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# DAY 2017

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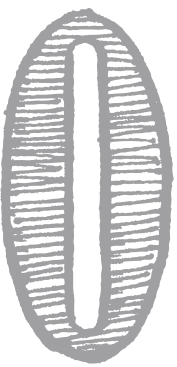
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# PREFACE



n behalf of the School of Engineering, welcome to Design Day 2017. This year you’ll see more than 70 engineering and computer science capstone projects completed in partnership with sponsors including Nissan North America, Siemens, Fiserv, Camgian Microsystems, Sterling Ranch Development Company, DENSO, NASA Marshall Space Flight Center, and more.

Senior design courses provide students with experience working on real-world projects that involve design constraints, budgets, reviews and deadlines. Students learn about professionalism, licensing, ethics, teamwork, entrepreneurship,

intellectual property and all the key skills of their disciplines. 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 prototypes, design processes or virtual demonstration. Design Day is the showcase for the lessons learned over four years of their engineering education.

We recognize the value of senior projects mentored and supported by external advisers – industry representatives, entrepreneurs, nonprofit members 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 sponsoring a project or to learn more, please contact me.



Sincerely,

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Brochure data were collected and managed using REDCap electronic data capture tools hosted at Vanderbilt University<sup>1</sup>.REDCap (Research Electronic Data Capture) is a secure, Web-based application designed to support data capture for research studies, providing: 1) an intuitive interface for validated data entry; 2) audit trails for tracking data manipulation and export procedures; 3) Automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for importing data from external sources. REDCap is supported by a Vanderbilt Institute for Clinical Trials and Translational Research grant (UL1TR0000445 from NCATS/NIH).

<sup>1</sup>Paul A. Harris, Robert Taylor, Robert Thielke, Jonathan Payne, Nathaniel Gonzalez, Jose G. Conde, Research electronic data capture (REDCap)—A metadata-driven methodology and workflow process for providing translational research informatics support, J Biomed Inform, 2009 Apr;42(2):377–81.

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6VDC ride-on power car to be donated to High Hopes Preschool.



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A catheter delivers stem cells into a target region such as the heart. The catheter design is crucial to determine stem cell outcome. Our mathematical model assesses the feasibility of a catheter model depending on the catheter parameters.



## FAST AND FURIOUS POWER WHEELS FOR MOBILITY-IMPAIRED CHILDREN

Children with mobility impairments lack a sense of independence, depth perception, cause and effect, and social acceptance. These children do not have access to power mobility because insurance doesn't cover power wheelchairs for this age group. The goal of our project is to give mobility-impaired children the independence and social interaction they crave by creating a highly-modified power toy car. Our team targets common limitations in children ages 2 to 5, and modifies one base car to fit the needs of many children, giving them development opportunities, independence, and the social interaction they crave, with a fun twist.

The organization GoBabyGo addresses the same need, but customizes a single car for a single child. Our design aims to be used by many children with varying limitations and diagnoses. The car features an adjustable seat, steering wheel, arm rests, and many possible inputs for motor activation.

## VALIDATION MODEL FOR CATHETER-BASED DELIVERY SYSTEMS

Stem cells are poised to revolutionize modern medicine. Transplants today have vastly improved the outcomes of thousands of patients battling leukemia and severe hepatic veno-occlusive disease. Researchers now are actively developing many therapies. While *in vitro* and *in vivo* experiments generally verify the efficacy and safety of potential therapies, regulators must also consider the effect of specific parameters such as transport on the outcome. Current testing methods do not look into important stem cell outcomes such as differentiation, nor are they cost-effective. Catheter-based delivery systems are the current stem cell-transport method of choice yet they remain largely misunderstood and not well-characterized. Many untested stem cell therapies are currently in market and need to be validated by the FDA as safe and effective. To further characterize catheter delivery parameters, a mathematical model was developed. Our mathematical model, alongside current *in vitro* validation methods, will serve as a preliminary screening tool for future potential catheter designs.

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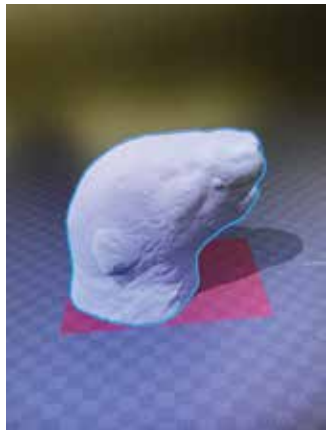
Vanderbilt University School  
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## REPRODUCIBLE STEREOTAXIC INJECTION SYSTEM FOR NEONATAL MICE

Stereotaxic injection rigs are primarily used to perform minimally invasive procedures on small animals for the purpose of research. The rig employs the use of a 3D coordinate system to accurately target small areas in the body. However, these rigs are designed for adult animals. Our objective is to design a supplemental platform adapted for neonatal animals, particularly mice, which fits into the existing rig. In addition to the platform, we have 3D modeled head molds based on microCT scans of neonatal mice at various weights, orientations, and stages of growth. This was achieved through the development of a pipeline that intakes 3D image files and produces a 3D printable mold based on an inversion of the file. The purpose of these molds is to stabilize the animals during injection, reducing movement and improving injection precision by combating the malleability of the neonatal skull.

Most research institutions induce hypothermia as the primary form of anesthesia. We are currently integrating a cooling system into the platform to safely prolong hypothermia, increasing potential procedure time. Additionally, our pipeline could be applied to CT or microCT scans of any animal model to produce a standard mold for other rigs or forms of research.



Head mold of neonatal mouse.



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## MULTIPLEXED SMALL-VOLUME STIRRED BIOREACTOR FOR BRAIN TUMOR ORGANOID DEVELOPMENT

Three-dimensional cell culture via rotating bioreactors is becoming a more appealing option for research as it distributes nutrients evenly throughout the cells under low shear stress conditions. However, current commercial techniques use inordinately large volumes and can only culture single cell types, making them ill-suited for high-throughput screening (HTS). The SpinΩ, a rotating bioreactor from Johns Hopkins University, paved the way for HTS bioreactors by incorporating gear-driven spinning impellers into a 12-well culture plate.

The STAM-24 spinning bioreactor for brain organoids expands on the SpinΩ by utilizing linked chain-and-sprocket systems to turn 3D-printed impellers. This system is integrated with 24-well culture plates to enable higher-throughput screening while fitting into a hypoxic chamber to better mimic the low-oxygen environment of brain tumors. With this bioreactor, further efforts can be made in screening drugs for patient-specific chemotherapy and understanding neural development.

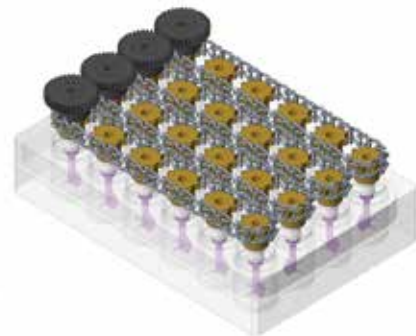


Illustration of STAM-24 spinning bioreactor system. Gears (black) drive train of chain sprockets (gold) connected by chains (gray), which turn the impellers (purple) in the cell culture wells.





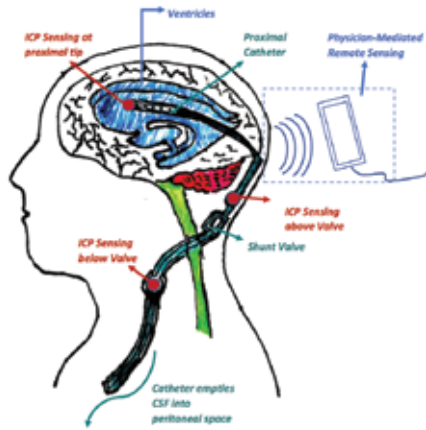
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## DEVELOPMENT OF A SMART HYDROCEPHALIC SHUNT

Our project is centered on ventriculoperitoneal shunt technology for pediatric patients afflicted with hydrocephalus. Hydrocephalus is a condition characterized by the excessive collection of cerebrospinal fluid (CSF) in the brain and affects 1 in 1000 live births, making its treatment the most frequent procedure in pediatric neurosurgery. The current shunt technology has seen no major improvement in the past 50 years, and has a 50 percent failure rate within two years of insertion. There is no proper way to detect this failure, which leads to severe neurological symptoms due to brain compression and swelling before the shunt is removed or replaced.

To address this issue, we are developing a “smart shunt” that will be able to detect failure before it is clinically apparent. This will be achieved through semi-continuous, remote monitoring of shunt function, represented by the Intracranial Pressure (ICP) of the ventricles in the brain. Not only will the shunt monitor its own function, it also will be able to detect failure and inform the patient and physician of this failure. This will allow for timely care and reduction in the prevalence of adverse, preventable symptoms.

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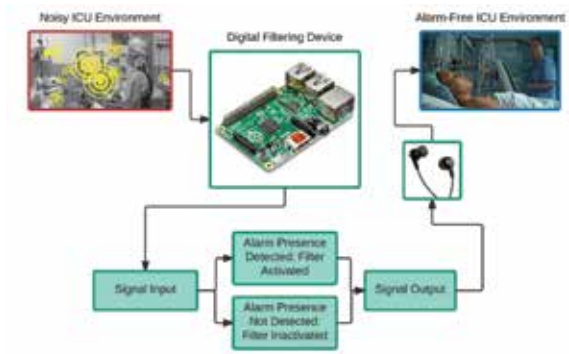
**Cutaway view of the ventriculoperitoneal shunt positioned in the brain. The proximal tip sits stationary in the ventricle where CSF builds up, and from there the fluid drains through the proximal catheter, past the shunt valve, and down into the abdominal cavity. Also depicted is the remote sensing mechanism used to communicate shunt failure detected at any of the three ICP sensor locations.**

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## FREQUENCY-SELECTIVE SILENCING DEVICE TO ENHANCE ICU PATIENT RECOVERY

Audible medical alarms have created hazardous and cacophonous environments in intensive care units due to the frequent nature at which they sound and the low positive predictive value of the information they convey. These characteristics have created numerous problems for both physicians and patients. While physicians are prone to alarm fatigue and desensitization, patients may experience both delirium and PTSD during ICU stays, and alarms may contribute to or cause these psychological problems. This project attenuates these problems through the creation of a frequency-selective silencing device for patients to wear in the ICU that removes free-field alarm sounds.

The solution to this problem is a comfortable in-ear device that will be worn continuously throughout a patient’s length of stay in the ICU. The device uses a Raspberry Pi to process incoming noise in real time, detect if an alarm is present, and digitally filter frequencies specific to common alarms. Importantly, environmental noise, like speech, passes through *without* distortion. This device surpasses previous solutions like traditional earplugs. It is more comfortable for long-term wear, is medical grade and reusable, and actively removes alarms rather than dampening all noise, making it more effective at preventing PTSD anchored to critical illness.



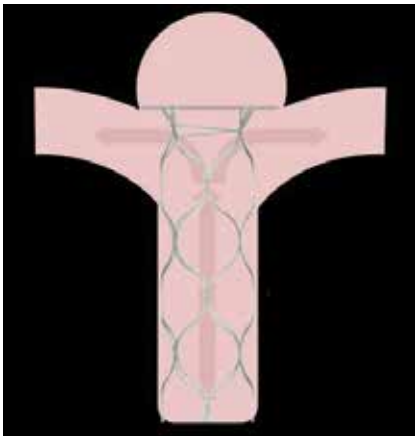
**Frequency-selective silencing device.**

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## A NOVEL CEREBRAL FLOW-DIVERSION STENT FOR THE TREATMENT OF BIFURCATION ANEURYSMS

It is estimated that 1 in 50 people in the United States has an unruptured intracranial aneurysm. Aneurysms can form anywhere in the brain but commonly occur in bifurcated areas such as the vertebrobasilar junction (VBJ). Constant pressure and blood flow at this junction increase the likelihood of rupture, a life-threatening event because the VBJ supplies blood to key brain structures. Current treatments of bifurcated aneurysms are either invasive or complex, making it difficult for both the patient and provider to ensure safety and efficacy. Our aim is to make treatments simpler and safer through the use of a single flow-diverting stent. The stent features layers of densely meshed leaves that expand within the aneurysm to reduce residual blood flow. These leaves are held up by a stent body in the luminal space featuring an open cell configuration to minimize the bodily exposure to metal. Our stent is recapturable and allows users to accurately position the device in various neck morphologies. We are testing the efficacy of our stent by running computational fluid dynamic models using parameters determined by Ouread et. al. Our goal is to achieve a two-thirds reduction in blood flow velocity to successfully treat the aneurysm.



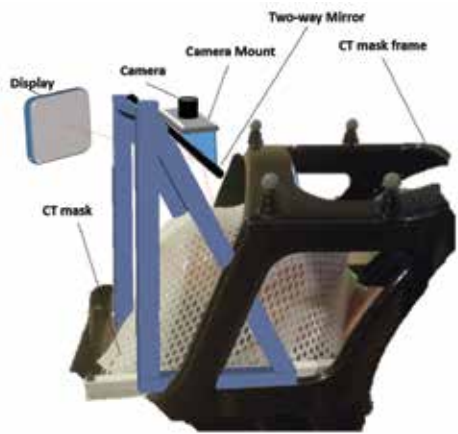
**Artist rendering of a flow-diverting stent to treat an aneurysm in the vertebrobasilar junction. Arrows represent diversion of blood flow into peripheral arteries.**

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## OCULAR TRACKING TO AID RADIOTHERAPY GUIDANCE FOR EYE TUMORS (O-TARGET)

Choroidal melanoma treatment requires the immobilization of the eye during both pre-treatment imaging and radiotherapy procedures in order to locate and target the tumor. Current clinical methods for immobilizing the eye are either invasive, highly inaccurate, or both. At Vanderbilt, the standard of care is to direct the patient to look at the end of a pencil. Thus, a need exists for a device that can non-invasively limit eye movement during these procedures. Our solution is an optical system mounted to the patient’s therapy mask that will provide a focus point for the patient, track eye motion, and prompt the patient to rectify deviations. Our system will provide improved accuracy in locating the tumor during the two pre-treatment imaging procedures and lead to a more specific treatment region for radiotherapy. This solution will improve the clinician’s view of the tumor during therapy planning and correct error introduced by patient movement, preventing vision loss and tumor recurrence. We intend to produce a CT and radiotherapy compatible version of our design that will successfully track and guide patient gaze during imaging and treatment.



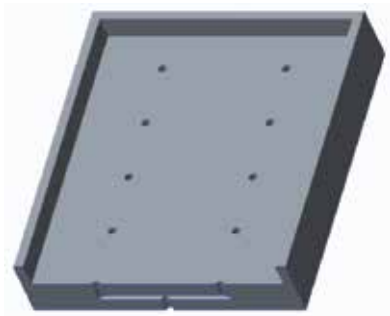
**This model illustrates the proposed assembly; a white radiotherapy mask, black stereotactic frame, and our system in blue.**

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## TEMPORALLY MODULATED CELL CULTURE SYSTEM

Cell culture systems allow simulation of *in vivo* conditions without necessitating the use of live model organisms. These systems allow science to study biological interactions on a fundamental level. However, there are still model discrepancies such as the lack of temporal modulation – varying the environment with time – which are needed for truly accurate physiological representation. Our goal is to create a more robust experimental apparatus that allows for temporal modulation and increases fidelity to *in vivo* conditions. This has been accomplished through the creation of a new cell culture plate lid that is compatible with commonly available commercial well plates and allows generation of temporal profiles for any delivered solution. With built in channels for flow and lids for varying numbers of wells, our epoxy molded lid is an accurate, precise and easily reproducible device. Our lid additionally improves sterility by eliminating the need to expose cells in culture to conditions outside the well plate, thereby greatly reducing exposure to contaminants. When completed, this new design will decrease the preparation time per trial, allowing for greater concurrency among projects, while also minimizing external confounding variables through material standardization and improving the power of each experiment.



Cell culture plate lid.

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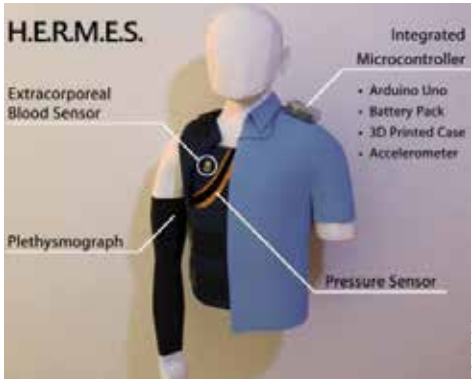
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## DEVELOPMENT OF A SMART BALLISTICS VEST FOR POLICE OFFICERS

Nearly 50,000 police officers were physically assaulted in 2015. Of these officers, nearly 60 percent were alone and 30 percent were seriously injured. The inability of an incapacitated officer to automatically communicate with dispatch exacerbates the dangers faced by officers. Providing an integrated system capable of biometric sensing and automated dispatch alerts could improve police communication and safety should an officer be incapacitated.

Our device, the HERMES (Health Evaluation with Real-time Monitoring-based Emergency Signaling) system, is an integrated system that retrofits ballistic vests regularly worn by officers. The system consists of an array of biometric and force sensors, including a photoplethysmograph, blood glucose sensor, accelerometer, and pressure conductive sheeting. These sensors allow for acquisition of data on heart rate, presence of extracorporeal blood, officer orientation, officer acceleration, respiratory rate, and external forces associated with blunt force and bullet impacts.

Our device integrates existing biometric sensor modules while taking into account customized design considerations for ballistic vests. In addition, sensory data is wirelessly transmitted and analyzed using an independently developed thresholding algorithm. These unique capabilities allow for continuous monitoring of vital biometric parameters of an officer's condition as well as rapid threat assessment and communication.



3D rendering of the HERMES system, retrofitting bulletproof vests with an integrated series of biometric and force sensors to monitor and assess officer condition. Sensory data acquired is transmitted via Bluetooth before threat assessment based on an established algorithm.

GPS-911

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## OPTIVENT: PERSONALIZED INTERVENTION FOR ACUTE RESPIRATORY DISTRESS SYNDROME

Acute Respiratory Distress Syndrome (ARDS) is characterized by fluid buildup in the lungs, which results in a significant loss of usable lung volume and susceptibility to ventilator-induced lung injury (VILI). ARDS is found in 10 percent of ICU patients and has an average in-hospital mortality rate of 40 percent. The current standard of care is one-size-fits-all, with recommended ventilator settings based on patient height alone. To minimize the risk of VILI, tidal volume (TV) and positive end-expiratory pressure (PEEP), settings should be chosen based on patient-specific respiratory mechanics and updated regularly to reflect changes in the patient's condition. Stress index is a measure of stress placed on the lungs. Prior research has shown that patient outcomes improve when TV and PEEP are chosen such that stress index is optimized.

We are developing OptiVent, a software that recommends optimal ventilator settings based on stress index, ideal body weight, and other patient-specific data. OptiVent collects data from a ventilator, then isolates relevant portions of each breath to calculate stress index and elastance. After stepping through different combinations of ventilator settings, the program recommends the TV and PEEP settings that minimize the risk of lung injury.



Optivent recommends optimal ventilator settings based on patient-specific data.

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## ADDRESSABLE LED BANK FOR STUDYING SENSORY INTEGRATION IN PRIMATES

Currently, there is not an effective way to study how the brain processes individual stimuli in a stimulus-rich environment. A device that meets these needs will provide valuable insight into multisensory integration and lay the foundation for further clinical research of neurological disorders like autism and schizophrenia.

We aim to build a concave display of LED lights to interface with a pre-existing speaker scaffolding that will project specific stimuli in a controlled space. A Rhesus Macaque monkey will experience the complicated stimuli. The Vanderbilt Department of Hearing and Speech will analyze its response with infrared eye tracking and electrodes to gather data from the superior colliculus, a midbrain structure where auditory and visual stimuli are processed.

Our design uses 672 addressable LEDs. A user can configure the desired location and intensity of the lights with a MATLAB GUI. The LEDs are anchored to a detachable scaffolding, which does not block the speakers. Previously, researchers were only able to study a monkey's perception of sound in an enclosed space, but our attachable LED display allows researchers to study monkeys' neurological responses in a more complicated environment. We expect researchers to easily project the lights and sounds in concert with one another.



The LED bank will be attached to the speaker apparatus currently used in the Ramachandran Lab, shown above. By creating an LED bank that covers the frontal visual field of a monkey, we hope to aid researchers in the Vanderbilt Department of Hearing and Speech in their study of sensory integration.

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## IMPROVING FOOTBALL HELMET DESIGN TO LIMIT MILD TRAUMATIC BRAIN INJURIES

Mild traumatic brain injuries alter the lives of American football players of all ages. Football related concussions affect more than 400 professional and Division I athletes each year and result in long-term medical costs that can exceed \$700 million, as in the case of the most recent National Football League settlement. Despite the high incidence rate, most football helmets do little to prevent concussions but focus instead on preventing skull fractures.

The goal of this project is to limit concussion incidence by designing a helmet to reduce both the linear and rotational acceleration experienced by football players during impact. The design incorporates external dynamic shock absorbing packets containing a non-Newtonian material. This helmet dissipates energy through the translocation and transformation of the shock absorbing material upon impact. The air-tight, water-tight packaging of the shock absorbing material allows the helmet to be used in intense weather conditions while the snap on attachment allows the packets to be easily replaced on the sideline in case of damage.



A frontal cross-section of a football helmet provided by the Vanderbilt University football program. A thin layer of shock absorbing material is enclosed inside of an air-tight, water-tight packet that is snapped to the traditional helmet shell.

VANDERBILT UNIVERSITY  
MEDICAL CENTER

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GPS-911

## BIOSENSING BALLISTIC VEST

Currently, the only methods of communication for police officers are the radio and the panic button, which is found either on the radio or the officer's belt. The manual process of having to reach for the radio or panic button to communicate can contribute to officer danger and sometimes death. The Biosensing Ballistic Vest aims to improve officer safety through physiological monitoring and enhanced, automated communication. The vest will read an officer's vital signs and discriminate between his/her resting and alarm states depending on deviations from his/her personalized baseline readouts. These monitoring capabilities, coupled with the ability to recognize blunt force impact, allow the vest to determine if the officer is in danger. If in danger, the vest will automatically communicate to other officers and/or the police department through a mobile phone app, which allows for seamless integration into the existing communication system. The vest will also house a Bluetooth beacon to provide closer-range location tracking ability so that backup can easily identify the location of the officer in danger. While existing vest designs offer passive protection, the Biosensing Ballistic Vest improves upon this protection by actively helping officers when they are unable to help themselves.



The Biosensing Ballistic vest monitors the physiological state of an officer and automates the call for assistance if his/her safety is at risk.

GPS-911

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## SYTE: THE INFANT MONITOR

Babies are social beings. The Bucharest Project in Romania found that infant orphans were stunted in their development due to the lack of personal care in understaffed orphanages. However, if the orphans were placed in a foster family by age 2, they were indistinguishable from a community control by age 8.

The SYTE system is a monitor built to detect the human interactions encountered by babies in the NICU to assure that they are receiving the interactions they fundamentally require. An Xbox Kinect is used both visually and phonically within NICU rooms to track visits as well as word counts. Previous attempts to monitor infant interactions have focused purely on the auditory realm. Research using these methods have raised questions about whether a parent or a nurse

talking to an infant are equivalent in regard to future development. Use of the SYTE monitor will provided observations about the type and amount of interactions, and whether parental interactions are especially potent.



An Xbox Kinect and a Minnowboard within its case. The single board computer (SBC) operates the Kinect within NICU rooms to monitor infant interactions.





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American Society of Civil Engineers

AISC-ASCE STUDENT STEEL BRIDGE COMPETITION

The overarching objective of the 2017 AISC-ASCE Student Steel Bridge Competition was to simulate a real structural engineering project from conception to completion in the form of a small-scale bridge competition. For the competition, the four members of the Vanderbilt Steel Bridge Team (Mr. Steel Yo Girl) developed a cantilever design capable of being constructed in under 30 minutes and to withstand a combined load of 2,500 pounds with minimal deflection. The three-dimensional deck truss provided excellent stiffness to resist both lateral and vertical deflection, and the upper chord and diagonals were optimized to reduce the number of members without sacrificing strength. The team learned all necessary shop skills to fabricate the bridge, including how to operate the steel saw, belt sander, cutting wheel, hand-grinder, and MIG welder. At completion, the finished product was an aesthetically-pleasing bridge that was strong, easy to construct, and, most importantly, a competitive entrant into the ASCE Southeastern Regional Conference at Florida Atlantic University in March 2017.



A member of the Vanderbilt Steel Bridge Team MIG welds steel lacing between three foot tube sections for the lower chord of the bridge.



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Sterling Ranch

STERLING RANCH HOME FOR RACE TO ZERO COMPETITION

Sterling Ranch is a master-planned “smart city” currently under development 20 miles southwest of Denver, Colorado. Sterling Ranch’s developers recognize that the energy usage in both residential and commercial buildings accounts for 40 percent of the United States’ total annual energy consumption, and they intend to design and build sustainably. Our team’s mission is to help Sterling Ranch and their predominant homebuilder, Lennar, modify their existing Colorado ranch home plan so that it achieves net-zero energy. We plan to design a home that is cost-effective, comfortable for its users, and easily reproducible nationwide. Additionally, our sustainable home design was entered into the U.S. Department of Energy’s “Race to Zero” competition.

To achieve net-zero energy we used BEopt, a building science energy and cost optimization program, to simulate various home design alternatives. We looked at innovative insulation methods, HVAC systems, household appliances, window types, and lighting systems, and we ultimately selected the alternatives that were both energy efficient and economical. Our design also includes solar panels on the roof that enable the home to achieve net-zero energy. It is our hope that this home inspires similar sustainable home design by proving that net-zero energy homes can be both architecturally stunning and affordable.



Elevation of the Colorado ranch home to be built in Sterling Ranch.



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Honduras Outreach, Inc.

CIVIL  
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HONDURAS PEDESTRIAN BRIDGE

During the rainy season in Honduras’ Agalta Valley, the Rio Grande reaches high water levels. San Esteban residents must travel four hours to the nearest bridge, limiting access to schools and clinics. We partnered with Honduras Outreach, Inc., a nonprofit organization serving communities in Central America, to design a safe, constructible, and cost-efficient pedestrian bridge for the 700 residents affected.

In May 2016, two members of the design team traveled to Honduras, conducted a site survey and collected geotechnical samples. The team evaluated the geotechnical and hydraulic conditions in order to select the type of bridge and foundations. The team chose a 165-foot-long cable-suspended bridge in order to span the river without a pier and to simplify construction. The bridge deck, steel cables and concrete foundations were designed after careful consideration of pedestrian usage, wind, and hydraulic loads. Construction of the bridge is scheduled to begin in August 2017.



3D rendering of the student-designed 165-foot-long suspended pedestrian bridge over the Rio Grande in Honduras.



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Sterling Ranch

CIVIL  
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STERLING RANCH MULTIMODAL TRANSIT SYSTEM

Sterling Ranch, a sustainable community located southwest of Denver, Colorado, lacked a comprehensive and innovative transit plan that would connect residents between major hubs inside and outside the 5-square-mile community. The goal of this project was to develop a multimodal, accessible and extensive transit plan that would allow residents to travel conveniently throughout the community and surrounding areas.

The team developed transit user profiles, performed a benefit analysis for transit modes, and analyzed traffic impact studies for Sterling Ranch. Additionally, the team determined how the transit system would alleviate traffic congestion and create a comfortable environment for the community members. The deliverables for the project included identifying the best alternate modes, locating major transit hubs, and devising the most efficient transit routes. The final transit system includes multiple low cost, convenient, and sustainable modes that efficiently transport residents between schools, recreational locations, and commercial centers.

This transit system provides safe and accessible transportation options for all members of the community. It improves the quality of life of Sterling Ranch residents while delivering the sustainable and eco-friendly practices promised. Perhaps most importantly, this innovative transit system enhances Sterling Ranch’s already strong image as the city of the future.



Generations of homeowners in Sterling Ranch will benefit from an innovative and sustainable transit system within the community.



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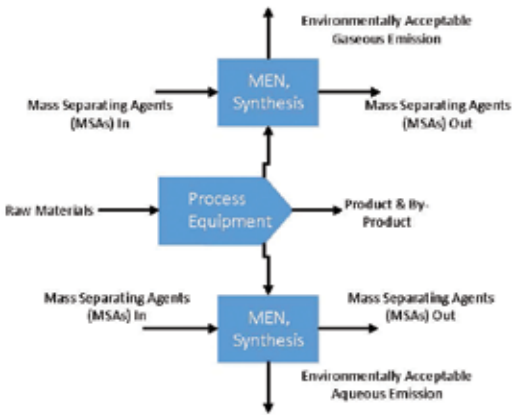
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## MINIMIZING WASTE USING MASS EXCHANGE NETWORKS (MENS)

High demand for environmental regulations has forced chemical production companies to spend money on waste treatment. Production cost can be reduced substantially by integrating waste streams and recycling valuable materials in the system. A software interface is one of the holistic ways to implement Mass Exchange Networks (MENS), because it can reduce the pollutants released to the environment.

Our software, an Excel user interface, is capable of identifying an optimal MENS while being cost-effective and energy-efficient. It provides graphical representations of the optimal MENS and data for all streams (up to 10 rich streams and 10 lean streams). The software considers various user inputs, design parameters, mass separating agents and environmental constraints. This user-friendly software contains features that allow users to adjust the minimum composition driving force for each MENS. The program is also equipped with a cost estimator that predicts the return on investment for the design. This prediction allows the engineers to create the most economical chemical plant.



The general schematic design of Mass Exchange Networks (MENS).

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## DEVELOPING SOFTWARE FOR VOLATILE ORGANIC COMPOUND RECOVERY IN AIR POLLUTION CONTROL

Volatile Organic Compounds (VOCs) are among the most important classes of chemicals used in the process industry and are a class of pollutant present in many gaseous and aqueous emission streams. In response to environmental regulations aimed at reducing air pollution, corporations are required to design innovative, cost-effective methods of eliminating VOCs from emission streams. The recovery and recycle of VOCs within a chemical process has the potential to control air pollution, increase process efficiency, reduce chemical waste and improve process profitability. Despite this, the widespread implementation of VOC recovery methods remains incomplete.

To address this, our team has designed a software package capable of analyzing a variety of recycling technologies and determining the most cost-effective method for recovering one or more pollutants from one or several emission streams. The software package is built within Microsoft Excel and performs calculations related to the design and cost of equipment and materials required to construct and operate adsorption, absorption, biofiltration, condensation, membrane separation and flaring processes. By constructing our software within Microsoft Excel, we hope to make our work accessible to a wide audience and encourage the widespread adoption of improved process methodologies.



Volatile organic compounds in waste streams are often discarded, but recovery of these compounds can reduce pollution and improve process profitability.

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## SOFTWARE FOR ECONOMIC COMPARISON OF VOLATILE ORGANIC COMPOUND RECOVERY TECHNOLOGIES

Volatile organic compounds (VOCs), due to their properties and prevalence in chemical processes, are susceptible to release into the atmosphere in a large variety of industrial situations. This issue signifies not only a massive loss of usable material, but also violates statutes dictating the legal limits of pollution meant to protect the environment from the effects of foreign emissions. A number of technology types, namely adsorption, absorption, and condensation/filtration, can be employed to collect and recover these VOCs within a process before they are released to the environment. In this project, a pioneer software comparing the performance and economic impacts of each technology is produced to evaluate the best possible technology choice for a given VOC recovery problem. This software, designed to be a companion program to a popular textbook about the engineering of emissions reduction, provides students with a streamlined, easy-to-use method to solve VOC recovery problems without the need to calculate by hand or research the financial parameters of each recovery technology.



The tendency for VOCs to be released into the atmosphere in the form of vapor from large, factory-scale plant processes necessitate an efficient means to perform a cost-benefit analysis of VOC recovery technologies before installation in factories such as the one pictured above.

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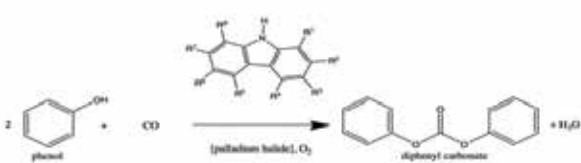
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## PHOSGENE-FREE ROUTE TO POLYCARBONATE PRODUCTION

Polycarbonates are a group of thermoplastic polymers that have high impact strength, heat resistance, optical clarity, and malleability. Thus, these plastics have a wide range of uses and applications. Polycarbonates make up many products ranging from DVDs and electronic components to fighter jet cockpits and sturdy construction materials. During the production of polycarbonates, it is necessary to synthesize an important intermediate, diphenyl phosphate (DPC). Historically, DPC production requires phosgene, a reagent toxic to humans and the environment. Not only is this process hazardous, but it also produces a solid sodium chloride (NaCl) byproduct that must be discarded as waste. An alternative to the phosgene route is desired and is possible by the direct oxidative carbonylation of phenol to DPC using palladium halide catalysts with nitrogen containing heterocyclic co-catalysts. The goal of the project is to design a process for synthesizing DPC using the direct oxidative carbonylation of phenol rather than the traditional phosgene route. Direct carbonylation is a much safer and economical route to form DPC because handling of phosgene and treatment of NaCl byproduct are avoided. We are designing a process capable of producing 100 million pounds of DPC per year.



This is the reaction mechanism for oxidative carbonylation of phenol to product diphenyl carbonate (DPC).





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## DESIGNING AN IDEAL HEAT EXCHANGER AND WASTEWATER RECOVERY NETWORK FOR A PVC COMPLEX CHEMICAL SITE

Tackling energy and wastewater problems is essential to reduce their impact on the environment. According to the Energy Information Administration (EIA), chemical industries consumed about 5 quadrillion BTU of primary energy in 2010, and the number has only increased since then. Most plants lack optimum energy and wastewater recovery networks, which lead to energy waste, environmental pollution and unnecessary expenditures. Energy recovery networks allow the plant to use high-temperature streams to heat low-temperature streams, and vice versa, reducing the need of hot and cold utilities. Wastewater recovery networks allow the plant to reuse streams with low contaminants to dilute more concentrated streams for use in chemical processes or for disposal.

In this project, our main approach includes analysis using the Heat Exchange Network Optimization Software (HENOS) and the Water Treatment Recycle (WTR) software, which were developed at Vanderbilt University, to design the optimum energy and wastewater recovery networks. We provide several design proposals that meet the client's requirement and consider safety analysis and the current plant design to determine the feasibility of each proposed network. Ultimately, our recommendation to the client is based on the design that has the best trade off between energy and freshwater savings and cost.



Distillation columns are common in chemical plants and they require a lot of utilities. Heat and mass integration could heavily reduce their utility consumption.



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## DESIGN OF A HEAT EXCHANGER NETWORK AND A MASS EXCHANGE NETWORK (HEN-MEN) TO REDUCE UTILITIES FOR A PVC SITE

Energy exchange and treatment of waste are major components of chemical site design. In both cases, expensive utilities are necessary to operate the plants. The reduction of external heating, cooling and waste treatment translates to lower operating costs. Our team designed a heat exchanger network that integrated process streams and designed a water network that eliminated unnecessary fresh water to reduce the utility usage across a site. Networks were examined through a combination of graphical methods, rigorous calculations and software manipulation and compared to the optimal networks to validate the designs. Options including cogeneration and pressurization were considered. Safety concerns, design limitations and the cost of implementation were evaluated for each design. The heat exchanger network achieved significant energy savings by judicious pairing of appropriate streams to offset cooling and heating utilities. The water network permitted a sizable amount of wastewater recycling that decreased both the need for freshwater utility and disposal of the wastewater the site produced. The implementation of the proposed designs offers significant savings.



This is an example shell-and-tube heat exchanger for an integrated PVC site.



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## DESIGNING A MULTI-PRODUCT MICROBREWERY

Beer is one of the most widely consumed beverages, predating the construction of the Great Pyramids in Egypt. In the U.S., more than 19 billion barrels are produced annually, and in the 2015 fiscal year, total revenues exceeded \$105.9 billion. As compared to large-scale breweries, microbreweries focus more on quality, flavor and brewing technique in their varieties over mass production. In recent years, sustainability efforts have become mainstream with manufacturers, placing a greater emphasis on reducing waste and energy consumption.

Our team designed a microbrewery for the production of six year-round, four limited-edition, and four seasonal brews. We present two operations: constructing a new facility and contracting to an existing one. Our overall approach is to design the two operations from the ground up and then perform an economic analysis to determine the viability of both. We aim to reduce operating cost and negative effects to the environment, focusing on producing quality beer that exceeds expectations. Our proposed solution produces 100,000 barrels per year, with production facilities in the Midwest and negligible emissions to the environment.



The four simple ingredients of beer are water, yeast, hops and barley.



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## NITROGEN TRICHLORIDE PREVENTION AND CONTROL WITHIN THE CHLOR-ALKALI INDUSTRY

The synthesis of chlorine via membrane electrolysis of brine solutions has the potential to produce nitrogen trichloride as a contaminant. Chlorine ions react with ammonia derivatives in the feedstock, which are frequently present due to animal waste and fertilizers in the water used to create the brine stream. Nitrogen trichloride is a dangerous compound capable of auto-detonation. The project analyzes various points of intervention to eliminate synthesis routes and degrade or remove generated nitrogen trichloride. In addition, the team attempts to develop methods for nitrogen trichloride detection using continuous process methods. Product is stored in on-site pressurized vessels, creating potential for concentration of nitrogen trichloride contaminants. Existing methods rely on the removal of nitrogen trichloride through controlled purge streams, creating dangerous conditions for chemical operators and wasting product. The proposed solution reduces the need for operator intervention and provides secondary safety controls to prevent failure. Costing, safety and efficacy analyses were conducted to explore the inclusion of this process in existing chlor-alkali facilities.



This is a reactor clarifier for use in brine treatment within a chlor-alkali process.





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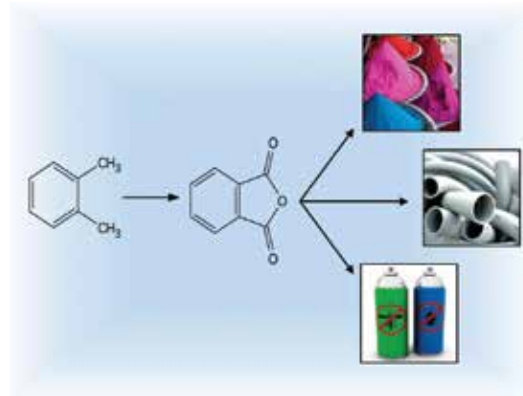
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## DESIGNING A FACILITY TO PRODUCE PHTHALIC ANHYDRIDE FROM O-XYLENE USING A NOVEL CATALYST

Phthalic anhydride and maleic anhydride are two common intermediates in the production of plastics. These two anhydrides can be formed by the oxidation of o-xylene or naphthalene. The primary product, phthalic anhydride, is a toxic chemical compound with several applications, including phthaleins, dyes, resins, plasticizers and insecticides. Phthalic anhydride is a key component in the plasticizers used to produce PVC, which is currently manufactured at 3 million tons per year.

A new catalyst for the oxidation of o-xylene to phthalic anhydride recently has been developed with the capability to minimize most of the side products associated with the reaction. The objective of our project was to design a new, grassroots facility to accommodate this promising new catalyst to produce 100,000 metric tons per year of phthalic anhydride. The production facility will be designed with consideration of potential reactor schemes, separation methods, heat exchange networks and waste management solutions that satisfy the product quantity and purity requirements. Energy consumption, production of waste, safety and economic feasibility will be key criteria in the design process. Potential designs will be modeled and analyzed using simulation software such as Aspen, Matlab and ChemCad. The novel catalyst used in the process can produce a high yield of product while significantly decreasing the amount of by-products incurred.



Oxidation of o-xylene to produce phthalic anhydride, followed by its multiple commercial uses, including dyes, polyvinyl chloride pipes and pesticides.



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## DESIGN OF A GRASSROOTS PLANT TO PRODUCE 100,000 METRIC TONS PER YEAR OF CUMENE

Cumene is mainly utilized as chemical feedstock to manufacture phenol and acetone and, subsequently, bisphenol-A and polycarbonates. Recently, demand for phenol-based products in the plasticizer industry has raised production requirements of cumene. Consequently, the global market value of cumene is projected to reach \$24 million by 2018. Our goal is to handle this increase by designing a grassroots plant to produce 100,000 metric tons of cumene annually. The overall process involves alkylation of excess benzene with propylene, using a new proprietary catalyst with provided kinetics.

Our design consists of a two-step process. The first step uses a shell-and-tube-packed bed reactor to convert preheated substrates into cumene. The second step separates this product from by-product p-diisopropyl benzene and unreacted feedstock for recycle. The design also considers the economic impact of using propylene with 5 percent propane impurity vs. purer propylene feed on annual operating cost.

The facility minimizes utility costs, particularly of steam, through appropriate usage and generation of economic credit. Our environmentally friendly design outperforms incumbent solutions in cost-efficiency and energy conservation.



A cumene production plant.



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## DESIGN AND OPTIMIZATION OF A CHLOR-ALKALI BRINE CONCENTRATION PROCESS FOR IMPROVED RECYCLING OF SPENT ELECTROLYSIS BRINE

Chlor-alkali plants generate three of the most vital commodity chemicals through manufacturing processes: sodium hydroxide, chlorine and hydrogen. The sodium chloride electrolysis reaction to produce these three commodity chemicals requires a feed of concentrated brine. However, as the reaction takes place, the concentration of the brine decreases at the outlet of electrolysis. For recycling purposes, it is necessary to increase the concentration of the spent brine solution to produce sodium hydroxide, chlorine and hydrogen in an economical, efficient and viable way. In this project, the chlor-alkali process was analyzed, optimized and designed to utilize the spent brine. The approach developed to solve this important process design issue included research and examination of the performance, viability, economics and other merits of the various brine concentration techniques. The analysis will provide the advantages and disadvantages of several brine concentration techniques and determine the cheapest option to meet the design specifications with best efficiency. Different concentration techniques considered include crystallization, evaporation, addition of salt and reverse osmosis. The recommended design is the most cost effective and operationally effective process for concentrating the spent brine to a specification that can then be recycled back into the chlor-alkali process.



A sodium chloride electrolyzer.



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## USING A NEW CATALYST TO ENHANCE THE SELECTIVITY OF LINEAR ALPHA OLEFIN PRODUCTION

Linear alpha olefins (LAO) are straight chain alkenes – unsaturated hydrocarbons containing double bonds – where the double bond is in a terminal position. They are used as co-monomers in the production of polyolefins such as polyethylene plastics, detergents, surfactants, synthetic lubricants and plasticizers. LAO are synthesized from the oligomerization of ethylene. However, this route produces a wide variety of olefins, resulting in a significant yield loss of 1-hexene (C6=) and 1-octene (C8=), the LAO of greatest commercial interest.

Our team has developed an economically feasible plant design that reacts an inexpensive ethylene feedstock with a new catalyst that greatly enhances the selectivity for 1-hexene and 1-octene. This plant produces 100 MM lb/yr of LAO and includes the option to adjust the mass split of the desired products based on fluctuating market demand. Additionally, it operates within federal and state safety and environmental regulations. This plant has the potential to yield greater profits than existing competitors because of its higher yield of commercially useful LAO.



A linear alpha olefin (LAO) production plant.





CHEMICAL & BIOMOLECULAR ENGINEERING

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CREATING USEFUL CHEMICALS FROM NATURAL GAS

Mixtures of the aromatic chemicals benzene, toluene and xylene have conventionally been produced from crude oil byproducts. However, the expansion of American natural gas exploration has uncovered extensive methane reserves that could provide an economic and sustainable substitute for petroleum feed stocks in the production of aromatic hydrocarbons. Our goal is to design a process to increase selectivity of para-xylene, be operable under EPA guidelines, and adhere to appropriate safety precautions.

The initial stage of the process uses a dehydrocyclization catalyst to convert methane into an aromatic mixture. This process is highly endothermic, necessitating constant heating of the reactants to maintain a high product yield. The following stage is alkylation and subsequent methylation to produce para-xylene. Procedure options include using olefins, zeolite catalysts, methanol streams or syngas streams to alkylate the various aromatic streams. These alternative reactions are compared for economic efficiency. The process concludes with a separation scheme to purify para-xylene.

The utility of para-xylene as an intermediate in the petrochemical and polymer industries drives the economic success of this plant. Optimizing selectivity for para-xylene will result in the most profitable plant design.



A nighttime image of a natural gas plant.



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ADVISERS

Ralph Bruce, Professor of Electrical Engineering  
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SPONSORS

Sterling Ranch

ELECTRICAL ENGINEERING & COMPUTER SCIENCE

STERLING RANCH LOW-ENERGY HOME DESIGN

Rising environmental awareness and advances in sustainable technologies have given yield to communities like Sterling Ranch, an environmentally focused master planned community outside of Denver, Colorado. The Low-Energy Home Design team aims to provide a variety of potential building alternatives that could be applied to Sterling Ranch homes to improve energy efficiency and push toward net zero, a home that produces more energy than it uses. Using BEopt modeling software, we are able to analyze a large number of building options, including the envelope, appliances, major systems, lighting, on-site power production and more. The resulting simulations will help us determine which changes are both beneficial for energy consumption and financially feasible. The breadth of the software allows us to look at options and components that may have not been considered in the previous design process and make an argument for their implementation or consideration. We intend to produce a set of proposals that show a range of potential options varying in cost and efficiency with the most efficient option being a net zero design. In addition to the modeling, alternative options that go beyond the ability of the software will be analyzed and considered.



TEAM

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ADVISERS

Gary D. Butler, Camgian Microsystems  
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SPONSOR

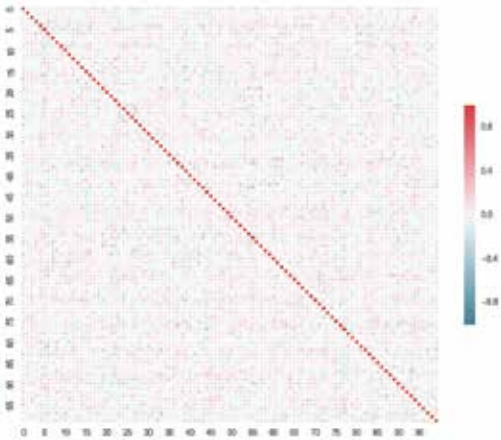
Camgian Microsystems

ELECTRICAL ENGINEERING & COMPUTER SCIENCE

BUILDING A CORRELATION ENGINE INTO CAMGIAN EGBURT

The high volume stream of sensor data being generated by large industrial systems like bridges, locks and dams, presents an obstacle for data analytics. Petabytes of data from a wide variety of sensors must be transmitted back to data centers for analysis – a process requiring an expensive and impractical amount of bandwidth. Camgian's Egburt platform performs the data processing and analysis on site, allowing for real-time extraction of actionable intelligence for inspection by the end user.

Our project will expand on Egburt's data processing capabilities, supplementing the eventual data presented to the end user. The deliverable is a correlation engine, i.e. a platform that can receive real-time data from a network of sensors, calculate the correlation over time between each pair, and visually represent those relationships in an intuitive and informative way. Our design will be integrated into Camgian's Insight Portal, a cloud-based user interface for interacting with the data Egburt produces. A visualization of the subtle relationships between components in these structures will help engineers refine their understanding of the system, allowing them to efficiently and effectively track anomalies and resolve issues.





TEAM

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ADVISER

Andrew Cowart, Vice President of Technology

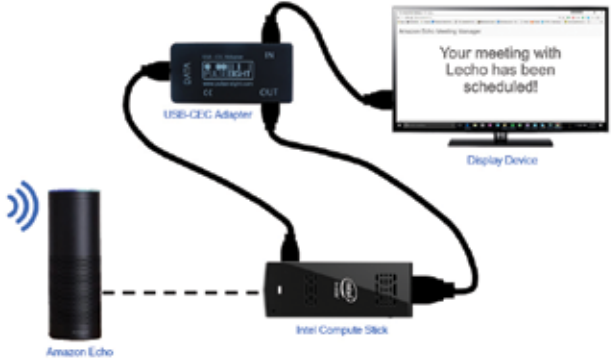
SPONSOR

Metova

AMAZON ECHO DISPLAY

Meetings are an integral part of any business, and a good deal of time is spent organizing the event and operating the display devices in a meeting room. Traditional interfaces, such as Google Calendar and remote controls, are not always intuitive and users need to have prior knowledge in order to operate them effectively. Productive meeting time is reduced as a result of this management overhead. Our system will improve meeting management by allowing users to manage meetings and control display devices using simple, intuitive voice commands.

The system uses an Amazon Echo to receive and respond to verbal user requests. The requests are then sent to an Intel Compute Stick, which is attached to the meeting's display device via HDMI. The Compute Stick translates the requests using a USB-CEC Adapter into commands that control the display. This allows users to conduct meetings easily using only their voices. This is more intuitive than existing interfaces, and can be used by people with physical disabilities who cannot operate a standard computer or remote. Our system will simplify meeting management, improve productivity, and save businesses time and money.



Schematic of the overall communication flow for using natural language processing to control a display device using an Amazon Echo.

TEAM

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SPONSOR

Vanderbilt University  
Department of Public Safety

VANDY VAN BUS SHELTER

Vanderbilt University currently provides an immensely valuable service to students through the Vandy Van system. This system is used by hundreds of students each day to move across campus quickly and safely. However, the program currently lacks designated shelters to make stops easily identifiable and protect students from inclement weather. Working with many campus stakeholders, our team designed a Vandy Van bus shelter that not only shields students from the weather but also keeps them safe and up-to-date on the status of the Vandy Vans. The design is highly modular to be more sustainable and practical as the campus continues to grow and develop. It incorporates safety elements such as a security camera and blue light system, and the shelter includes a screen to provide riders live route information and arrival times. The shelter will serve as a useful contribution to student life and will further roll out as the Vandy Van program continues to develop and evolve.



Digital rendering of the proposed bus shelter.

TEAM

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ADVISER

Brian Sierawski, Research Assistant  
Professor of Electrical Engineering

SPONSOR

Institute for Space and  
Defense Electronics

FPGA VERSION OF A CUBESAT EXPERIMENT

Approximately one year ago, the Institute for Space and Defense Electronics (ISDE) at Vanderbilt designed and launched a CubeSat experiment to monitor data errors in commercial memories on-orbit. This design used a microcontroller to operate the experiment. In future experiments, ISDE is looking to expand the capabilities of the design implementation to include control of the guidance and navigation of the space-craft bus as well as replace multiple ICs with a single chip. The objective of this project is to enable this goal by designing a board that uses a Field Programmable Gate Array (FPGA) in place of a microcontroller to operate an experiment.



The team has designed a board that meets the power and form requirements of a CubeSat experiment board. In operation, the FPGA writes and reads from an on-board memory every five minutes. When errors are detected between what was written to the memory and what was read, those errors will be corrected by the FPGA. The team can also communicate externally with the FPGA and receive the number of errors that have taken place.



TEAM

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ADVISER

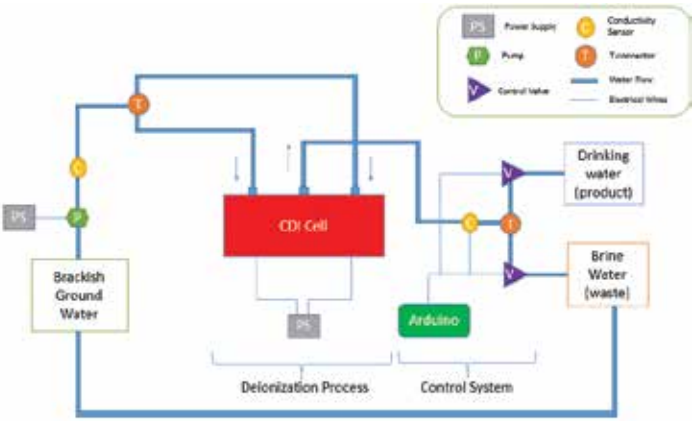
Shihong Lin, Assistant Professor of Civil  
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SPONSOR

Vanderbilt University School  
of Engineering

SOLAR POWERED CAPACITIVE DEIONIZATION

Access to safe drinking water is a significant challenge in many communities, especially those in typically remote areas without access to large-scale infrastructure of power and water supply. Furthermore, some of these communities' only water source is brackish groundwater. Existing water treatment technologies all have significant limitation when applied in small-scale and off-grid brackish groundwater desalination. For example, reverse osmosis is more suitable for continuous operation, which poses a challenge using periodic solar energy, whereas distillation processes are energy inefficient. In order to address the issues presented by the lack of potable water and the problems in existing water treatment, we will use an emerging technique known as Capacitive Deionization (CDI). CDI can provide drinkable water to these regions in an energy efficient, sustainable manner by means of solar energy. CDI works by removing ions from water flowing through charged supercapacitors. These supercapacitors have a positively and negatively charged plate which attracts ions of opposite charge, pulling the ions from the brackish water. Additionally, unlike previous CDI systems, our system will feature real-time feedback to control the destination of the output flow, be entirely solar powered, and significantly reduce the concentration of ions in brackish water.



The solar powered system will deionize the input solution by attracting ions to charged supercapacitor plates and send the output to reservoirs via an Arduino-controlled switching mechanism, based on conductivity readings.



VANDERBILT  
School of Engineering



**ELECTRICAL  
ENGINEERING &  
COMPUTER  
SCIENCE**

**TEAM**

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**ADVISER**

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**SPONSOR**

Siemens

**SMART HOME ANALYTICS AT STERLING RANCH**

Though sustainability continues to be a hot topic in modern architectural development, much of the research in this area focuses on developing resource-efficient appliances and buildings. Sterling Ranch, a housing development in southwest Denver, Colorado, is working to couple its focus on sustainable facilities with the addition of software that can help residents develop sustainable habits. Each home at Sterling Ranch is equipped with sensors that monitor water, electricity, and energy use as well as photovoltaic energy production.

Our system uses information from these in-home water sensors to help Sterling Ranch residents understand their water consumption patterns. The software analyzes collected sensor data to produce a time-segmented water consumption summary and tips about how residents can reduce their overall use. The graphical results of this analysis are displayed in real time on an in-home tablet application, making these insights easy to access and understand. It is our hope that access to this analysis will motivate residents to develop more sustainable habits and fully understand the environmental and financial benefits of reducing their water consumption.



In-home water sensors feed meter readings to data analysis software, which communicates with the in-home tablet application to display a visual analysis of the home's water consumption to residents.



**ELECTRICAL  
ENGINEERING &  
COMPUTER  
SCIENCE**

**TEAM**

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**ADVISER**

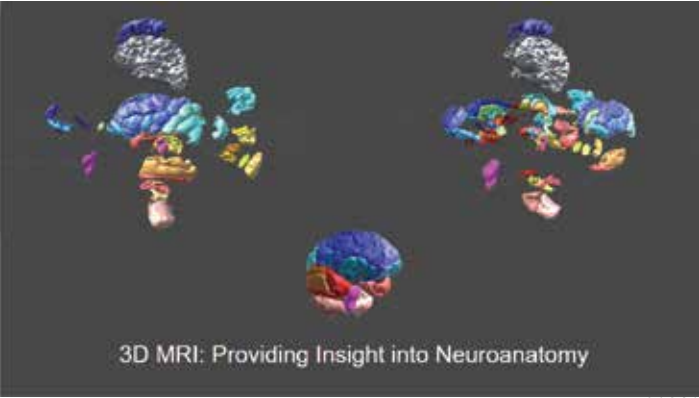
Kevin Wilson, MESC, Director of the Center for  
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**SPONSOR**

Vanderbilt University Institute  
of Imaging Science

**3D MRI PROVIDING INSIGHT INTO  
NEUROANATOMY**

Our project's overarching goal is to harness the transformative power of virtual and augmented reality to reduce the ambiguity of radiological data for medical students and clinicians. We provide a clear visualization of radiological medical data with a multi-platform, easy-to-use application. Clinicians and medical students often have difficulty analyzing traditional radiological data because it is presented in only two dimensions. Even when these images are combined and 3D printed anatomical regions of the brain are created, they are often difficult to analyze due to the medium's rigidity and opacity. Our application, coded in the game engine Unity3D, displays a three-dimensional model of the brain taken directly from a set of magnetic resonance images. With our application's intuitive user interface, users can manipulate, rotate, expand, and visualize the model clearly. Further applications of the project include assisting with neurosurgery, diagnoses of pathologies of the brain, and inviting other anatomical regions to be segmented and modeled.



This 3D model of the brain was created using segmented structural MRI data. Top left: The brain segmented into 204 different anatomical regions in expanded view seen on one axis. Top right: The expanded model shown with a 45-degree rotation along one axis.



**TEAM**

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**ADVISERS**

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Ralph Bruce, Professor of the Practice of  
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**SPONSOR**

Vanderbilt University  
Medical Center,  
Department of Pediatrics

**ELECTRICAL  
ENGINEERING &  
COMPUTER  
SCIENCE**

**iOS APP INTEGRATED WITH HEXOSKIN  
SMART SHIRT TECHNOLOGY**

A Department of Pediatrics research team studies the physiological effects that slowed breathing has on the body. The research involves subjects following breathing protocols while wearing a Hexoskin Smart Shirt, a shirt that transmits the subjects' biometric data to Hexoskin's servers. Currently, the research team manually requests the data from the servers and then inputs the data into a third party program for analysis. This mobile app retrieves the data from the servers to analyze the results. The main advantage of the mobile app is that it handles the data retrieval and analysis automatically. Additionally, the app contains breathing exercise interfaces that help subjects follow the exercises more precisely. Previously, subjects memorized the exercise, but this app makes the exercise requirements easier for them to follow.



Screenshot of the app's  
breathing exercise interface.





MECHANICAL  
ENGINEERING

TEAM

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Mary Brown  
Jonathan Hinds

ADVISERS

Lizard Walker, Aerial Dance Artist  
Thérèse Keegan, Aerial Dance Artist

SPONSORS

Lizard Walker, Aerial Dance Artist  
Thérèse Keegan, Aerial Dance Artist

AERIAL DANCE APPARATUS

Aerial dance is a subgenre of modern dance that incorporates a structure suspended in the air to allow for full three-dimensional creative movement. Lizard Walker and Thérèse Keegan are local Nashville aerial dancers who have asked us to create a custom apparatus for their performances. The apparatus must remain safe and portable while designed to be different than other, existing aerial dance apparatuses to ensure that it provides the opportunity for a unique performance. Additionally, each individual part of the apparatus needs to be replicable at a high volume level and designed so that a customer or performer can easily piece the entire configuration together with simple instructions. This will allow for other artists in the field to experiment with the apparatus as well. Our solution is a two-piece pyramidal steel structure suspended with structurally graded spansets. The custom joints provide the opportunity for complete disassembly of the apparatus. The upper tier fits within the lower for ease of transportation, and the painted steel bars provide comfortable gripping for the performers.



Lizard Walker practices with the two-piece pyramidal aerial dance apparatus.

MECHANICAL  
ENGINEERING

TEAM

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Ricardo Herrera  
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SPONSOR

Vanderbilt School of Engineering, Biomechanics & Assistive Technology Lab

NEXT-GENERATION ANKLE EXOSKELETON

For centuries, people have strived to enhance human performance, and our aim is no different. We are trying to enhance human walking by reducing the metabolic energy consumption by 10 percent. In order to do this, we are designing an ankle exoskeleton that stores energy and transfers it back to the user. Our ankle exoskeleton contains an energy storage device (i.e. spring or resistance band) that is placed parallel to the user's Achilles tendon. When the user takes a step, some of the energy produced is stored in the device (i.e. the spring or resistance band stretches). When the user then pushes his foot off the ground, the stored energy is transferred back to the user (i.e. the spring or resistance band is released and returns to its original position).

A key element for the success of the ankle exoskeleton is a clutching mechanism that allows the energy storage device to engage and disengage at the appropriate times in order to not interfere with the natural walking motion of the user. The exoskeleton is completely passive, meaning that it does not contain actuators, such as motors, and it

BAT

does not require batteries or any other external source of energy. This gives the user the freedom to wear the ankle exoskeleton in any situation.



This is how the next-gen ankle exoskeleton is worn.

TEAM

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ADVISERS

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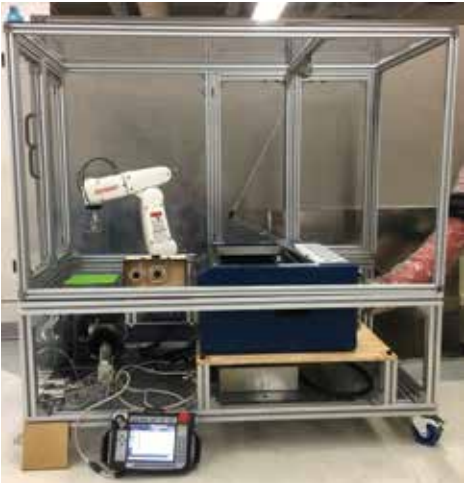
DENSO Manufacturing Tennessee Inc.

MECHANICAL  
ENGINEERING

DENSO AUTOMATED MANUFACTURING AND ASSEMBLY CELL

DENSO engages in many educational outreach programs, demonstrating manufacturing techniques and robotics projects to teach basic engineering principles and inspire young students to pursue higher education and careers in STEM fields. This project aims to integrate a variety of systems in a cell that automatically manufactures cardboard figurines. Individual slices of a model are produced by a laser cutter, and a six-axis robot is utilized to move and stack the pieces. The cell also includes several custom-designed components which enhance the automation of the assembly process and display a wider range of electromechanical systems. Upon completion of the laser-cutting process, the robot applies tension to a cord that opens the laser cutter's door, enabling easy access to the cut pieces. A vacuum chuck with suction cups is attached to the robot's flange and used in conjunction with a compressor and vacuum generator to lift and move the cardboard pieces. Adhesive is affixed to the bottom of each slice before being added to the assembly. The completed figurines are given to students attending DENSO's programs as souvenirs and reminders of the vast capabilities of engineering systems.

DENSO



The cardboard figurine manufacturing and assembly cell.

TEAM

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Zhaffan Radzi

ADVISERS

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Greg Walker, Associate Professor of Mechanical Engineering

SPONSOR

Vanderbilt University Plant Operations

MECHANICAL  
ENGINEERING

DESIGN OF AN ALGORITHM FOR EFFICIENT COOLING TOWER CONTROL

Modern cooling towers operate under a simple cycle system. Cooling towers provide buildings with cold water and receive hot water back from the buildings after air and water heat exchange has taken place. Large fans inside the cooling towers are responsible for cooling the hot water that enters the towers. The purpose of this design project is to develop an algorithm for more efficient cooling tower operation with Vanderbilt University Plant Operations. Cooling towers are often operated at unnecessarily high loads under certain weather conditions. The main goal is to establish relationships between atmospheric conditions and cooling tower fan speed to find the most efficient use of power. In order to research and test these relationships, the Polar Power team has built several prototypes of small-scale cooling towers in order to test fan operation speeds based on different atmospheric conditions. As a result of this testing and analysis, the team is developing a flowchart to map the algorithm based on the team's findings. A proper algorithm will lead to significant savings through lowered power use and provide a universal guideline for cooling tower operation.



Cooling tower prototype used to find cooling results through different fan speed operations and atmospheric conditions.



MECHANICAL  
ENGINEERING

TEAM

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SPONSOR

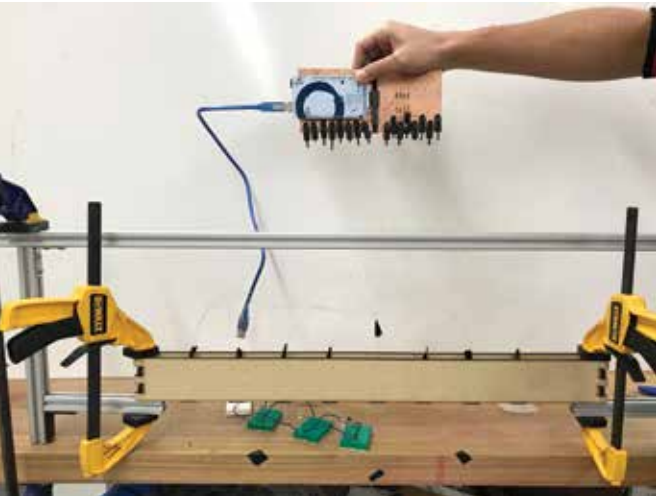
Fiserv

FISERV’S MAGNETIC STRIPE QUALITY PROJECT

Fiserv Output Solutions (FOS), a credit card manufacturer in Nashville, is facing challenges in the factory. The FOS facility is responsible for manufacturing secure and non-secure credit, debit, gift, and other bank or membership cards. Using either or both an offset lithography or silk screen press, we print the desired image onto sheets of 56 cards. These sheets receive a plastic overlay, including the magnetic data stripe, are laminated and die cut into cards. Cards are then inspected for defects before being sent elsewhere for personalization.

We have identified one common defect that affects the functionality of the cards, which is the location of the magnetic stripe on the back. When the mag stripe is not in the right location, it is called “mag float.” There are a number of possible sources of this error. When mag float occurs, cards no longer fall within ISO specifications for the location of the magnetic stripe on financial cards, which are set in place to ensure that any card reader can read the data from any mag stripe. If a job fails due to mag float, FOS incurs the cost of reprinting the entire job from the beginning.

The goal of this project is to build a system that can detect when mag float occurs on rolled overlay to prevent these defective cards from traveling through the finishing processes, wasting time, energy and money.



The solution devised to the problem of magnetic float.



MECHANICAL  
ENGINEERING

TEAM

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ADVISER

Tracie Prater, Aerospace Engineer

SPONSOR

NASA Marshall Space  
Flight Center

IN-SPACE MANUFACTURING

NASA wishes to investigate the feasibility of 3D-printing tools and parts on the International Space Station. As a part of the in-space manufacturing feasibility studies, NASA also intends to study the effects of doing these prints in microgravity environments. Marshall Space Flight Center in Huntsville, Ala., is heading NASA's project to explore these in-space manufacturing capabilities. In conjunction with MSFC, our goal is to develop hand tools, an arm cast, and hybrid rocket fuel, as well as a 3D part file library with an interface. With this, the astronauts on the ISS will be able to create tools in a variety of sizes by inputting only a few dimensions, as well as have immediate access to a cast print in case of injury. (NASA currently does not have a 3D part file library, and there is no existing process which provides this service.) We anticipate to have an interface capable of providing intuitive access to the part models we create.



Sample 3D prints: lattice pattern used for casts (left) and hand tools of varying sizes (right).

TEAM

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William Emfinger, Software Engineer  
Liyun Guo, Product Engineer

SPONSOR

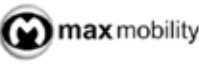
MAX Mobility

MECHANICAL  
ENGINEERING

TWO-WHEEL DYNAMIC CENTER OF GRAVITY WHEELCHAIR

The current power wheelchair market is dominated by four-wheel devices that are often bulky, have large turning radii and are potentially unsafe when operating on steep inclines. A two-wheel, self-balancing wheelchair addresses many of these issues. It allows the user to remain vertical on an incline, minimize their physical footprint, turn with a smaller radius, and overcome obstacles with its large wheels.

The Nino Robotics wheelchair currently employs self-balancing technology, but in order to make the product more accessible for users with disabilities, the team modified the Nino device by removing the leaning motion required to accelerate and replacing its obstructive steering handle with an integrated steering and motion control device. A mass displacement system simulates the leaning motion required to accelerate and includes a feedback control system to regulate the user's speed, all of which is integrated with steering via a single, user friendly joystick. With this solution, the accessibility and safety is improved for individuals with disabilities while maintaining optimal performance for an innovative transportation experience.



The self-balancing NINO Robotics wheelchair.

TEAM

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ADVISERS

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Leslie-Anne Owens, Public Art Project  
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SPONSOR

Nashville Metro Arts  
Commission

MECHANICAL  
ENGINEERING

METRO ARTS PUBLIC ART COLLECTION:  
CONSERVING PUBLIC ARTWORKS

Metro Arts’ public artwork installations cover many notable pieces, including the large number of artistic bike racks seen throughout Nashville. These bike racks, despite each being unique, face the same problems such as paint chipping, metal rusting and disruptive removal from the ground. This daily wear and tear is the result of the racks serving as “usable artwork.” Additionally, commissioned artists have been making design decisions based on aesthetic, not sustainability, thus adding to the maintenance and upkeep required.

With the ultimate goal of extending the bike rack lifespan and time between maintenance, the team began to design subterranean mounting systems that would not detract from the artist's original intentions but would allow for easy bike rack removal. This mounting system is welded during fabrication to the bike rack posts and consists of an industrial hidden hasp lock, subterranean compartment containing the lock and a lid covering the compartment. In addition to fabrication, the team collected data and research throughout the year to compile into an infographic series. This series will allow for the rack's required technical specifications to be communicated to the artists in a clear, concise way.



A Metro Arts removable bike rack mount.



TEAM

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Brandon Ward

ADVISERS

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Joel Wotruba, Senior Manufacturing Engineer  
Dan Schmidt, Senior Manager  
John Tian, Process Engineer  
Dustin Nichols, Senior Engineer

SPONSOR

Nissan

## NISSAN OVER-UNDER MATERIAL HANDLING SYSTEM

In Nissan's Smyrna, Tenn., Vehicle Plant – the highest-volume auto plant in North America – parts are often kept in large containers near the assembly line where workers may access them for use in a specific manufacturing task. A large portion of the plant floor is kept clear for cart and worker traffic, leaving limited space for parts containers. Currently, Nissan uses forklifts to place these containers in designated areas where they remain until emptied of parts. A forklift is then used to remove the empty container while the assembly line worker waits for a full container to arrive. Often, multiple parts containers are lined up and interfere with traffic. This process results in a significant amount of wasted time and movement. This design project aims to improve this process through the implementation of a gravity-driven, over-under material-handling system that allows for three containers to be stored in the footprint of two. This system will allow for a full container to be ready and easily accessed after the emptying of the previous container. The worker will be able to switch out empty and full containers with minimal effort, which will improve the efficiency of the Nissan assembly line.

**NISSAN**



A computer rendering of the material-handling solution.

TEAM

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Jonathan Enochs, ME/Physics

ADVISER

Kevin C. Galloway, Director  
of Making, School of  
Engineering

SPONSOR

Kevin C. Galloway, Director  
of Making, School of Engineering

## DEVELOPMENT OF A LOW-COST SOFT ROBOTIC DEEP SEA SAMPLE COLLECTION TOOL

While deep coral reefs and other deep sea environments have impressive ecological significance, they remain largely unexplored due to limitations in exploration and sample retrieval methods. The primary obstacle to studying deep coral reefs is depth. SCUBA divers rarely dive deeper than 30-50m underwater. Deep sea environments, such as deep sea coral reefs, located between 50-200m underwater, have been mostly inaccessible.

Using a growing selection of small remote operated vehicles (ROVs), biologists are able to collect samples at these previously unattainable depths. Despite these advancements, this research has been limited by a lack of low-cost, lightweight tools that can be mounted on a ROV and used to collect biological samples without damaging them. Conventional grippers, modeled after the Jaws of Life, are unfit for the delicate collection of soft biological samples – some of which are hundreds of years old and rare.

Using the previous work of our sponsor, our team has developed a solution. We have refined the soft robotic grippers, developed new cable-actuated cutters and joined them with a robust interface for use on an ROV. This provides a gentle grip on delicate ocean samples in a low-cost, lightweight package designed for continued use in seawater.



**VANDERBILT**  
School of Engineering



Illustration of a remotely operated vehicle (ROV) collecting samples from the sea floor. Circled is the portion that our team has redesigned.

TEAM

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Brandon Beans  
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Myles Lacy  
Stephen Wei

ADVISER

Kevin C. Galloway, Director  
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SPONSOR

Kevin C. Galloway, Director  
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## JUNCTIONAL HEMORRHAGING CONTROL DEVICE

Modern-day military body armor provides defense to critical areas such as the abdomen, thorax and head, but it does not protect the limbs or their areas of attachment to the torso. Consequently, these areas are prone to injury from energized fragments such as IED shrapnel, blasts and gunshots. Trauma to junctional zones is particularly troublesome because they are inaccessible with traditional tourniquets, thus hemorrhaging from major blood vessels cannot be controlled. In fact, 20 percent of U.S. soldier casualties deemed savable in Middle Eastern conflict from 2001-2010 were caused by junctional injuries.

The First Responders Junctional Hemorrhaging Control (JHC) team is addressing hip area junctional injuries with a low cost, hand-sized rapidly deployable junctional tourniquet. This is an improvement over FDA-approved JHC devices, which are rarely used by military field medics due high manufacturing costs, bulk, unreliable hemorrhaging control and cumbersome application procedures. Application of this new device relies on a custom-made ratchet mechanism, which allows a simple turning motion to tighten straps around a specifically designed pressure application block. This device has the potential to save hundreds of lives by equipping field medics with a quick and easy method for stopping junctional hemorrhaging.



**VANDERBILT**  
School of Engineering



Diagram of how the prototype is applied to the hip junction, anterior to the femoral artery.

TEAM

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Dzharif Sabri  
Hank Moore

ADVISERS

Kevin Redmond, Director of New Product Development  
Jay Hope, New Product Development Engineer

SPONSOR

Symmetry Surgical

## LAPAROSCOPIC TOOL DEVELOPMENT

Laparoscopic surgery is a minimally invasive surgical technique with many advantages to the patient. The surgery is performed through small incisions, approximately 1 cm in length, in the abdomen of a patient. By operating through these small incisions rather than an open procedure through a large incision, surgeons can reduce the overall pain and recovery times for the patient.

The overarching goal for our project was to develop a new laparoscopic instrument set that features intuitive assembly, ratcheting and non-ratcheting ergonomic handles of different sizes, comfortable operation and sturdy overall design. We also focused on designing modular tips that could be easily disposed of. These will provide surgeons the ability to quickly interchange tips, minimizing cost and effort.

The main issue with Symmetry Surgical's current laparoscopic tool line is the vast quantity of tools. In many cases, they have several tools that represent similar functionalities, which makes customer interactions more difficult. We created a basic package that can be purchased to perform most laparoscopic surgeries.



Shown here is an earlier design of a laparoscopic tool, including a finger-actuated handle and a removable tool tip.

 symmetry surgical



TEAM

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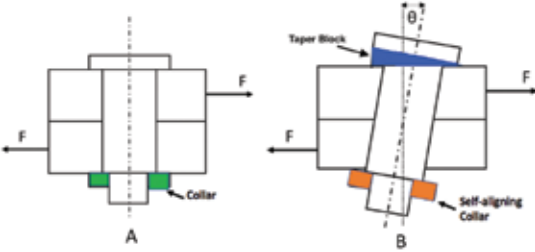
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Triumph Aerostructures

INSTALLATION ANGLE ANALYSIS OF WING FASTENERS  
ON GULFSTREAM G-650

Airplane wings are constructed from wing skins, ribs, spars, stringers and thousands of Hi-Lite pin/collar fasteners. The fasteners are installed manually to connect the wing ribs to other components, and thus, there is innate human error associated with drilling holes into difficult-to-reach locations. Some holes are unintentionally drilled at an angle instead of perpendicular to the parent aluminum material. This phenomenon is called a slant-drilled hole and is the basis of this design project.

Triumph currently fixes slant-drilled holes by installing an angled block of metal, called a taper block, under the head of the fastener in order to recreate a perpendicular surface and regain some of the lost joint strength due to the angled configuration. The team performed a full analysis of various sized Hi-Lite pin/collar fasteners for both perpendicular and slant-drilled holes. The analysis involved analytical by-hand calculations, finite element modeling solutions and physical testing in order to determine the loss of joint strength from the perpendicular configuration to the angled configuration – a quantitative value that has been coined as the knock-down factor. The goal was to prove a consistent loss of strength across all three analysis platforms.



The team performed a full analysis of various sized Hi-Lite pin/collar fasteners for both perpendicular and slant-drilled holes.



TEAM

Dustin Howser, ME/Math  
Jimmy Pan  
Brian Ramsey  
Derek Phillips  
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ADVISERS

Amrutur Anilkumar, NASA Student Launch Competition Team Adviser, Professor of the Practice of Mechanical Engineering, Professor of the Practice of Aerospace Engineering

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POST-BOOST ROLL CONTROL USING COLD GAS THRUSTERS

As one half of this year's NASA Student Launch Competition team, we are responsible for the fabrication, testing and integration of the physical system that will perform our in-flight experiment. The objective of the experiment is to launch the rocket to an altitude of exactly one mile and perform a roll and counter roll about the main axis of the rocket using two pairs of thrusters. The team has fully designed and machined these thrusters to expel air from the onboard high pressure tank supersonically, generating enough thrust to roll the rocket in the face of the extreme resistance experienced during high speed flight.

The high-acceleration takeoff (~14 g's) requires an innovative carbon fiber reinforced airframe that is fabricated in-house. A dual-parachute deployment system allows us to safely recover and reuse our rocket. Subscale testing of a shorter rocket with single-directional control and the construction of a ground-based testing facility for roll control have allowed us to verify the efficacy of our vehicle and thruster design before the construction of our 95-inch, dual-directional, full-scale rocket. Our design and experiment have far-reaching implications outside of model rocketry alone, such as fine attitude control for satellites.



The rocket on a launchpad and the thruster system CAD model.

TEAM

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Bradley Bark, EE  
Arthur Binstein  
Grady Lynch  
Paul Moore  
Ross Weber

ADVISER

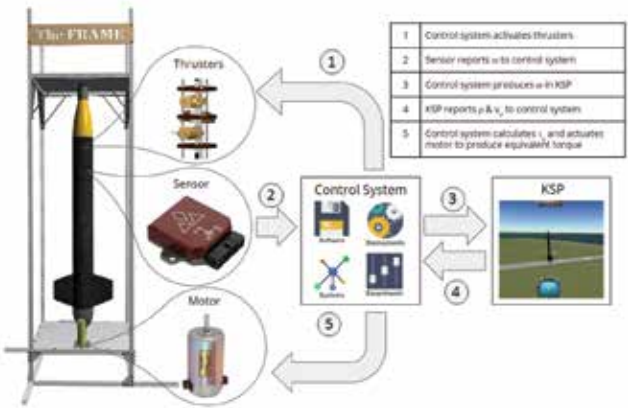
Amrutur Anilkumar, NASA Student Launch Competition Team Adviser, Professor of the Practice of Mechanical Engineering, Professor of the Practice of Aerospace Engineering

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SUBORBITAL LAUNCH VEHICLE ROLL CONTROL  
SYSTEM AND AVIONICS

The ability to control the movement of a rocket or other aircraft can improve vehicle performance and provide mission-critical maneuverability. Thus, the team's design directive is to successfully design, build, test and fly a fully integrated electromechanical payload that imparts two rotations about a rocket's vertical axis during ascent by using an onboard cold gas thruster system. Design of a control system for the rocket is a large portion of this challenge. This control system consists of a sensor that will detect when the primary rocket engine has stopped burning and inform the onboard computer that it is time to start firing the aforementioned thrusters to perform the roll experiment. After two rotations, the control system will fire the counter-roll thrusters to halt rotation. Using an onboard sensor and controller allows the rocket to make decisions in real time and thus be robust to any disturbances such as a sudden wind. This control scheme has been and will continue to be tested and refined on a ground-based test facility designed and built by the team, known as the FRAME, to ensure success on launch day.



Schematic of the testing procedure for our control system and how it communicates with real rocket on the FRAME and simulated rocket in Kerbal Space Program (KSP).



TEAM

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Taylor Larsen

ADVISER

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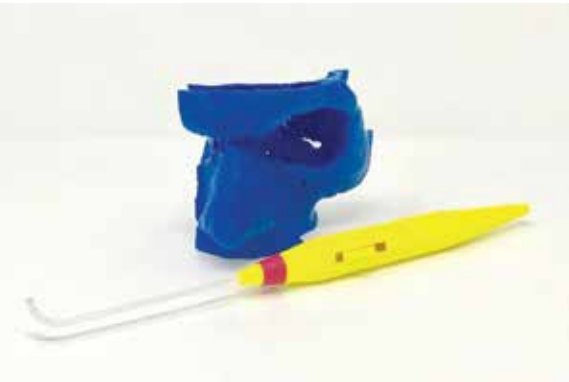
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THE NEEDLESCOPIC OPERATION FOR SINUS  
ENDOSCOPY (THE NOSE)

Chronic sinusitis is a condition characterized by the swelling of the sinuses that affects over 29.4 million Americans, with symptoms including congestion, sinus pressure, runny nose and headaches. Currently, doctors use patient-reported symptoms and larger endoscopes that only reach the entrances of the sinuses. This limitation commonly results in a misdiagnosis. The goal of this project is to develop a tool that navigates a fiberscope through the nasal passage to observe the various sinus cavities. This will prevent unnecessary antibiotic or steroid medication and radiation exposure through CT scans for the patient.

The project is divided into two components: the handle and the flexible tip. The handle needs to be intuitive, ambidextrous and capable of housing a bending mechanism and ports for the camera, catheters or balloon sinuplasty device. The design of this is refined through an iterative 3D printing process. The tip, made of a biocompatible material, has a mechanical wrist (small notches cut by CNC and a wire tendon) that can bend up to 135 degrees to enter the various sinuses. The final device is expected to prove its viability, after phantom and cadaver testing, as a better alternative to current nasal endoscopes.



A 3D-printed endoscopic tool and sinus model used for demonstration and testing.





# DESIGN AND PROJECT FACULTY

We take great pride in recognizing these faculty members who are the core of our design program. Their outstanding contributions and excellence as instructors, advisers, and mentors in our senior design and project courses have led to the work exhibited at Design Day 2017 and have transformed our Class of 2017 into young professionals.



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