Project ID: 351

Senior Division

Physics and Astronomy

Rohan Badal
University City High School
Gr. 11

Optical Flow-based Thruster Control for Asteroid Landers

AWARDS:

San Diego Astronomy Association - Senior Division 2nd Place

BACKGROUND: Several recent lunar and asteroid landers have failed to soft land on their targets. The challenges to soft landing arise out of several reasons including 1) a lack of dense atmosphere that precludes use of parachutes, 2) a negligible gravity makes it difficult for the lander to orient itself relative to the target, 3) remote control or telemetry lags and high speeds may be too limiting to allow control from earth. Solution may lie in using visual input-based navigation and onboard computations to control the landers landing approach to the moon or the asteroids.
HYPOTHESIS: It is possible to train a Convolution Neural Network (CNN) to trigger a thruster with >90% accuracy to compensate for its motion based on Optical Flow (OF) computed from video sequences that show 1) accelerating approach, 2) Decelerating approach, 3) constant-rate or steady approach, and 4) fixed distance but rotating clockwise/anticlockwise approach.
METHODS (DATA): I captured a total of 20 video recordings of a textured wall or floor using a camera, when the camera is approaching it at a steady rate, accelerating, decelerating, and rotating at a fixed distance from it. I used 6 sets of videos to train the CNN and five to test.
METHODS (PROCEDURE): 1) Identified 20x20 (Total 400) evenly spaced points on each frame to track 2) repeatedly calculate Optical Flow using Lucas-Kanade Algorithm on these points. 3) The computed flow vectors were used to train a CNN such that in the accelerating case, the CNN outputs 1 with increasing frequency, in slowing videos the CNN outputs 1 with decreasing frequency, and outputs 1 at a fixed rate in steady approach. In the rotation at fixed distance case, it does not output 1 at all.
RESULTS: The CNN produced the correct output in 98% of the cases on the test video data.
CONCLUSIONS: CNN in conjunction with a Optical Flow computer on a video stream can be used to control a thruster for controlled descent on the moon or asteroid.

Project ID: 352

Senior Division

Physics and Astronomy

Vikramaditya Chandra

San Marcos High School

Gr. 11

Astronomical Image Deconvolution Using a Novel Deep CNN Architecture with Minimal Artifacts

AWARDS:

Armed Forces Communications Electronics Association (AFCEA) Senior Division Winner

San Diego Astronomy Association - Senior Division 1st Place

CSEF Qualified

Image Deconvolution refers to estimating the PSF (Point. Spread. Function) to reverse the Convolution applied to an Image. Common deconvolution algorithms such as Richardson-Lucy and Statistical Deconvolution introduce unwanted artifacts into the reconstructed image. Many deep-learning models have been proposed to limit artifacts and restore the original image. However, the reconstructed images continue to have various artifacts. In this paper, we propose a Novel Convolutional Neural Network (CNN) Architecture tailored for image deconvolution and the restoration of astronomical images. The proposed architectural layout allows for a network that can be retrained for various datasets and yields images with minimal artifacts. Extensive experimentation on various model architectures applied to Hubble Images retrieved from the Hubble Legacy Archive proves the superiority of the proposed architecture as compared to other existing architectures.

Project ID: 353

Senior Division

Physics and Astronomy

Trevor Chen
Westview High School
Gr. 11

Enabling Ultra-Broadband High-Efficiency Gratings for High-Power Infrared Single-Cycle Lasers

AWARDS:

DRS Daylight Solutions Award for Optical Physics and Engineering - Senior Division
Office of Naval Research - Senior Division Winner
Society of American Military Engineers - San Diego Post - Senior Division Winner

Ultrafast technology has been awarded three Nobel Prizes with one to chirped pulse amplification, where the laser beam diffracts eight times through 4 gratings. Current grating fabrication introduces considerable errors and grating degradation, especially true for infrared gratings with limited substrates and coatings. Recently, I have designed an ultra-broadband high-efficiency mid-infrared (MIR) grating to support MIR single-cycle lasers, the shortest MIR pulse possible. A global optimization over 8 parameters is used to achieve diffraction efficiency > 90% and bandwidth > 65%. A novel method of electron-beam lithography (EBL) combined with anisotropic wet etching (AWE) is used to fabricate the grating with nanometer precision. The tested efficiency is 92%, close to designed efficiency 94.2%. A "double blazing"feature is discovered to further enhance grating efficiency and bandwidth. Compared with MIR gratings developed so far using traditional fabrication methods such as mechanical ruling and holographic recording, the grating I have developed is the only grating meeting both efficiency and bandwidth requirements for the single-cycle MIR lasers. Finally, I have extended the design from mid IR to both near IR and long IR. Overall, the 8-parameter globally optimized design with "double blazing" combined with fabrication of EBL and AWE has been proved to be a reliable way to make high-performance gratings in the entire IR region. These IR gratings will accelerate development of single-cycle IR lasers for crucial research such as nuclear fusion and high-power laser weapons in the atmospheric window.

Project ID: 354

Senior Division

Physics and Astronomy

Jennifer Chen

Canyon Crest Academy

Gr. 10

Gate Rescheduling for Quantum Circuit Error Mitigation on IBM Quantum Computers

Classical computing is nearing its developmental limit. In places where classical computing fails, quantum computers can succeed. One obstacle that continues to suppress quantum computing's advancement is quantum noise, mainly caused by environmental decoherence or gate errors. This study seeks to minimize the error rate of quantum circuits by analyzing which logic gates have the least amount of errors, and then ordering them such that the error carried over is minimized. The hypothesis is that there is always noise on quantum computers, but quantum noise is minimized when logic gates are put in a specific order. Create two circuits with the same output for a different order of logic gates on the IBM quantum composer. Theoretically prove that these two circuits have the same function. Run these circuits in shots of 5000 on two machines. Run different circuits and calculate the error rates. Analyze the error rate and how it relates to the ordering of the circuit. The Belem machine had greater error, with Circuit 1's error being 21.66% and Circuit 2's error being 5.22%. Overall, the error from the Lima machine was negligible. Although Circuits 1 and 2 have the same function, they have different error rates due to the ordering of their logic gates. Circuit 1 has a higher error rate than Circuit 2. This is because the C-NOT gate's error is significantly higher than the Hadamard gate on the Belem machine. In Circuit 1, the C-NOT gate is the first logic gate, which propagates the errors.

Project ID: 355

Senior Division

Physics and Astronomy

Jeremy Feng
The Bishop's School
Gr. 11

Matthew Ni
Canyon Crest Academy
Gr. 11

A High-Resolution Gamma Ray Detector for Positron Emission Tomography Using Liquid Xenon

AWARDS:

CSEF Qualified

Positron Emission Tomography (PET) is a process widely used in the medical industry that assists in diagnosing diseases by producing 3D images of the body. This project seeks to improve upon existing PET scans by using silicon photomultipliers (SiPMs) coupled with Liquid Xenon (LXe) as a detector medium, allowing for a lower dosage of radiation needed for the patient and making the detection a safer and more efficient process.

We utilize Monte Carlo simulations and the engineering design process to prototype and design a LXe PET module that incorporates techniques originally developed for dark matter neutrino detection. By improving upon detection efficiency for photons and electrons generated in the module, we compare our design metrics with industry standards to evaluate our design's feasibility.

With our prototype design, a nearly 100% detection efficiency for electrons created in the LXe module can be realized. From simulation, we estimate a light collection rate of 56 -78% when comparing different reflectivities of the module boundary. Combining these detection efficiencies, we estimate that 2.1% FWHM (full width at half maximum) energy resolution for 511 keV gamma rays can be obtained, which is five times more efficient compared to ~10% in the existing industry standard PET imagers.

This design significantly improve the energy detection compared to existing industry standards. We recommend to develop this technology in a lab and implement it into the the medical imaging field in the future.

Project ID: 356

Senior Division

Physics and Astronomy

Nandana Madhukara

Canyon Crest Academy

Gr. 11

Analyzing the Effects of Higher-Order Terms in the Nonlinear Dynamics of Galactic Systems

AWARDS:

San Diego Astronomy Association - Senior Division 1st Place

One of the most famous models of motion of stars around a galactic center is the Henon-Heiles System. Originally created by Michel Henon and Carl Heiles, the system was used to study integrals of motion but due to its simple yet complicated nature, it has become a paradigm of dynamical systems. It is one of the canonical examples of chaotic dynamics.

Lots of modifications have been made to this system since its inception. One class of such changes is expanding the system to a higher order. The original system is a third order expansion of a general axisymmetric potential and researchers have expanded this to higher orders. These additional terms make the system a more accurate model of the stars. In this project, we expand the system to the seventh order and for the first time, keep individual parameters for the fifth and seventh order terms. This allows us to separately analyze how the higher order terms affect the dynamics, specifically the chaotic dynamics of the system.

Project ID: 357

Senior Division

Physics and Astronomy

Krish Mandadi

Canyon Crest Academy

Gr. 11

Developing Novel Spectral Unmixing Technique for Stellar Spectroscopy Using Artificial Intelligence

AWARDS:

San Diego Astronomy Association - Senior Division 2nd Place

Spectroscopy is one of the most useful methods used to investigate diverse properties of celestial objects. By developing a machine learning model that can differentiate between different elements of light-emitting objects before scientific analysis, the speed of research and analysis can be increased significantly. Can an artificial intelligence classification model be created to more accurately predict the major components of stellar spectra compared to a standard linear unmixing model? I hypothesize that utilizing a Support Vector Classifier model will allow more accurate predictions of spectra composition compared to current mathematical models.

Project ID: 358

Senior Division

Physics and Astronomy

Rachel Susan

Mission Vista High School

Gr. 9

Our Effect on Light Pollution

Light bulbs have a big effect on our environment, in addition to this they also have a big impact on light pollution. To conduct this experiment, I tested to see if different types of light bulbs would affect light pollution, also known as skyglow. My hypothesis is "will LED light bulbs travel further compared to incandescent light bulbs?" In addition I wondered, when LED lights are in clusters, does the light travel further? I hypothesized that LEDs will have a stronger effect on the amount of light produced. My independent variable in this experiment is the type of light bulb used but also the amount of light bulbs used. My dependent variables were the brightness generated judged by how far it can be seen by 63.5cm. To conduct my experiment, I plugged in 2 sets of light bulbs (1 pair of LED and 1 pair of incandescent), to see how small things such as lamp poles can affect light pollution. I measured the lux from certain distances in 12.7cm increments, up until I measured the light 63.5cm away. According to my data, LED light bulbs were still brighter than incandescent light bulbs, proving my hypothesis correct. In my data, when measuring 63.5cm away from 2 LED light bulbs, it ended up being a stronger beam of light than the Incandescent Bulbs. (70lx vs 60lx). To further improve my experiment, I'd consider testing how colours impact these brightnesses.