National Science Foundation (NSF)
Research Experiences for Teachers (RET) Site
RET Site: Integrating data-driven research in Renewable Energy Across Disciplines (I-READ)
Texas A&M University-Kingsville

June 12, 2023 to July 21, 2023

Research Project List

Project #1: Solar Radiation Big Data Analysis to Increase the Efficiency of Organic Solar Cell

Faculty Advisor: Dr. Mohammad Motaher Hossain, Mechanical and Industrial Engineering

***i. Motivation*:** Organic/polymer solar cells (PSCs) or organic photovoltaic (OPV) technology have attracted considerable attention in recent years due to their potential for low-cost solar energy harvesting and ease of fabrication, as well as applications in flexible, light-weight, transparent and multicolor devices. However, the power conversion efficiency (PCE) of PSCs is still relatively low compared to their inorganic counterparts. Introducing texture on the surface could increase the efficiency of PSCs by minimizing reflection and maximizing absorption of incident sunlight through multiple internal reflections. It could also improve the self-cleaning capability by enhancing the hydrophobic properties, which can improve the solar cell efficiency in the long run. The research question is: "How to employ the solar radiation big data to increase the sunlight absorption by introducing texture on polymer surface?"

***ii. Project Description*:** The research objective is to design an optimal surface texture, by employing the solar radiation big data available at the National Renewable Energy Laboratory (NREL), to maximize the solar energy absorption, and investigate the self-cleaning capability of textured surfaces. By introducing nano- and/or micro-texture on the surface, sunlight absorption and, therefore, the efficiency of the solar cells have shown to increase significantly in both inorganic and organic solar cells. However, most of these studies employed ideal/hypothetical scenarios of sunlight incidence. By using selective light absorption technique, PSC efficiency can be increased while maintaining sufficient transparency. The following tasks will be performed: 1) Using the 30 year monthly average solar radiation data of South Texas along with the solar position and intensity (SOLPOS) calculator available on NREL websites, sunlight incidence on the roof and windows, based on a house plan, orientation and location, will be calculated using Excel or MATLAB. 2) A MATLAB based Graphical User Interface (GUI) will be developed to calculate light absorption with variation in texture size and shape, incident wavelengths and angles, and material and optical properties. By considering multiple internal reflections, optical simulations will be performed to obtain light absorption in textured surfaces for two scenarios: *S1*) all incident wavelengths can be absorbed (roof applications), and *S2*) all wavelengths except visible wavelengths can be absorbed, i.e., selective transmission (for window applications). 3) Fabricate micro-textured polymer surfaces using hot embossing or 3-D printing and perform contact angle measurement.

***iii. Participant Component*:** Two RET participants will work together in this project to collect necessary data from NREL websites, import the raw data into Excel and MATLAB, clean up the raw data, and develop MATLAB GUI for S1 and S2 scenarios. They will also fabricate micro-textured samples to study the improvement in hydrophobicity based on the contact angle measurement of textured surfaces.

Project #2: Dynamic Visualization of Wave Energy Big Data for Discovering Its Behavior
Faculty Advisor: Dr. Hua Li, Mechanical and Industrial Engineering

***i. Motivation*:** Wave energy harvesting has lagged significantly when compared to other renewable energy sources. One of the fundamental problems is the lack of in-depth understanding of wave energy behavior in different locations. Wave energy has significant spatial and temporal variation in nature, creating complex data that is considered difficult to visualize and analyze using traditional methods, such as static maps. The research question is: "How should the wave energy big data be visualized to accurately capture and analyze its spatial and temporal variation for discovering its behavior?"

***ii. Project Description*:** The research objective is to develop a dynamic visualization method by integrating computer animation and geographic information systems (GIS) for conducting exploratory and explanatory analysis on wave energy related meteorological data. The research tasks include: 1) Huge meteorological data, including wave height, wave period, and wind speed for every three hours in the last 30 years in the Gulf of Mexico, will be collected from WaveWatch III system. 2) An open source based Generic Mapping toolbox in MATLAB will be used to manipulate the cleaned raw data through the application of mapping package. Since each static map only shows one three-hour period, the dynamic visualization, which will help understanding wave energy behavior better, will be achieved through the representation of successive sequential layers of data on the same screen using animation function in MATLAB. 3) A MATLAB 3D matrix algorithm, which uses computational implied loop functionality that is much faster than explicit loops and requires much less computing resources, will be used to calculate wave power density using cleaned raw data. The results will be simultaneously animated with other factors on the same screen to discover patterns that each factor is creating and how they influence each other.

***iii. Participant Component*:** Two RET participants will collect necessary data from WaveWatch III system, learn to import the raw data into Excel and MATLAB, and clean up the raw data. They will learn to use computer animation and GIS toolboxes in MATLAB to visualize the processed raw data. RET participants will also work together to calculate wave power density using MATLAB, and to create a GUI to animate different factors on the same screen for exploratory and explanatory analysis purposes.

Project #3: Effect of Daylighting on Students' Learning and Classroom Electricity Consumption
Faculty Advisor: Dr. Hui Shen, Civil and Architectural Engineering

***i. Motivation*:** In the past few decades, daylighting has gained increasing importance as the immediate exploitation of solar energy in buildings for energy savings. Psychologically, the presence of controlled daylight positively impacts the overall attitude and well-being of occupants. However, little scientific data exists on students' learning efficiency under different daylighting levels to enhance learning experience. The research question is: "How and to what extent daylighting affects students' learning efficiency and how much electricity can be saved *via* daylighting in the classrooms?"

***ii. Project Description*:** The research objective of this project is to measure the effect of daylighting on students' learning efficiency, correlate it with classroom electricity consumption, and estimate annual electricity savings of a typical educational building. The following tasks will be performed: 1) The RET participants will use their teaching experience to design activities that are easy to implement and straightforward to reflect students' learning experience. Multiple metrics will be defined or selected from existing literature to evaluate students' learning efficiency. A questionnaire will be developed to collect participating students' information and feedback about the designed activities, lighting environment, daylighting level, etc. after each test. 2) Repeated tests will be performed under different daylighting levels in classrooms. A group of at least 20 TAMUK students will be recruited to conduct the designed activities under different scenarios: daylight with no electric light, strong daylight with low electric light, weak daylight with strong electric light, and no daylight. Three types of data will be collected for each

test: metrics of learning efficiency, amount of daylight, and questionnaire feedback. 3) The collected data will first go through an identification process to determine the preferred lighting level. The presence of daylight will be correlated with students' learning efficiency. Meanwhile, transmitted daylight through windows will be correlated with the light level on work plane to formulate an equation for electric lighting energy simulation. The annual electricity savings from daylight utilization of a typical educational building will be estimated, considering optimal learning efficiency. To ensure its completion within the summer program, Dr. Shen will complete the IRB approval and student recruitment before the summer program starts.

***iii. Participant Component*:** Two RET participants will work in this project. They will first complete CITI training and be added into IRB protocol, and work together to: 1) design learning activities and conduct experiments, 2) define metrics of learning efficiency, 3) develop questionnaire, 4) analyze the effect of daylighting on learning efficiency, and 5) develop electricity consumption equations and estimate annual electricity savings from daylighting for a typical educational building.

Project #4: Study the Potential of Converting Food Waste into Renewable Energy in the Backyard

Faculty Advisor: Dr. Xiaoyu Liu, Civil and Architectural Engineering

***i. Motivation*:** Food waste accounts for about 14.5% of Municipal Solid Waste generation in the U.S., and up to 98% of which is discarded without recycling and recovering. Households account for the largest portion of food waste, and one person's food waste per year in the U.S. can provide enough renewable energy for powering a 100-watt light bulb for two weeks. However, majority of the existing studies and products on energy recovery from food waste focus on large-scale application, consumers' behavior, and policy, with little information available at the household level. Therefore, the research question is: "Is it feasible to recover energy from household food waste at the residential scale?"

***ii. Project Description*:** The research objective of this project is to study the potential of converting food waste into renewable energy in the backyard through experiments with different combinations of food waste types. The following tasks will be performed: 1) RET participants will derive the data on food waste from the consumer level of USDA Loss-adjusted Food Availability data series, and re-organize it with the household size and geographic region. A proper average daily food waste per household will be determined. 2) RET participants will study and define experimental scenarios covering food waste types with ingredients and household sizes. Experimental platforms will be developed, consisting of two main components (aerobic composting reactor and anaerobic digester) and three auxiliary components (pre-treatment module, energy recovery system, and biogas burner). The reaction residue after the active phase will be moved from composting reactor to the mixing chamber and then sent to an anaerobic digester. RET participants will investigate and determine key parameters for anaerobic process, including total solid content, carbon/nitrogen ratio, pH value and ambient temperature. 3) All the experimental data will be compiled based on the region and household size. Statistical analysis will be conducted to reveal the connections among the potential of food waste recovery, household size and region. Net Present Worth analysis will be applied to show the potential economic benefits of food waste recovery.

***iii. Participant Component*:** Two RET participants will be working together in this project to complete the following tasks: 1) determine the average daily food waste from existing documents, 2) prepare food waste for experiments, and 3) design and construction of experimental platforms. They will collaborate to develop experimental platforms, conduct the experiments, and analyze the data.

Project #5: Wind Farm Layout Study, Future Development, and Cost Analysis

Faculty Advisor: Dr. Kai Jin, Mechanical and Industrial Engineering

***i. Motivation*:** With the rapid growth of wind energy, the wake effects within a wind farm and between the neighboring wind farms have attracted considerable attention as they cause lower power output efficiency and higher cost of energy. Researchers estimated that wakes can extend more than 50 km downwind, resulting in significant economic losses. This project will investigate the impacts of wake effect on wind farm future development. The research question is: "How do the wake effects within a wind farm and between the neighboring wind farms affect the wind farm future development?"

***ii. Project Description*:** The research objective is to evaluate the impacts on the power output and cost of energy of a wind farm due to the wake effects caused within itself and by its neighboring wind farms. The research tasks include: 1) Data related to wind farms in Texas in the last 10 years will be collected from various sources, including wind farm locations, wind turbine characteristics, wind farm power generation, wind speeds, and wind directions. 2) The collected data will be imported into GIS software to create maps, which will be used to create time sequence based dynamic animation for exploratory analysis and calculation of distances between different wind farms. 3) Jensen wake model will be used to analyze wake effect within selected wind farm and its impacts on power output and energy cost by considering selective shutting down of wind turbines in the wind farm. 4) Change in wind speeds and directions caused by neighboring wind farms over 10 years will be analyzed using GIS software, which will then be used to estimate the impact caused by the upwind wind farms before and after they were built.

***iii. Participant Component*:** Two RET participants will work together in this project. They will collect data from available resources, learn to process the raw data in Excel, and visualize the processed data using GIS software. RET participants will learn to use Jensen wake model to analyze the impact of wake effects within a wind farm, and use GIS software to analyze the changes in wind speeds and directions.