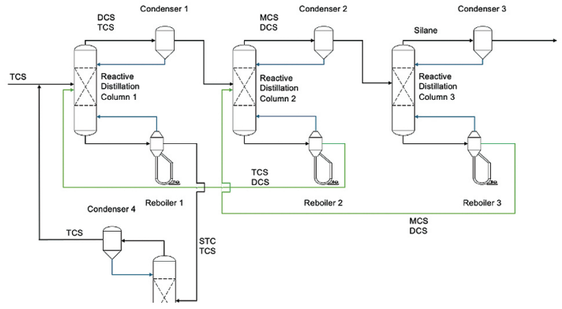
School of Engineering

Design of a 50 TPY silane plant using the redistribution of trichlorosilane via reactive distillation

Globally, silane production surpasses 20,000 tons per year (TPY). Silane or SiH4 is a gaseous compound that is critical in the semiconductor industry. It is most known for its use as a precursor to fabricate silicon-based films in the microelectronics industry. Currently, almost all silane is produced in large or medium sized plants (over 200 TPY). The project objective is to design a 50 TPY greenfield silane plant. The design team selected the trichlorosilane (TCS) disproportionation chemistry pathway, well documented over the past half century. We designed a series of three reactive distillation (RD) columns to produce ultra-high purity silane. The bottom products of the second and third RD columns recycle to the previous columns to drive equilibrium toward reducing chlorosilanes. Moreover, some of the bottom product from the first column contains tetrachlorosilane (STC), an oxidized chlorosilane from TCS. This unavoidable byproduct is purified via a traditional distillation column for sale as well, wherein remaining TCS is fed back as starting material. Hazard and economic analyses are being conducted to (1) gauge viability of this process and (2) guide further optimizations of the plant as necessary.



A process flow diagram (PFD) showing the major units involved in the chemical pathway as well as the distribution of chemicals.

VANDERBILT School of Engineering

TEAM

Harmony Bickerton, CE
Megan Higgins, CE
Katie Lombardi, CE
Tina Nguyen, CE

ADVISERS

Dan Borsos, P.E., EMC Structural Engineers
Keith Louiseau, Architect
Rich Teising, CEE

SPONSORS

The Village at Glencliff
Civil Design Center
EMC Structural Engineers

CIVIL AND ENVIRONMENTAL ENGINEERING

CEE-1

Structural design for The Village at Glencliff multi-storey and quadplex buildings

The Village at Glencliff is a respite care community providing temporary accommodation for unhoused people to recover from hospitalization. The nonprofit also provides supportive services including access to healthcare, food, and assistance with securing permanent housing. Phase I of the community's development consisted of 12 tiny homes. Phase II will add residential accommodations and increase the structures' sustainability. Our team will design two options for the Village at Glencliff's second phase of development. We propose adding three quadplex structures or converting an unused wing of the onsite church into a two-story apartment building. Both options make space for more residents while limiting the construction footprint. The team has created floor plans and structural drawings to depict the typical structural elements for each proposed building. The precision of structural drawings allows for material and labor cost estimates. The team will evaluate a novel, thin-shell concrete hyperbolic paraboloid roof for the quadplexes. The paraboloid roof will increase the quadplexes' efficiency by facilitating rain capture, minimizing lifetime maintenance costs, and maximizing material strength. We will compare the thin-shell concrete hyperbolic paraboloid roof to a typical wooden roof for cost and workability, producing a scaled model of the paraboloid roof.

Architectural rendering of the proposed quadplex design.

VILLAGE AT GLENCLIFF

CIVIC DESIGN CENTER

EMC STRUCTURAL ENGINEERS, P.C.

TEAM

Carolina Herrera CE
Christian Rojas CE
Laura Kwon CE

ADVISERS

Travis Todd, P.E., Thomas & Hutton
Austen Randolph, Thomas & Hutton

SPONSORS

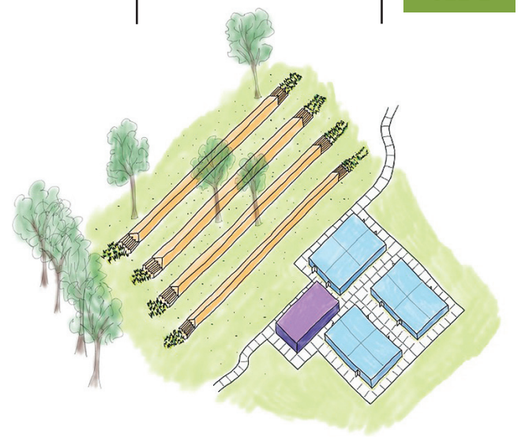
The Village at Glencliff
Thomas & Hutton
Civic Design Center

CIVIL AND ENVIRONMENTAL ENGINEERING

CEE-2

The Village at Glencliff phase II site design

The Village at Glencliff, a local nonprofit, provides housing for homeless individuals as they recover from hospitalization. Hosting 12 tiny homes, the facility seeks to expand its capacity to meet the needs of local hospitals. The civil engineering team is envisioning Glencliff's expansion, proposing a multi-storey building, three quadplexes, and a community center. Through interviews and consultations, they designed with a resident-first approach that emphasizes accessibility and privacy. The design plans include drawings and cost estimates that offer tangible evidence of the project's viability to potential donors. These site plans serve as a detailed blueprint for contractors, aiming to expedite the construction process. The site design team has maximized the area usage and arranged for three quadplexes and the community center to coexist on site with minimal need for grading and earthwork. These improvements include reduced development cost, alternative material sourcing and increased greenspace for residents.



Concept drawing of Phase II of The Village at Glencliff includes three quadplexes (12 units) and the community center as well as a landscaped amphitheater.

THOMAS & HUTTON

VILLAGE AT GLENCLIFF

CIVIC DESIGN CENTER

CIVIL AND ENVIRONMENTAL ENGINEERING

CEE-3

TEAM
Addy Novak, CE
Dara Elqadi, CE

ADVISER
Jennifer Osgood, P.E., CDM Smith

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The Village at Glencliff
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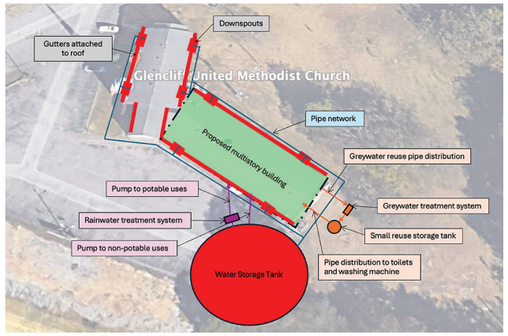
Water reuse system: rainwater harvesting and greywater reuse

The Village at Glencliff is a respite care community providing temporary accommodation for unhoused people in Nashville to recover from hospitalization. As the community expands, they face challenges regarding development, sustainability, and economic viability of their current water systems. Our team addresses these challenges by designing three separate water reuse systems that treat and recycle water for use within the tiny home community. The three systems treat rainwater for non-potable use, rainwater for potable use, and greywater for non-potable use. We will present a water reuse system from the three options that is both environmentally sustainable and cost-effective. We will aim for the selected water treatment system to align with the Water Petal of the Living Building Challenge certification, enabling the Village at Glencliff to receive sustainability funding for future developments. The water system proposed will be sufficient to promote the project for future implementation.



Basic schematic of the rainwater harvesting and greywater reuse system incorporated into the site.

TEAM
Alejandro Barrera-Waters, CompE
Michael Delaney, CompE
Andrew Della Penna, CompE
Timothy Schachner, CompE

ADVISERS
Professor Walter Collett, ECE
Marcy Pedzwater, Ph.D., AdvancED

SPONSORS
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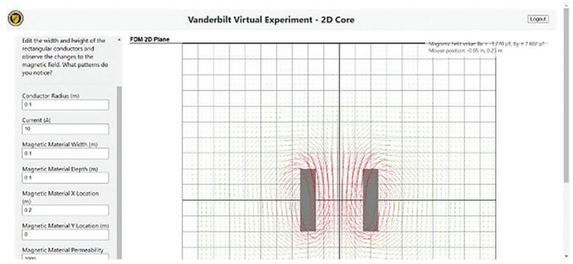
ELECTRICAL AND COMPUTER ENGINEERING

ECE-1

Design of a virtual experiment

The rapidly evolving integration between educational practices and the digital world demands the development of technology-based learning tools. The Electrical and Computer Engineering (ECE) Department and Vanderbilt's Institute for the Advancement of Higher Education (AdvancED) are co-sponsoring a project that seeks to enhance Vanderbilt's electromagnetics curriculum by designing a virtual experiment to complement some class material. The creation of a comprehensive, interactive online learning platform will circumvent many practical challenges associated with in-class hands-on learning experiences. The platform features virtual experiments designed to deepen the user's understanding of the concepts of electromagnetic circuits and current-generated magnetic fields, catering to students' needs for practical, accessible education tools. By implementing robust practices in web development, backend infrastructure, and educational theory, the project combines technological innovation and pedagogical effectiveness. In doing so, it should overcome logistical obstacles associated with traditional labs, provide a flexible learning environment, and offer a scalable solution for hands-on digital education.



The web application will feature experiments that encourage the use of input/output simulations such as the one above, which simulates the magnetic field on a 2D plane around two rectangular conductors with current running through them in opposite directions. Access to these experiments will be controlled by Google SSO and individual user permissions for specific logged-in accounts.

TEAM
Reagan Massey, ECE
Sahil Reddy, EE
Rui Wang, ECE/CS/Math

ADVISERS
Professor Tim Holman, ECE
Professor Walter Collett, ECE

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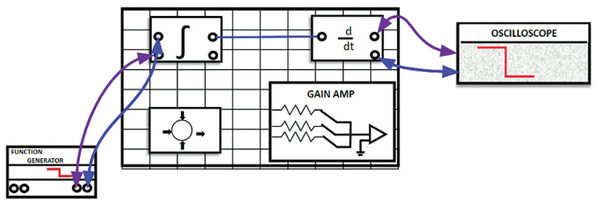
ELECTRICAL AND COMPUTER ENGINEERING

ECE-2

Design of a portable classroom demonstration

Our team designed a portable demonstration device to introduce circuit concepts to engineering and science classes. The goal is to create an interactive, portable classroom demonstration that allows the instructor and students to reconfigure and visualize the signal processing occurring in circuits like integrators, differentiators, summers, and amplifiers with adjustable parameters. The boards have adjustable components like variable resistors and switches to change gain, time constants, etc. The demo is easily accessible for professors to use as a teaching tool. The concepts taught in ECE-2112 (Circuits I) are difficult to visualize and there are no physical demonstrations used to teach basic concepts. The intention is to create a working container displaying four different circuits that will be created using universal PCB boards and fixed into a container. Compared to static demonstrations, this hands-on, reconfigurable system provides an engaging way for students to learn by directly manipulating the circuit parameters and observing the real-time signal changes. It is our intention that the demo unit will be used in future Circuits classes as a teaching tool.



An initial schematic of a portable demonstration device with an external oscilloscope and function generator. The device contains one or multiple differentiators, integrators, gain blocks and summator blocks. Each of the blocks is in a separate box and connected to a common base through a magnet.

ELECTRICAL AND COMPUTER ENGINEERING

ECE-3

TEAM
Neil Badlani, ECE
Meredith Hunter, EE
Ashley Potts, ECE/Math

ADVISER
Professor Andrea Locke, BME

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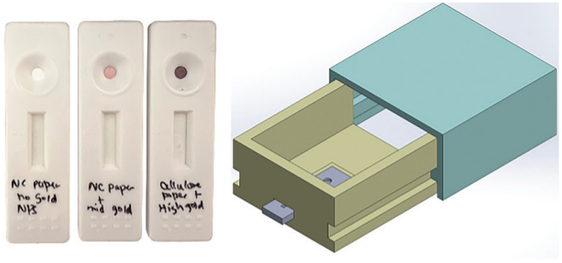
Vanderbilt University School of Engineering
Locke Biosensing Lab

Low-cost spectroscopic system for biosensing

In 2023, an estimated 3.1 million cases of tuberculosis went unreported, primarily due to inadequate diagnostic testing in low-resource areas. We address this issue by developing an affordable point-of-care diagnostic device capable of reliably detecting tuberculosis. The Locke Biosensing Lab has developed a gold nanoparticle biosensor to detect tuberculosis bacteria in saliva samples. The biosensor functions by binding to the bacteria, causing a change in the reflectance value of the gold nanoparticles. Our team designed a low-cost, handheld device that measures sample reflectance to determine the presence of tuberculosis. The device illuminates the sample with white light and then measures reflectance at several wavelengths using a color sensor. A weighted average of the wavelengths is computed and compared to a threshold to determine if the sample contains tuberculosis bacteria. Testing of the device on gold nanoparticle samples has demonstrated the device's ability to effectively differentiate different concentrations of the nanoparticles. With its potential for enhanced sensitivity and specificity compared to existing low-cost tuberculosis diagnostics, this device offers a promising solution for resource-constrained communities.



Samples with different concentrations of bound gold nanoparticles have different reflectance values (left). A sample is inserted into the handheld device, which reports if tuberculosis bacteria are detected (right).

VANDERBILT School of Engineering

ELECTRICAL AND COMPUTER ENGINEERING

ECE-4

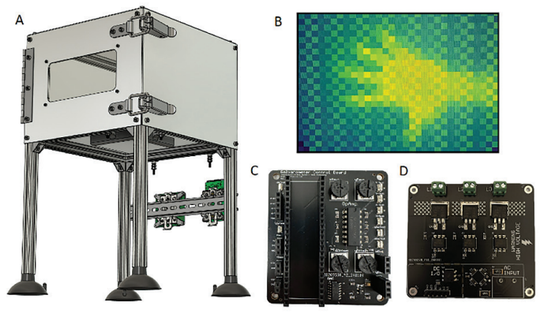
TEAM
Grey Aycock, ECE
Jenna Kronenberg, EE
Joseph Quatela, CompE

ADVISER
Professor David Florian, ChemE

SPONSOR
Vanderbilt Digital Fabrication Lab

Open-source SLS printer

Selective Laser Sintering (SLS) is an additive manufacturing process that uses a high-powered laser to sinter plastic powder to build complex objects without support material. However, SLS 3D printers are cost-prohibitive to small businesses and hobbyists. The goal of this project is to build an SLS 3D printer using off-the-shelf hardware and open-source software to ultimately allow for the printing of bone scaffolds at a lower price than using a commercially available printer. The team designed custom circuit boards and software algorithms to implement the two most important electrical systems involved in the SLS printer: the system to regulate and manage the heat of the print chamber and the system to control the galvanometers, which work to scan the laser across the powder. These components will be integrated together to allow for a more accessible SLS printing system.



(A) Testing assembly used to prototype the heating and optical systems of the SLS 3D printer.

(B) Heat map generated by custom software using an infrared sensor inside the testing chamber.

(C) Galvanometer control board used to scan a laser reflected by mirror galvanometers across the surface of the print bed. (D) Heating control board, which consists of a zero cross detector and three solid-state relays. These subsystems work together with a Raspberry Pi to achieve phase-angle control of three quartz heat lamps.

TEAM
Cierra Anderson, ECE/Physics
Alex Fullerton, EE
Alli Hebdon, ECE/Applied Math
Ryan Lenart, ECE
Alex Oh, EE/CS

ADVISERS
Professor Ashwaq Amat, ECE
Charles Gerrity, ECE

SPONSORS
Vanderbilt University School of Engineering
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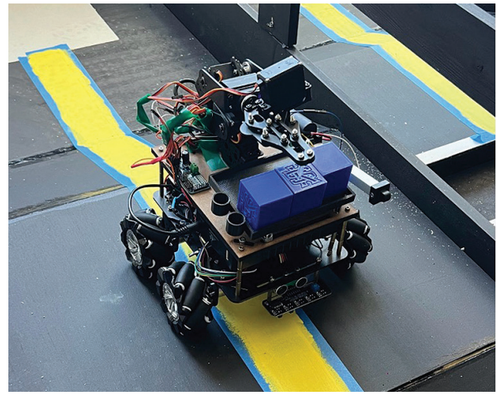
ELECTRICAL AND COMPUTER ENGINEERING

ECE-5

IEEE hardware competition robot

The Institute of Electrical and Electronics Engineers Region 3 (Southeast US) hosts an annual hardware competition. This year, the robot must pick up, sort, and drop off packages, pick up and assemble "fuel tanks," cross a ravine via zipline, and press a button to stop a clock. Each task completed earns points. To achieve these tasks, a Raspberry Pi 4 and ESP32 are the microcontrollers. A PCB was developed to host major components. The basic movement of the robot and the linear actuator will be controlled through the ESP32, while the mechanical arm, sensors, and control loop will be controlled by the Raspberry Pi. A PixyCam 2.1, ultrasonic sensor, and line follower are used to detect objects based on color, find distance to object, and to track a yellow line on the playing field. The high-level software is written in Python with threading to enable multitasking, while C is used for low-level software to control the wheels and motors. The high-level software will consist of a control loop that goes through Tasks, which are implemented as Python threads. The C code will contain a main loop that will wait on a message through serial communication, then execute the corresponding command based on the given parameters.



The autonomous robot uses mecanum wheels, a 6-servo mechanical arm, a raspberry pi, ESP32, and various sensors such as a line follower, a PixyCam and ultrasonic sensor to collect and dispense objects, traverse ziplines and move around the track.

VANDERBILT School of Engineering

TEAM
David Limpus, ECE
Ryan Taylor, ECE
Isabella Wynocker, ECE

ADVISER
Professor Amrutur V. Anilkumar, ME

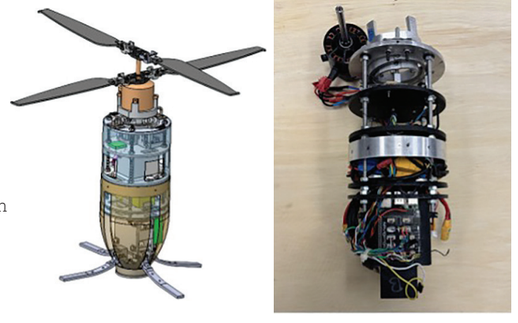
SPONSORS
Vanderbilt Aerospace Design Laboratory

ELECTRICAL AND COMPUTER ENGINEERING

ECE-6

Coaxial drone for planetary landings

A VADL team will compete in the 2024 NASA University Student Launch Initiative launching a rocket to an apogee of 4,400 feet above ground level (AGL) and safely deploying the STEMnaut Atmospheric Independent Lander (SAIL) at 400 feet AGL. Our project primarily focuses on the development of the electrical and software components of the SAIL, which features an onboard autonomous control system designed to work with a coaxial high-speed rotor propeller system and land the payload with its four STEMnauts in a predetermined orientation. The electronics onboard the SAIL are designed to provide several key functionalities: localization, perception, and motion planning. For localization, data measurements from a LiDAR, 6-axis IMU, and barometric altimeter are fused using an Extended Kalman Filter to provide state estimation so SAIL can determine its rate of descent and configure a response. For visual perception, an FPV camera system provides a way to monitor the descent of the SAIL if manual control is activated. For motion planning, an autonomous landing flight mode is configured through Ardupilot to engage after the SAIL is deployed from the rocket to land safely on the ground.



The STEMnaut Atmospheric Independent Lander (SAIL) is a coaxial drone engineered to deploy from a rocket and autonomously navigate the STEMnaut housing unit to the ground using various electrical sensors and an electromechanical control system.

VANDERBILT AEROSPACE DESIGN LABORATORY

ELECTRICAL AND COMPUTER ENGINEERING

ECE-7

TEAM

Dan Arnold, ECE
Hunter Bergstrom, CompE/Math
Kevin Cao, ECE/Phys
Andrew Ciccarone, ECE
Thomas Wu, ECE

ADVISERS

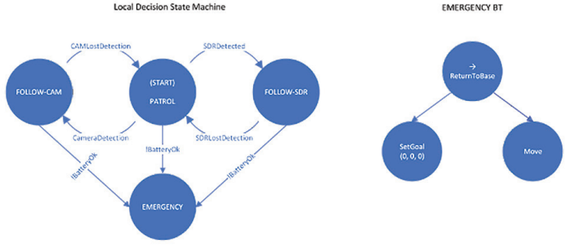
Noah Baijo, Booz Allen Hamilton
Rojae Johnson, Booz Allen Hamilton

SPONSOR

Booz Allen Hamilton

Simulation of data framework for UAVs

Unmanned aerial vehicles (UAVs) are used increasingly for surveillance due to their ability to efficiently monitor areas under minimal human guidance. However, larger areas necessitate the deployment of multiple drones to observe a significant portion of the area at all times. In typical deployments of UAV swarms, drones receive commands and mission plans via a centralized ground control station (GCS) that can act as a potential bottleneck to operation when multiple actions need to be conducted. To solve this problem, the team designed a framework that allows autonomous communication between drones within a swarm. The framework combines state machines for their reactivity and behavior trees for their action expressiveness, both of which are implemented through Robot Operating System (ROS). This allows for the UAVs to be able to keep track of their own state and operations as well as those of the other drones deployed in the swarm. We use Ardupilot software in the loop (SITL) simulation software to monitor the drones and demonstrate their capabilities.



Finite State Machine (FSM) and Behavior Tree (BT) hybrid architecture. The BTs control the individual actions of each drone while the FSMs control transitions between different types of behaviors.

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ELECTRICAL AND COMPUTER ENGINEERING

ECE-8

TEAM

Oscar Cortez, ECE
Walker Larivee, ECE
Arianna Santiago, ECE
Trenton Weaver, ECE
Xianduo Zhao, ECE

ADVISERS

Noah Baijo, Booz Allen Hamilton
Roshawn Treadwell, Booz Allen Hamilton

SPONSOR

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Low-cost autonomous UAV

The Unmanned Aerial Vehicle (UAV), due to its flexibility in application and cost-effectiveness in tackling traditionally costly airborne tasks, has taken a commanding position in both consumer, commercial and military applications. However, current market offerings lack a budget-friendly UAV platform with operational autonomy and high customizability. This project aims to create an affordable platform suitable for a variety of specialized uses with a focus on security and surveillance applications. Using a NVIDIA Jetson Nano as the onboard processing unit and a widely available S500 drone frame as the base, the drone delivers great capability at an affordable cost. Compared to currently available products, the project aims to introduce additional autonomy through the advanced machine learning capability of the Jetson Nano, which offers greater computational power and operational flexibility than the popular Raspberry Pi setup. While the design includes only a minimal number of peripherals, additional features could be easily implemented in the future using the existing structure of the frame.

The low-cost UAV drone frame with motor, propeller, and component mount installed.

Booz | Allen | Hamilton

TEAM

Kaitlyn Phan, ECE
Wesley Schelling, ECE
William Wu, CompE

ADVISERS

Professor Walter Collett, ECE
John Camilleri, PSC Consulting

SPONSORS

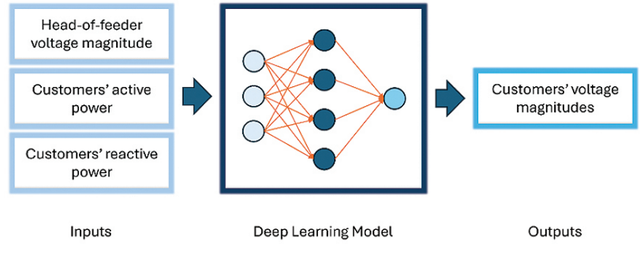
Vanderbilt University School of Engineering
PSC Consulting

ELECTRICAL AND COMPUTER ENGINEERING

ECE-9

Deep learning model for residential voltage prediction

Utility companies traditionally conduct computationally intensive power flow analyses to calculate grid voltage, but this requires accurate electrical models that are often incomplete, missing or incorrect. The team has developed a deep learning algorithm leveraging smart meter data to predict customer voltage that offers a cost-effective alternative to conventional methods. This innovation addresses the limitations of previous approaches, particularly in neighborhoods with residential distributed energy resources (DERs), such as solar panels. The team's effort in designing a better final product is not limited to improving the algorithm, but also includes developing better data simulation and data processing approaches. The algorithm is intended to improve voltage predictions for both standard households and those with DERs. It is showing promising results in enhancing accuracy and efficiency over previous machine learning approaches. After the capacity of the algorithm is fully realized, it can perform in parallel with conventional voltage calculation methods to aid in verification.



Inputs for the deep learning algorithm include head-of-feeder voltage magnitude, customers' active power, and reactive power. These inputs are processed by the deep learning model to predict the customers' voltage magnitudes.

School of Engineering

PSC

ENGINEERING SCIENCE AND MANAGEMENT
ESM-1

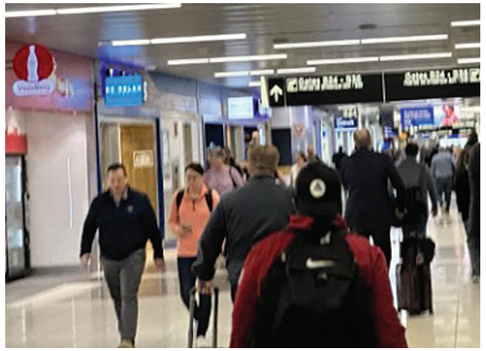
TEAM
Dillen Cameron, ES
Sara Cooley, ES
William Johnston, ES
George Zakaria, ES

ADVISER
Professor Courtney Johnson, ES

SPONSORS
Airport Cooperative Research Program (ACRP)

Meeting growing electricity demands in airports

The Airport Cooperative Research Program (ACRP) hosts an annual research and design competition challenging teams of university students to explore and offer a solution to a problem threatening the world's airports. One such problem is the expected growth in global electricity demands, driven by technological advancements and growing passenger numbers. It is projected that by 2029, the amount of travel will surpass its pre-pandemic 814 million trips in 2019, reaching around 865 million trips. The team's solution offers significant improvements over existing systems by prioritizing renewable energy sources and leveraging IoT for smarter energy management. The proposal includes a cost-benefit analysis and implementation plan. It not only addresses the current challenge of high energy demand but also sets a precedent for future sustainable practices in airport operations, aligning with global environmental goals.



Airports are searching for solutions to meet electricity demands as passenger volumes increase.

ACRP AIRPORT COOPERATIVE RESEARCH PROGRAM

ENGINEERING SCIENCE AND MANAGEMENT
ESM-2

TEAM
Chandler Alexander, ES
Jackson Germond, ES
Connor Pierce, ES

ADVISER
Professor Courtney Johnson, ES

SPONSOR
Airport Cooperative Research Program

Dual jet bridge implementation

In partnership with the Airport Cooperative Research Program (ACRP), we propose a project to revolutionize the airplane boarding process through a dual-jet bridge system design, focusing on front and rear boarding to dramatically reduce gate time and increase flight frequencies within FAA hours. This project aims to streamline airline operations, offering an industry-standard solution while working closely with airports, airlines, and regulatory bodies to align with FAA regulations and industry needs. Our work includes designing a dual-jet bridge system, conducting cost-benefit analyses, and evaluating the feasibility of adoption with advisement from industry subject matter experts provided by the ACRP. Anticipated outcomes include decreased boarding times, enhanced operational efficiency, and the potential for reduced travel costs and increased flight availability, representing a significant advancement in air travel efficiency.

A digital rendering of operations with a dual jet bridge on commercial passenger aircraft

ACRP AIRPORT COOPERATIVE RESEARCH PROGRAM

TEAM
Nia Cole, ES
Dzifa Dumenyo, ES
Claire McQuillen, ES
Mariyam Shamshidova, ES

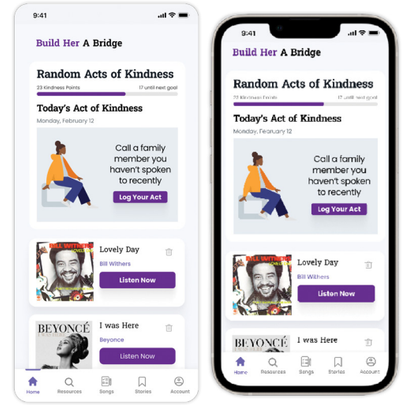
ADVISER
Samantha DeGrasse, Build Her a Bridge Founder

SPONSOR
Build Her a Bridge

ENGINEERING SCIENCE AND MANAGEMENT
ESM-3

Build Her a Bridge app development

Mental health is one of the most broad reaching public health challenges in America, particularly among young people. Build Her a Bridge (BHaB) is a nonprofit that seeks to provide relief, support, and a platform to discuss mental health for teen girls in Tennessee. BHaB provides in-person and virtual opportunities for connectivity through group discussion, journaling, and wellness activities such as yoga and meditation. They also facilitate connections with low-cost counseling services and offer college scholarships. Our team is developing a mobile application to expand BHaB's mission by creating a safe and private space for teen girls to express their feelings and access key resources. The BHaB app features a Resources page, a Stories page where girls can keep a private journal log, access to BHaB's shop, and an interactive incentive program encouraging wellness activities and random acts of kindness. It reaches the BHaB community in an intimate and personal way, acting as both a confidant and a potentially lifesaving resource.



A Figma mockup for the app homepage displaying the random acts of kindness and songs tile.

build her a bridge

ENGINEERING SCIENCE AND MANAGEMENT
ESM-4

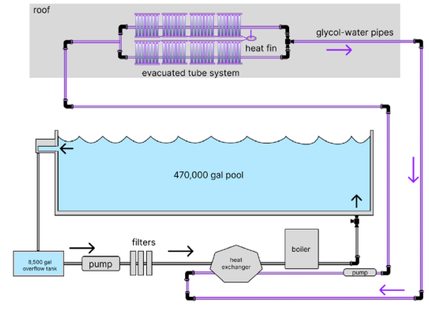
TEAM
Anya D'Costa, ES/CLIM
Igolo Ohalete, ES/CMA
Jayson Stern, ES
Jake Underwood, ES

ADVISER
Howard Parker, Vanderbilt University Facilities Department

SPONSOR
Vanderbilt University Facilities Department

Solar heating for Vanderbilt Recreation Center pool

To address the dual challenges of financial strain and negative environmental impact from fossil fuel use, Vanderbilt University has initiated a FutureVU sustainability framework, aiming to power the campus entirely with renewable energy by 2050. Within this framework, Campus Facilities has embarked on numerous endeavors to produce renewable energy on site to lower carbon emissions and reduce dependency on non-renewable energy sources from Nashville Electric Service. This project, in collaboration with Spectra Energy Providers, is a notable undertaking to retrofit the current gas-powered heating system of the pool at the David Williams II Recreation and Wellness Center with a solar-powered alternative. The new system uses efficient UV evacuated solar tubes positioned on the recreation center's roof to transform solar energy into heat, maintaining the pool's 470,000 gallons at an optimal 78.5°F. Our comprehensive project management and implementation approach involves evaluating the current system, upholding stakeholder interests and needs, and conducting thorough analyses on the feasibility, cost-effectiveness, efficiency, benefits, and potential risks of adopting UV evacuated solar tube technology. This project is projected to save approximately $30,000 in fuel costs annually and signifies an exemplary stride toward achieving the ambitious sustainability and environmental stewardship targets set by FutureVU.



A proposed evacuated tube system for the existing pool system at the David Williams II Recreation and Wellness Center.

VANDERBILT UNIVERSITY

ENGINEERING SCIENCE AND MANAGEMENT

ESM-5

TEAM

Sarah Mesa, ES
Nicole Montenegro, ES/CLIM
Ethan Rand, ES/Math
Aiden Stavros, ES

ADVISER

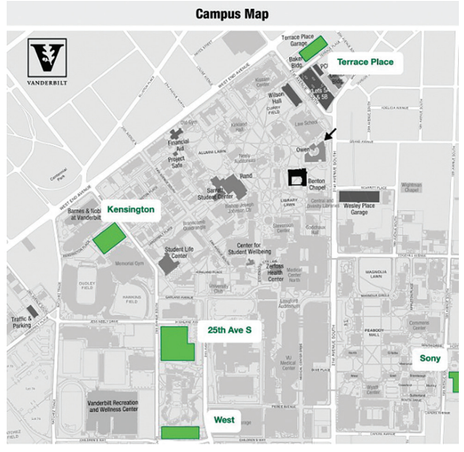
Howard Parker, Vanderbilt University Facilities Department

SPONSOR

Vanderbilt University Facilities Department

Solar array design development for Vanderbilt parking garages

Through the FutureVU: Sustainability program, Vanderbilt University aims to power the campus entirely with renewable energy by 2050. The initiative includes provisions for significantly reducing energy related costs and carbon emissions, positioning Vanderbilt as the first university campus to independently produce 100% of its energy needs. This project advances that goal by proposing designs for vaulted solar arrays on the rooftops of campus parking garages. The arrays are projected to generate 6 million kWh of energy annually, substantially reducing the university's reliance on electricity purchased from Nashville Electric Service (NES). Vanderbilt will lease the energy produced over a 30-year period, with the option to acquire the solar installation at the contract's conclusion. This project is projected to save at least $500,000 annually, with savings growing over time as energy prices fluctuate. The team will develop a comprehensive proposal for Vanderbilt's administration, encompassing the final design, projected benefits, and associated costs of the project.



Solar array proposal will include designs for five campus garages: Terrace Place, Kensington, 25th Ave S, West, and Sony.

VANDERBILT UNIVERSITY

ENGINEERING SCIENCE AND MANAGEMENT

ESM-6

TEAM

Albin Aliu, ES
Hannah Dresner, ES/Econ
Matthew Mays, ES/Econ
Payton McGrath, ES

ADVISER

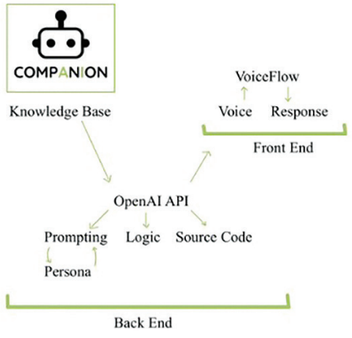
Professor Lynne P. Cooper, ES

SPONSOR

Granger Cobb Institute for Senior Living

AI conversation application for senior adults

One of the more prevalent problems for senior adults today is social isolation, a condition that can relate to health complications, mental wellness issues, and a sense of disconnection from society. The product, CompAnIon, aims to bridge the gap of social isolation for seniors by using artificial intelligence (AI) to offer a personalized and adaptive conversational device. Many of the products that exist today are leveraged to serve as an assistant for seniors in various capacities. How CompAnIon distinguishes itself from these products is through the prioritization of social companionship rather than utility. The data and knowledge we fed to our prototype focus on communication with seniors and optimizing their personal well-being within social interaction. Overall, the goal of this project is to mitigate the substantial effects of social isolation with the ever-present opportunity to engage in conversation.



The chatbot will use the Assistant GPT Turbo 4.0 platform and integrate a personalized knowledge base as well as back-end logic to exhibit an advanced conversational system.

Independence Community Quality of Life Dignity

TEAM

Isabella Fraczek, ES
Jennifer Mazzola, ES/Econ
Paterne Migwaguro, ES
Ethan Smiley, ES

ADVISER

Professor Lynne Cooper, ES

SPONSOR

Granger Cobb Institute for Senior Living

ENGINEERING SCIENCE AND MANAGEMENT

ESM-7

Grocery shopping tool for senior adults

Grocery shopping presents a major challenge for many senior adults. Obstacles relating to mobility, memory, vision, hearing, and other cognitive abilities present significant barriers. Grocery shopping requires the ability to remember desired items, navigate throughout the store, and manage heavy loads. In collaboration with the Granger Cobb Institute for Senior Living, the goal of the project is to design a solution that enables senior adults to grocery shop more effectively. This can be a tool that assists in managing a grocery list, identifying and viewing items and labels, navigating to items within the store, and carting and bagging groceries for transport. The team has conducted fact-finding interviews with residents and staff at a senior living facility and field studies of shopping behaviors in grocery stores to determine the most pertinent challenges seniors face while grocery shopping. With this information, the team intends to prototype a solution that will minimize current grocery shopping barriers and positively impact both residents and staff at senior living communities.

The preliminary prototype includes a shopping basket that clips into a standard assistive walker and offers accessibility attachments such as adjustable basket floors and clips for store maps and shopping lists.

Independence Community Quality of Life Dignity

TEAM

Andrew Barclay, ES
Adam Ebersole, ES
Gage Pitchford, ES
Michael Spencer, ES

ADVISER

Burkley Allen, Nashville Metropolitan Council

SPONSOR

Nashville Metropolitan Council, Committee of Transportation and Infrastructure

ENGINEERING SCIENCE AND MANAGEMENT

ESM-8

Nashville Metropolitan Council sidewalk improvement project

The city of Nashville is currently growing at an unprecedented rate, leading to a massive demand for pedestrian infrastructure in suburban areas. The current method of sidewalk development requires the placement of large underground concrete pipes that are both costly and time-intensive to install. The overall objective of this project is to develop a new form of sidewalk development that can help save time and money as well as help mitigate the environmental burden that the current solution creates. The main focus of this project relates to the handling of stormwater runoff in a way that will not require underground sewer systems or treatment after being redirected. The current method of installing concrete pipes is costly and environmentally unsustainable both during installation and long term. The anticipated result of this project will be an innovative sidewalk design for the communities of Nashville that accommodates stormwater runoff in a safe, economical, and environmentally friendly manner.

Case study of current sidewalk construction project underway on Bowling Ave near Saratoga Dr. In this case, using conventional stormwater management practices necessitates the installation of curbside inlets and pipes of up to 39" beneath the right of way.

ENGINEERING SCIENCE AND MANAGEMENT

ESM-9

TEAM

Jason Burke, ES/Econ
Gian Luca Lupica-Tondo, ES/MCB
Brooke Stevens, ES/Math
Kela Totherow, ES

ADVISERS

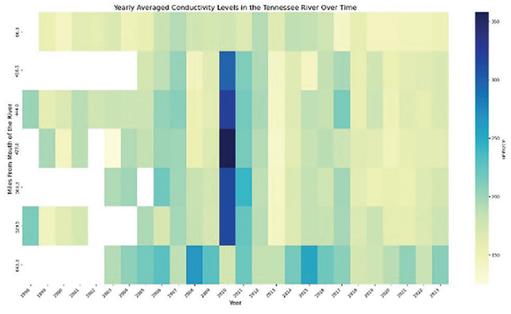
Vojin Janjić, Tennessee Dept. of Environment and Conservation
Kim Laster, Tennessee Dept. of Environment and Conservation

SPONSOR

Tennessee Dept. of Environment and Conservation, Division of Water Resources (TDEC, DWR)

Tennessee water quality data analysis

The Tennessee Department of Environment and Conservation's (TDEC) Division of Water Resources (DWR) is responsible for managing, protecting, and enhancing the quality of the state's water resources through voluntary, regulatory, and educational programs. The DWR is the administrative agent for Tennessee Statutes, Rules, and Regulations such as the Water Quality Control Act, which regulates surface waters. The DWR conducts routine water quality monitoring following the 5-year watershed management cycle. We are assisting the DWR by analyzing digital data dating back to the 1990s, focusing on long-term spatial and temporal water quality analysis. Such analysis provides new insights into water quality trends and helps identify potential changes to water quality management actions across Tennessee. We are analyzing four waterways over time and the Tennessee River for eight nutrients and field parameters such as dissolved oxygen, temperature, pH, phosphorus concentration, and others. Our analyses use Python and R, and we are presenting cohesive visualizations and detailed summaries of our findings to the DWR team.



A spatiotemporal heat map displaying conductivity levels across all seven Tennessee River monitoring stations from 1998 to 2023.

TN Department of Environment & Conservation

TEAM

Feven Desta, ME
Yadale Gebriel, ME
Claire Im, ME
Luke Kim, ME
Caimin Xi, ME

ADVISERS

Kyle Betts, Amazon Robotics
Adam Ingerman, Amazon Robotics
Sid Madhavapeddi, Amazon Robotics

SPONSOR

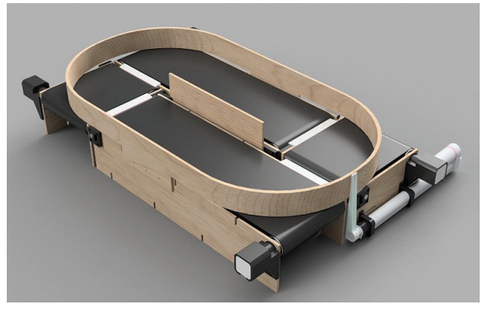
Amazon Robotics

MECHANICAL ENGINEERING

ME-1

Amazon Work-In-Progress (WIP) buffer

Amazon's Mt. Juliet fulfillment center utilizes Cardinal, a robotic arm, to sort packages into bins based on their destinations. Currently, a percentage of packages are classified as exceptions due to an absence of a valid destination during sorting, damage, or an inability to correctly identify a package. These exceptions are rerouted to an exception cart for manual processing, decreasing the workcell's productivity rate and increasing processing costs. The work-in-progress (WIP) buffer is an exception handling solution that provides a space within the workcell to store packages without an available destination bin until they can be reintroduced to Cardinal for resorting. We designed and prototyped a rotating conveyor platform located above the exception cart for Cardinal to deposit packages onto. The available space within the workcell that is reachable by Cardinal is highly limited, so the incorporation of a controlled conveyance system allows for a more effective use of previously unavailable space. The WIP buffer uses four conveyor belts in conjunction with computer vision to store and track the location of up to 15 packages. By providing a secondary location for these temporary exceptions, Amazon Robotics will increase their autonomous productivity rate and decrease processing costs of their fulfillment centers.



The work-in-progress (WIP) buffer is a rotating conveyor system that provides a temporary space for packages in the Cardinal workcell without a valid destination at the time of sorting until a new bin matching the package's destination is introduced to the workcell.

amazon robotics

TEAM

Nathan Angell, ME
Benjamin Dauber, ME
Jason Hwong, ME/Clim
Sebastian Nuñez, ME
Emily Van Schaack, ME
Jem van Tyn, ME

ADVISER

Professor Thomas Withrow, ME

SPONSORS

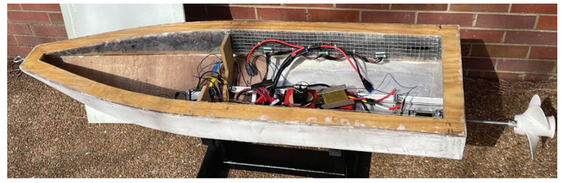
Vanderbilt University School of Engineering
American Society of Naval Engineers

MECHANICAL ENGINEERING

ME-2

Design, build and testing of an electric power boat to compete at Promoting Electric Propulsion 2024

The Promoting Electric Propulsion competition is hosted by the American Society of Naval Engineers in Virginia Beach. The goal of the competition is to prepare the next generation of engineers to tackle modern engineering problems. The competition is a time trial race in open water; the fastest boat to complete five 1-mile laps wins. Vanderbilt's 2024 competition team is competing in the unmanned vessel division. Our team constructed a 5-foot hull, which provides ample buoyancy for the weight of the batteries and drivetrain while minimizing drag. Compared to teams in previous years, our hull is designed to be most efficient at higher speeds, and we plan to complete the course in under 20 minutes. A closed loop water cooling system is implemented to manage the heat generated by the batteries, motor and gearbox. The boat is remote-controlled and powered by an 800-Wh lithium polymer battery pack. The drivetrain assembly was custom designed to couple the most optimal motor, gearbox and propeller for the format of the race.



The boat consists of an electric drivetrain connecting a propeller to a gearbox and motor, an electrical system powered by rechargeable battery packs, a cooling system, and a steering system consisting of a dual rudder with servo control.

AMERICAN SOCIETY NAVAL ENGINEERS · 1888 ·

School *of* Engineering

MECHANICAL ENGINEERING

ME-3

TEAM

Mary Burke, ME
Nina Gallinar, ME
Reaves Gardner, ME
Emmie Lew, ME

ADVISERS

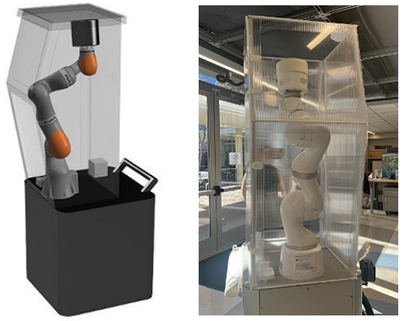
Abbie Weeks, Vanderbilt Institute for Surgery and Engineering
Emily McCabe, Vanderbilt Institute for Surgery and Engineering

SPONSOR

Vanderbilt Institute for Surgery and Engineering

Environmental protection and storage system for surgical robots

The project goal is to design and build two housing environments for surgical robots in the Vanderbilt Institute for Surgery and Engineering (VISE). The two robots, a magnetic flexible endoscope and an endonasal concentric tube robot, require precise environmental conditions in storage and transport, shielding them from moisture, dust and impact. The design must be an aesthetically-pleasing, waterproof, and collapsible encasing that can be installed by no more than two people. The design consists of a 3/32" acrylic segmented frame with a 1/16" window insert and a 3/32" acrylic lid. Each panel is attached with flexible hinges that allow it to collapse in a quad-fold manner, while gasketing ensures that the robot is protected from moisture and dust. The encasings both weigh under 20 pounds, enabling two staff members to assemble and secure it with adjustable straps. Additionally, sensors will be used to notify the VISE team of changes in temperature, humidity and dust levels. The translucent design ensures each surgical robot remains visible while enclosed, and that doctors can access each robot without removing the encasings. This cost-effective and lightweight design scheme can be modified for other robot casings in VISE.



Left, A 3D rendering of the encasing for Magnetic Endoscope Robot that details the frame design with thinner inner panels and an acrylic lid for an aesthetic display of the robot.

Right, A full-scale corrugated polycarbonate frame model on the robot.

VISE VANDERBILT INSTITUTE FOR SURGERY AND ENGINEERING

MECHANICAL ENGINEERING

ME-4

TEAM

Jack Abrams, ME
David Obi, ME
Brett Reamon, ME
Kaleb Williford, ME
Yilan Xu, ME

ADVISERS

Professor Nilanjan Sarkar, ME
Alexandra Watkins, ME

SPONSOR

Vanderbilt Robotics and Autonomous Systems Laboratory

Expanding augmented reality through thermal feedback

Augmented Reality (AR) seamlessly merges virtual objects into the real-world environment, creating immersive experiences that can enrich the integration of tactical cues such as temperature. Despite its critical role in how we perceive and interact with objects, thermal feedback is frequently overlooked in AR applications. Real-time spatiotemporal thermal feedback is invaluable for AR applications, including safety training, medical simulations and industrial use. Recognizing this, our team built upon a previous design from the VU-RASL to develop a glove to simulate the thermal properties of objects and their surroundings through a series of thermoelectric modules (TEMs) capable of heating or cooling on demand. Our improved design achieves realistic levels of thermal feedback in addition to real-time wireless control, enhanced portability and extended runtime. This is facilitated through a wireless microcontroller that runs a PID control loop with thermistor feedback. Furthermore, a custom water-cooling glove ensures extended runtime, while the custom PCB and integration with a fanny pack enhance portability. Combined with AR simulations and Microsoft Hololens, our glove enables real-time temperature control during interactions with augmented reality objects.

The thermal feedback device features thermoelectric modules for precise temperature simulation, a water-cooling system with a pump, Microsoft Hololens for AR experiences, and a custom PCB with a battery for seamless control and connectivity.

RSL

TEAM

Varun Aggarwal, ME
Hayden Kraus, ME
Kevin Masih, ME
Everest Zhou, ME

ADVISER

Deanna Romanello, Nashville Zoo

SPONSOR

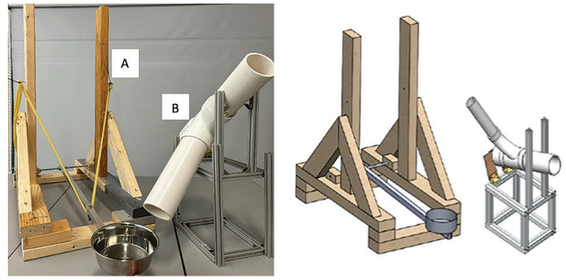
Nashville Zoo at Grassmere

MECHANICAL ENGINEERING

ME-5

Forage feeding device for stimulating natural animal behaviors

Animals in captivity are often restricted from performing foraging behaviors that are practiced in nature. Feeding times and locations are regulated. To benefit the natural behaviors and mental health of animals, the Nashville Zoo intends to design a device capable of dispensing food in a random, yet safe, manner. The forage feeder device project intends to provide an interactive and stimulating method of feeding the Sumatran tigers and Andean bears at the Nashville Zoo. The team has created a launching device that utilizes a catapult-like throwing method to spread food out 10-15 feet from the device. A revolving food container is used to load the food prior to dispensing. The device is highly modular, which allows for ease of cleaning and replacement of parts. The current design also accommodates future developments that allow zookeepers to use the device remotely. The device improves the current system that requires hands-on repetitive operation.



Left, Forage feeder launching device (A), constructed from 2x4s, surgical tubing, and aluminum components; and loading device (B), constructed from economical PVC tubing, aluminum 80/20 bars, and a servo motor.

Right, CAD rendering of loader and launching device.

NASHVILLE ZOO AT GRASSMERE

TEAM

Ahmed Bourguiba, ME
Landon Peaden, ME
Cameron Smith, ME
Trace Teodori, ME

ADVISER

Brittany Canfield, Nashville Zoo at Grassmere

SPONSOR

Nashville Zoo at Grassmere

MECHANICAL ENGINEERING

ME-6

Climbing structure for ring-tailed lemurs at the Nashville Zoo

Animals in captivity, such as the Ring-tailed Lemurs at the Nashville Zoo, thrive when provided with an environment that mirrors their natural habitat. The current exhibit has degraded, depriving the Madagascan lemurs of essential stimulation. This project introduces a central structure comprising three columns of PVC piping (8, 10, and 12 feet), creatively arranged in a triangular pattern. Wood steps, grapevine rope, mesh climbing, feeding and jumping spots, and sunbathing platforms interconnect the columns, offering options for the lemurs to engage in natural behaviors. By addressing various disabilities of mobility and vision within the lemur population, this design not only enriches their lives but also captivates viewers. Ensuring safety and stability through rope supports and stainless-steel brackets, the structure combines minimalistic aesthetics with practicality. Using common materials and an intended lifespan of more than seven years, the design is simple to replicate and visually pleasing. This project goes beyond meeting physical needs; it strives to create an immersive experience that fosters a deeper connection between the lemurs and those who observe them.

The ring-tailed lemurs climbing structure features 3 bamboo covered, vertical PVC poles with individual base plates, and creates instinctual opportunities for the Lemurs to engage in natural behaviors.

NASHVILLE ZOO AT GRASSMERE

MECHANICAL ENGINEERING

ME-7

TEAM

James Becker, ME
Evan Chow, ME
Isaac Collins, ME
Nicholas Grummon, ME
Ivan Ntwari, ME

ADVISERS

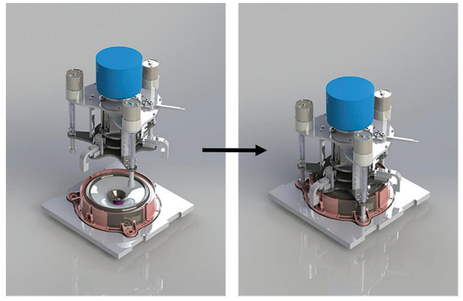
Bryan Meadows, Nissan North America
David Blaylock, Nissan North America

SPONSOR

Nissan North America

Automated installation of speakers on Nissan Pathfinder vehicle doors

The purpose of this project is to automate the installation of speakers into Nissan Pathfinder car doors. Currently, this process is performed manually, which invites unnecessary variance and inefficiency, taking on average 40 seconds. Using a Universal Robots UR10e collaborative robot, we designed and fabricated an end effector to pick-up speakers and fasten them into car doors. The end effector was machined out of aluminum and steel and consists of two main subsystems: a clamping system and a fastening system. The clamping subsystem features a three-follower face CAM mechanism that converts the rotary motion of a stepper motor into linear actuation of three clamp fingers to hold a circular speaker. The speaker-fastening subsystem features three direct-current motors that connect to spring loaded bolt wrenches to tighten bolts. To allow for speaker pick-up reliability, we created a custom tray to position and orient the speaker before it is picked up. The end effector is attached to the UR10e via a machined connector and is controlled through an Arduino microcontroller. The robot is controlled through custom programs made using Universal Robots programming tools, and communication between the UR10e and end effector is done through digital signals. Our designed solution is expected to automate the speaker installation process and reduce cycle times by about 30%.



The end-effector includes a cam-follower clamp and three spring-loaded nut drivers as well as the electronics necessary to actuate these parts and the mounting hardware for connecting the end-effector to a UR10e collaborative robot.

NISSAN

MECHANICAL ENGINEERING

ME-8

TEAM

Molly Birdsall, ME
Kaylee Combs, ME
Samuel Gaizutis, ME
Connor Webb, ME
Hieu Ve, ME

ADVISERS

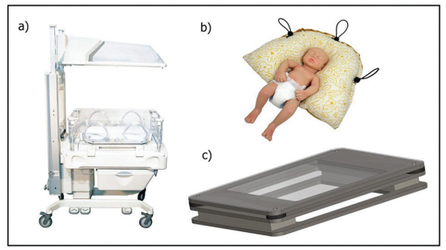
Leon Dupree Hatch, M.D., Department of Pediatrics, VUMC
John Jeffrey Reese, M.D., Department of Pediatrics, Biomedical Engineering, and Cell & Developmental Biology, VUMC

SPONSOR

Vanderbilt University Medical Center

Engineering solutions to minimize the adverse impact of neonatal transport

Preterm infants delivered at the VUMC maternity ward immediately face a ¼ mile journey to the neonatal intensive care unit (NICU). Their vehicle is a 300-lb incubator and climate control unit, and their path consists of bumps, potholes, turns, ramps, and elevators. As fragile infants, such forces and vibrations can and do cause complications such as internal hemorrhaging and displacement of IVs, breathing tubes and vitals monitors. This project's objective was to make this trip safer for preterm infants. The initial steps focused on determining the dominant forces and vibrations during transport via IMU-based data acquisition. The complexity of the cart as well as the range of obstacles during transport, lead to a multifaceted approach. A passive weighted damping system was designed to fit underneath the mattress, and the hospital's coddling technique was expanded upon with a custom-sewn neck support device. These workarounds were necessary in order to maintain manufacturer warranties and medical standards associated with the expensive incubator systems. Upon completion, these approaches will reduce both vertical and horizontal vibrations and impulses transmitted to a fragile preterm infant during transport.



(a) A GE Giraffe Omnibed incubator used at VUMC for transport.

(b) An iteration of the infant neck support device cradling the head of a 1000 g silicone baby model used for testing.

(c) A CAD model for the multi-layered weighted damping system to go beneath the bed of the incubator.

VANDERBILT UNIVERSITY
MEDICAL CENTER

TEAM

Isai Andrade, ME
Jose Leonardo Brenes, ME
Evangelos Chatziandreou, ME
Mohamed Aziz Medhioub, ME
Jonothan Zak, ME

ADVISER

Professor Amrutur Anilkumar, ME

SPONSOR

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MECHANICAL ENGINEERING

ME-9

Coaxial drone for planetary landings

A VADL team will launch a vehicle to achieve an apogee within 5% of 4400 feet above ground level, jettison the STEMnaut Atmospheric Independent Lander (SAIL) at 400 feet, and safely land vehicle sections using the drogue and main parachutes. The SAIL will be a coaxial drone payload that jettisons from the fore rocket section via the unlocking of electronic rotary latches and will land safely through manual operation. The SAIL consists of five main subsystems: rotor deployment system (RDS), coaxial propulsion system (CAPS), SAIL leveling system (SLS), landing orientation system (LOS), and STEMnaut housing unit (SHU). RDS allows the SAIL rotors to be stored vertically within the rocket and once jettisoned will lock the rotors horizontally. CAPS is the drone motor with counter-rotating rotors that provide thrust for the SAIL. SLS is a double-concentric ring gimbal system powered by two servo motors to provide thrust vectoring for stability. LOS is a mechanically passive system activated upon parachute deployment that extends four carbon fiber legs and locks them in place to enable vertical landing. Finally, the SHU is where the four mock astronauts (STEMnauts) will be safely stored and recovered upon landing.

The coaxial drone, designated as the STEMnaut Atmospheric Independent Lander, is designed as a modifiable payload that jettisons from a rocket and is guided to touchdown through manual control.

VANDERBILT AEROSPACE DESIGN LABORATORY

NASA

Design and Project Faculty

Biomedical Engineering
Chemical Engineering
Civil and Environmental Engineering
Electrical and Computer Engineering
Engineering Science and Management
Mechanical Engineering

We take great pride in recognizing these faculty members who are the core of our design program in their respective departments. Their outstanding contributions and excellence as instructors, advisers and mentors have led to the work demonstrated on Design Day, April 22, 2024.

JASON MITCHELL
Assistant Professor of the Practice of Mechanical Engineering

MARC MOORE
Associate Professor of the Practice of Biomedical Engineering

WALTER COLLETT
Professor of the Practice of Electrical and Computer Engineering

RANJANA SAHAI
Assistant Professor of the Practice of Mechanical Engineering

RUSSELL DUNN
Professor of the Practice of Chemical and Biomolecular Engineering

LORI TROXEL
Professor of the Practice of Civil and Environmental Engineering

COURTNEY JOHNSON
Assistant Professor of the Practice of Technical Communications

THOMAS WITHROW
Assistant Dean for Design
Professor of the Practice of Mechanical Engineering

Administration

Dean
Krishnendu (Krish) Roy
Bruce and Bridgitt Evans
Dean of Engineering
krish.roy@vanderbilt.edu
615-322-0720

Vice Dean
Douglas Adams
douglas.adams@vanderbilt.edu
615-322-2697

Senior Associate Dean for Faculty Affairs
Nilanjan Sarkar
nilanjan.sarkar@vanderbilt.edu
615-343-3773

Senior Associate Dean for Graduate Education
E. Duco Jansen
duco.jansen@vanderbilt.edu
615-343-3773

Senior Associate Dean for Undergraduate Education
Cynthia B. Paschal
cynthia.paschal@vanderbilt.edu
615-343-3773

Senior Associate Dean for Research
Cynthia Reinhart-King
cynthia.reinhart-king@vanderbilt.edu
615-875-8309

Associate Dean for Development
Garrett Munro
garrett.munro@vanderbilt.edu
615-343-1654

Associate Dean for Academic Success
Julianne Vernon
julie.vernon@vanderbilt.edu
615-343-1543

Assistant Dean for Academic Services
Adam McKeever-Burgett
adam.w.mckeever-burgett@vanderbilt.edu
615-343-8061

Assistant Dean for Graduate Education
Gabriel Luis
gabriel.w.luis@vanderbilt.edu

Assistant Dean for Professional and External Education Programs
Joanne Wang
joanne.wang@vanderbilt.edu
615-875-8386

Assistant Dean for Design
Thomas Withrow
thomas.j.withrow@vanderbilt.edu
615-322-3594

Departments

Biomedical Engineering
Michael Miga, Interim Chair, Harvie Branscomb Professor
michael.i.miga@vanderbilt.edu
615-343-8336

Chemical and Biomolecular Engineering
Paul E. Labinis, Chair
paul.e.laibinis@vanderbilt.edu
615-936-8431

Civil and Environmental Engineering
Caglar Oskay, Chair
caglar.oskay@vanderbilt.edu
615-322-2697

Computer Science
Xenofon Koutsoukos, Chair
xenofon.koutsoukos@vanderbilt.edu
615-322-2771

Electrical and Computer Engineering
Bennett Landman, Chair
bennett.landman@vanderbilt.edu
615-322-2771

Mechanical Engineering
Haoxiang Luo, Interim Chair
haoxiang.luo@vanderbilt.edu
615-322-2709

Division of Engineering Science and Management
Yiorgos Kostoulas, Director
yiorgos.kostoulas@vanderbilt.edu
615-343-4965

School *of* Engineering

PMB 351826
2301 Vanderbilt Place
Nashville, TN 37235-1826

Connect with us:

vanderbiltengineering
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