DESIGN CENTER COLORADO

SIEMENS Gamesa
RENEWABLE ENERGY

Virtually Operated Robot for Wind Turbine Diagnostics and Service

TEAM 9:

Vishwamorti Chandrasekar, Quintin Cook, Jackson Dixon, Alex Hein, Daniel Jin, Garrett Pierson, Jack Plantz, Sofia Springer, Jillian Weber

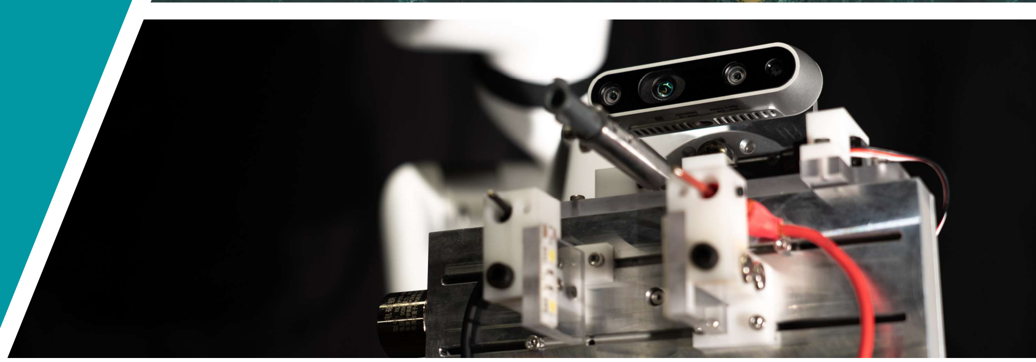


Table of Contents

DESIGN CENTER COLORADO

SIEMENS Gamesa RENEWABLE ENERGY

Project Background

Siemens Gamesa annually produces over **107 gigawatts** of wind energy across **75 countries**, and is the **industry leader** in **offshore** applications.

Offshore wind turbine maintenance is logistically challenging, and requires skilled technicians.

Electrical maintenance technicians are dispatched to offshore turbines by helicopter or service vehicle, typically take 5+ hours to diagnose and repair electrical problems, and must work in pairs for safety.

With more than 3,700 offshore wind turbines, this can lead to time-consuming, expensive, and sometimes dangerous work.

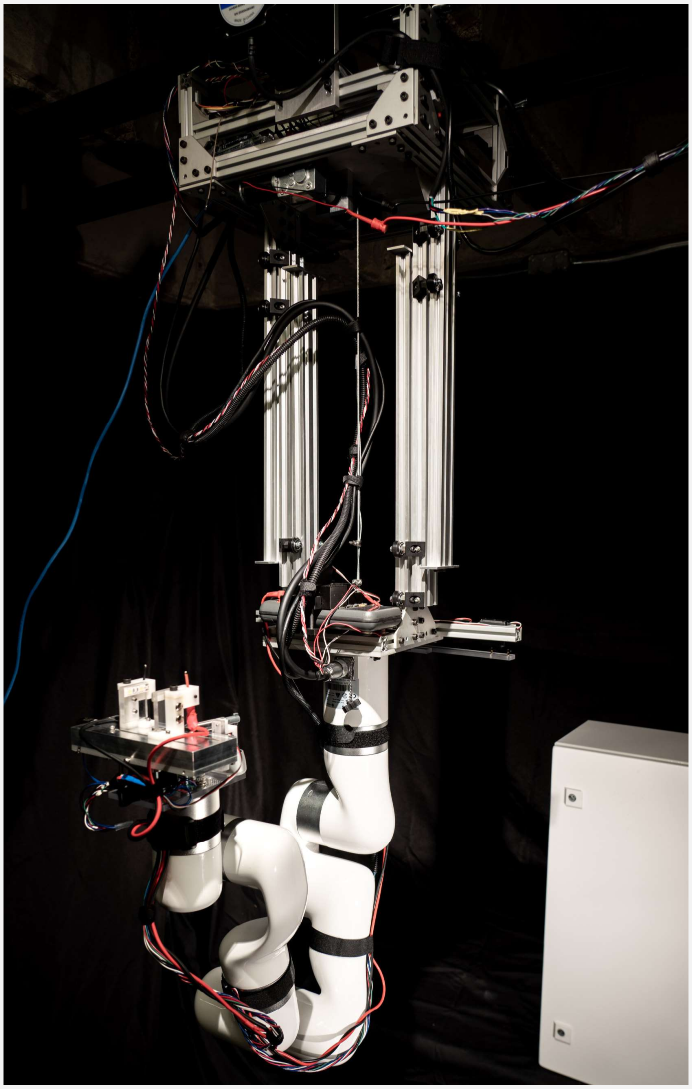
Siemens Gamesa partnered with CU Boulder's Senior Design Team 9 to engineer a solution.

With a system that is permanently stationed offshore, capable of traversing through the turbine, and remotely controlled, a majority of diagnostic and troubleshooting tasks could be completed before the technician is flown in.

With live visual data and remote electrical testing and verification, turbine uptime and wind energy production can be maximized.

Executive Summary

The Virtual Operated Robot for Wind Turbine Diagnostics and Service Project aims to perform a majority of the required electrical diagnostic and troubleshooting tasks within the electrical cabinet of a wind turbine. This would be accomplished via a remotely controlled robot permanently stationed at the top of the turbine.

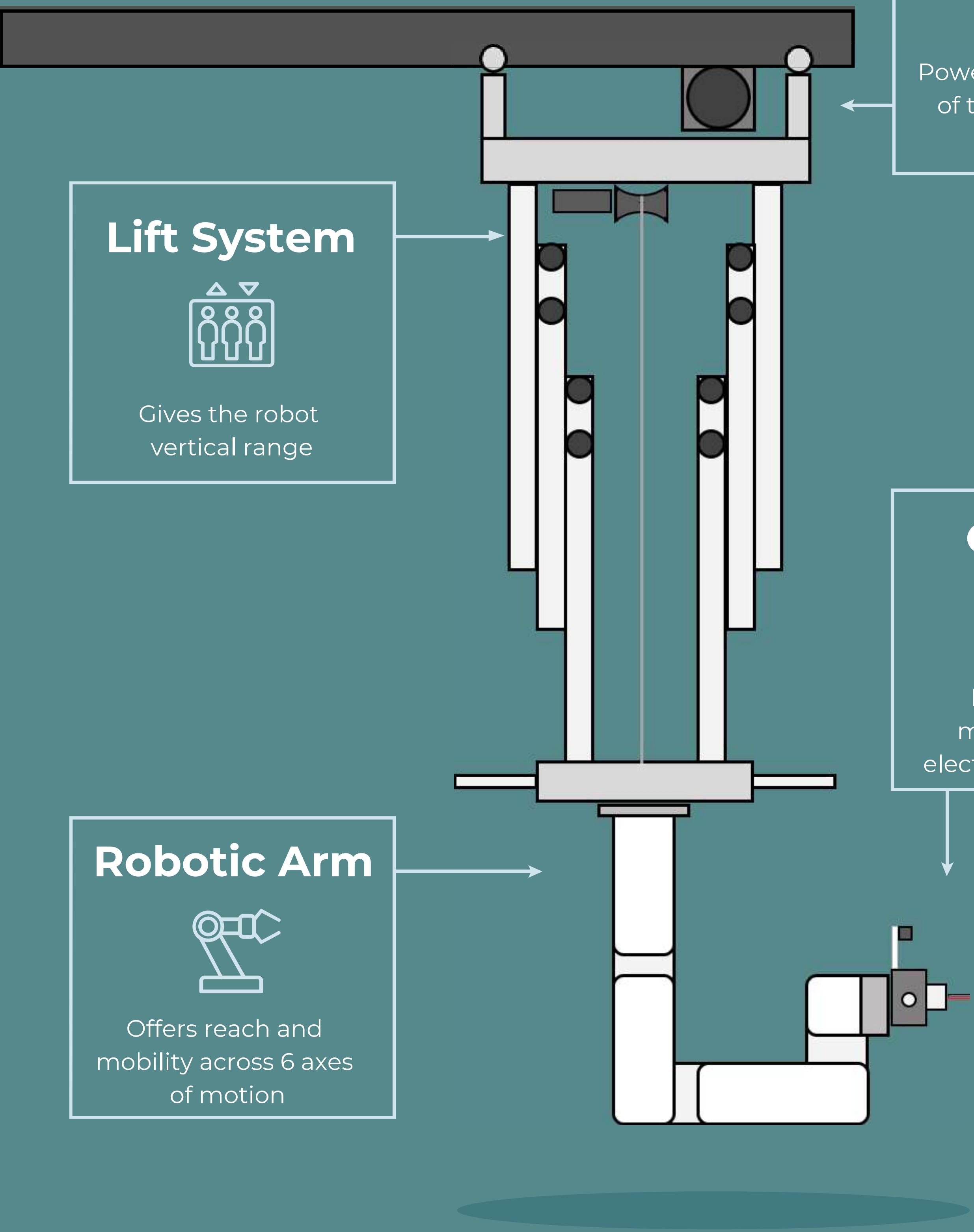


This robot will allow technicians to diagnose a problem in a turbine from afar, so that when they are flown in to the turbine, they know exactly what the issue is, and have brought the correct replacement parts and tools with them. This reduces the technician's time inside the turbine diagnosing the issue, the number of trips to the site, the dangers of the work environment, and means that the turbines can be available for more time overall to produce clean energy.

The robot needs to be able to traverse the turbine "nacelle" (the housing that holds important electrical components to turn the kinetic wind energy into electricity), and go to various electrical cabinets.

This is done via rail infrastructure and a friction-based **drive system**. The robot can access the entirety of an electrical cabinet with its vertical **lift system** and a **six-axis robotic arm**. The robot can interact with components both mechanically and electrically through a **gripper** attachment that contains a camera, multimeter probes, a cabinet key, and an electromagnet. A camera allows for remote vision capability. The multi-meter probes are located on the ends of gripper pads, which actuate between less than half an inch to over six inches wide. This actuation allows the user to probe terminals of varying sizes, alongside a Fluke 87 multi-meter control mechanism. These pads also allow the gripper to grab onto things, such as the emergency stop button of the turbine. The key and electromagnet are for opening the electrical cabinet doors to testing the electronics within.

Project Overview



Drive System

Powers the movement of the robot around the turbine

Lift System

Gives the robot vertical range

Gripper

Interacts with mechanical and electrical components

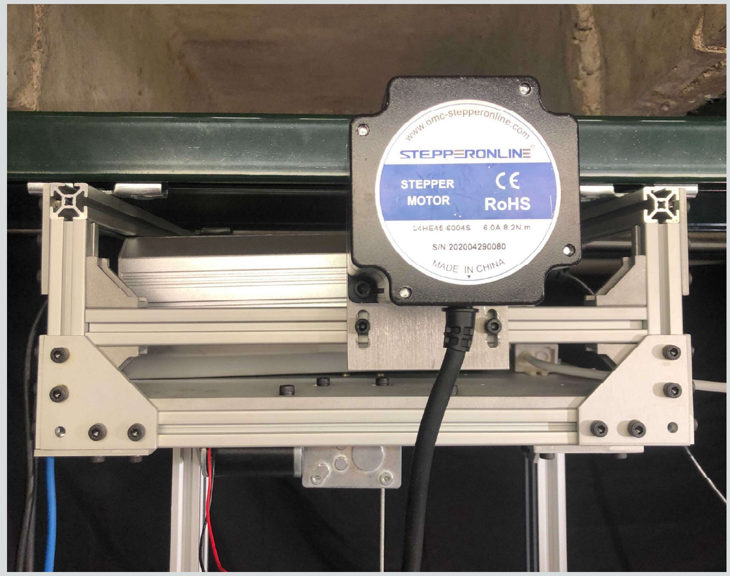
Robotic Arm

Offers reach and mobility across 6 axes of motion

Project Subsystems

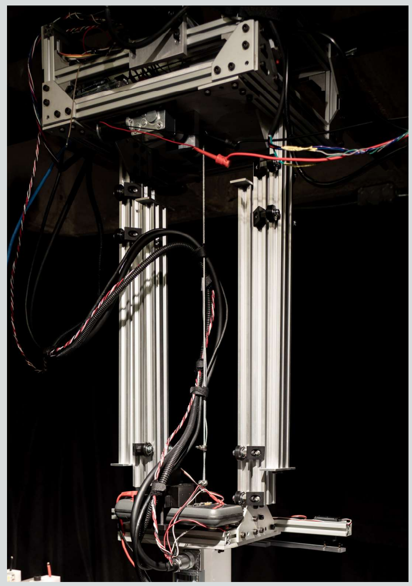
Drive System

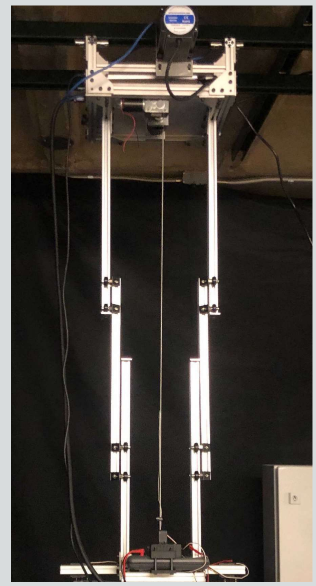
The drive system allows the robot to travel though the turbine using a high-torque motor and skateboard wheel. This presses against a Unistrut rail, and drives the robot via friction. Parallel rails offer support and stability to the robot, which is suspended via four rolling trolleys. Power cords are managed via a festoon-style structure, to be pushed or pulled as the robot drives.



Lift System

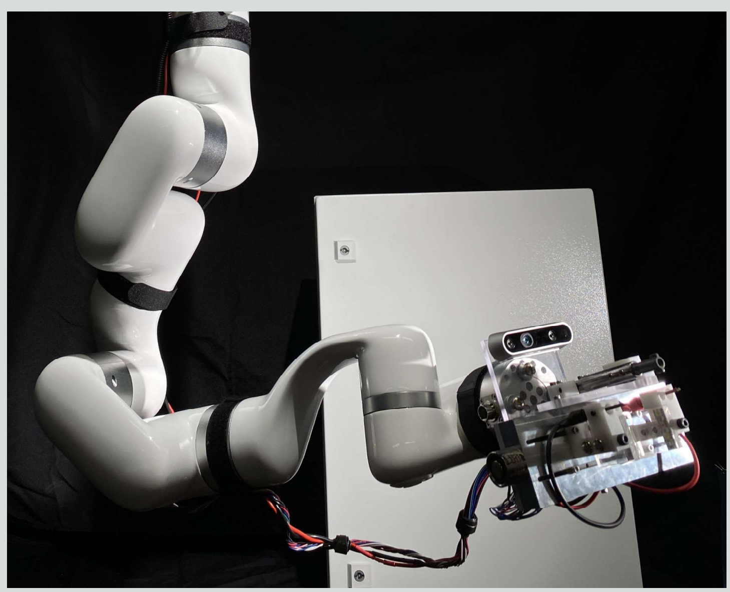
The lift system offers vertical translation to reach across 6 foot cabinets via two sets of three tiers of 2040 rail, and a motor, spool, and cable. This provides stability, limits weight, and maximizes reliability against binding. By raising the lower platform and door-blocking system, the robot can keep the doors of the electrical cabinet open, allowing the gripper to probe unhindered.





Robotic Arm

The xArm 6 robotic arm allows for the precise range and control of the overall robot, with repeatable accuracy within 0.1 mm, a net reach of 700mm, and 6 degrees of freedom. The arm allows for versatility and adaptability of the robot, and houses the gripper via its payload capacity of 5kg. It also has its own user interface, motion control software, and supporting software development kits.



Project Subsystems Continued

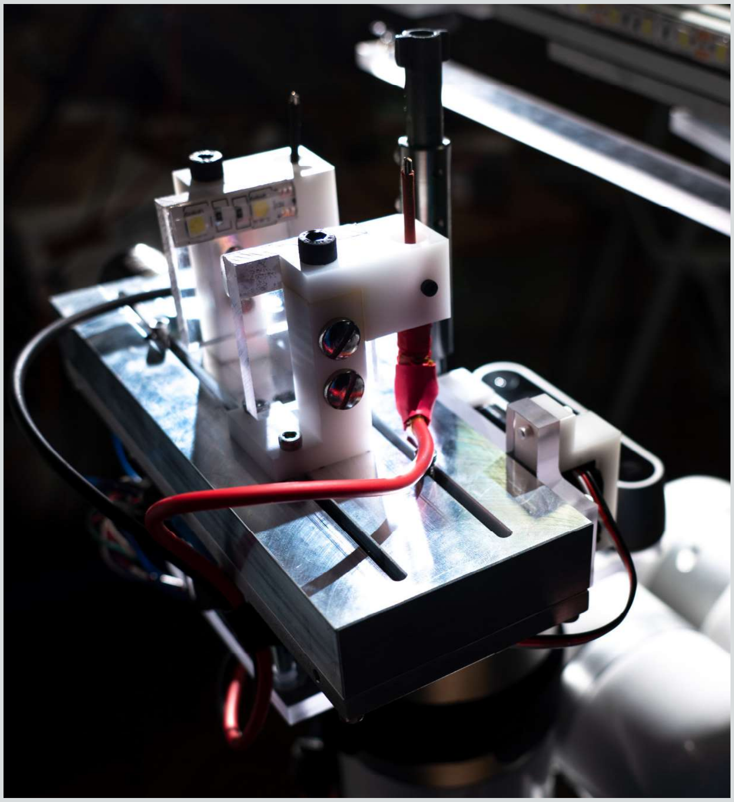
Software and Electronics

The electronics are powered from a 120 Volt AC power outlet. A remote user controls the robot by connecting to a Raspberry Pi, which communicates with the Explorer 16/32 development board and two printed circuit boards (PCBs). These PCBs contain the power converters control circuits and connections for all electronics on the robot (all motors, wheel encoder, color sensor, lasers, electromagnet, humidity and temperature sensor, LED strip, push pull solenoids).

In terms of software, the robot is built primarily in C++, Python, and Robotic Operating System. The software integrates and controls all the subsystems, including the arm, drive system, lift system, gripper, and electronics. For the remote user to operate the robot, they first connect to the Raspberry Pi via Virtual Network Connection. Once connected, the Graphical User Interface, which was made with the program QtCreator, provides video live feed views to look between, and data from sensors to control the robot. The program Gazebo is used to simulate the xArm virtually, and ensure the off-the-shelf control scheme is working properly. ROS is used to translate the game-controller, and send inputs for refined movement.

Gripper System

The gripper mechanism accomplishes critical functions such as unlocking the cabinet doors, electrical probing, actuating the emergency stop, and providing visual feedback to the user. The use of an Intel RealSense camera and pinpoint lasers allow the user to precisely navigate with positional awareness of all components. Probes and pads are actuated via a rack-and-pinion and stepper motor, and allow for electrical measurements via the multimeter, and interaction with any necessary components.



Project Outcome

Since this project is a proof-of-concept prototype for developers at Siemens Gamesa, its success was largely measured by demonstrating functionality against set performance requirements.

Requirement	Outcome
Navigation To traverse the nacelle and access all cabinets	Successful via the drive and rail systems
Vision For a user to control the robot remotely	Successful via the gripper system, and software & electronics
Voltage Voltage measurements to diagnose electronics	Successful via the gripper system and Fluke 87 mechanism
Doors Un/lock, and open/close of cabinet doors for access	Successful via the gripper system and key & electromagnet
Reach To access any electrical ports necessary	Successful via the arm gripper system, and lift system
Report Give necessary data to the remote user	Successful via the electronics and software
Actuation To activate the emergency stop	Successful via the gripper and drive system
Remote Controlled with software by an off-site user	Partially successful via the software. Full integration and control was not achieved.

Future Work

As a prototype, there are many ways that this project could be developed further given more time and resources. We considered a number of options, and have listed several here:

1. **Designing** the **rail** and **drive systems** for the **Demag rails** that are currently mounted within Siemens Gamesa wind turbines. Since we could not obtain this rail for our project, the drive system is designed around two parallel Unistrut rails. In the future, this system would be custom developed for the existing turbine infrastructure.

2. **Integrating microcontrollers** to the **Printed Circuit Board (PCB)**. This addition would divide the computational workload between a parent and child microcontroller, enabling the system to handle a larger software load and additional sensors and electronics. This combination would improve user awareness, and better support their control of the robot.

3. **Upgrading** the **multimeter** to **export data values**. Currently, voltage measurements are reported to the user via a camera that faces the multimeter screen. However, high-end multimeters can export data values as a spreadsheet file. This would allow data gathering to be automated to direct export rather than manual reading and input.

4. **Further building** the **Graphical User Interface (GUI)**. Currently, the GUI is built in C++ and Python, but its aesthetics and functionality could be improved using C# and JavaScript. These languages would accommodate enhancements such as adding capability for turning subsystems on/off, more sensors, and a multi-angle camera display.

5. **Traversing** the turbine with a **wheeled** or **treaded version** of the robot. The robot could improve its mobility by traversing the nacelle on wheels or treads like a remote-control car, rather than a rail system, since it would not be limited to the path of the built-in rail. This would involve other obstacles like traction against the swaying of the turbine, and climbing stairs.

Meet the Team

Jillian Weber
Logistics Manager
Jillian.Weber@colorado.edu

Vishwa Chandrasekar
CAD Engineer
Vishwamoorti.Chandrasekar@colorado.edu

Jack Plantz
Project Manager
Jack.Plantz@colorado.edu

Quintin Cook
Manufacturing Engineer
Quintin.Cook@colorado.edu









Daniel Jin
Software Engineer
Daniel.Jin@colorado.edu

Alex Hein
Financial Manager
Alexander.Hein@colorado.edu

Jackson Dixon
Test Engineer
Jackson.Dixon@colorado.edu

Sofia Springer
Electrical Manufacturing Engineer
Sofia.Springer@colorado.edu

Garret Pierson
Systems Engineer
Garrett.Pierson@colorado.edu

Acknowledgements

Team 9 would like to acknowledge and express our gratitude to the many people who have guided and supported us through every step of our project.

First, we would like to thank **Jeff Elberling**, **Danny Sale**, and **Ryan Reynolds** from Siemens Gamesa Renewable Energy, as well as **Riley Kenyon**, for the invaluable opportunity to partner with them on this project, and their guidance and mentorship.

We would also like to thank the Design Center faculty and staff, **Daria Kotys-Schwartz**, **Julie Steinbrenner**, **Victoria Lanaghan**, **Shirley Chessman**, **Lauren Wheeler**, **Greg Potts**, and **Chase Logsdon**, for their limitless hard work, resources, and dedication to us, and all of their students.

Finally, we would like to thank our staff director **Pat Maguire** for his insight, dedication, encouragement, and phenomenal enthusiasm that he offered every one of us throughout the entirety of our project.