Space Science and Engineering Workforce Development at UNLV

Ke-Xun Sun, Daniel Valdes, Brandon Munguia,
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Kayla De Soto, and Alfredo Garzona

University of Nevada, Las Vegas (UNLV)

CubeSat Developer Workshop 2023

UNLV

Space Science and Engineering Workforce Development at UNLV

University of Nevada, Las Vegas is developing a program for training space science and engineering workforce for future Nevada space industry via research in CubeSats. We have both laboratory and curriculum activities. Our laboratories currently support several senior design teams, involving more than ten undergraduate and graduate students. Our research and development are in quantum space science instruments, optical imaging, laser ranging, MPU control using Android environment, CubeSat structure, space construction, and ground testing platforms. Noteworthy progress has been made in the development of the onboard cameras and lidar, which have been successfully integrated into CubeSats to provide critical sensory information for operations. We have also developed 12 degree of freedom CubeSat test platforms. In curriculum development, we have developed four undergraduate and graduate courses: Space Systems, Space Sensors and Instruments, Spacecraft and Payload Engineering, and Quantum Space Science. Most of these courses include both lectures and laboratory projects. The student course reports have been presented at aerospace conferences and will lead to a series of publications. Many students are from underrepresented groups. We will present our progresses at CDW 2023. This program is supported by Nevada Space Grant and University of Nevada, Las Vegas.

NASA / Nevada Space Grant Curriculum Development Program

- **Space Sensors and Instruments**

  (EE416/ECG616, offered Summer 2021)
- **Space Systems**

  (ECG716, offered Summer 2022)
- **Spacecraft and Payload Engineering**

  (EE415/ECG615, offered Fall 2022)
- **Introduction to Quantum Space Science**

  (EE411/ECG611, being offered Spring 2023)

Courses have mixed lectures and lab sessions

UNLV

EE416 / ECG616 Space Sensors and Instrument

Course Topics

- Frontiers of astrophysical and space science
  - Gravitational waves
  - Gamma ray and X-ray
  - Cosmic microwave
  - Solar observation
  - Exoplanet search
  - Earth observation
  - Microgravity
- Optical sensors
  - Semiconductor theory
  - Semiconductor photovoltaic and photocurrent sensors
  - Photoelectron sensors
  - Spectrometers
  - Radiometry
  - Signal to noise ratio
  - Radiation hardness
- Radiation sensors
  - X-ray and gamma ray sensors
  - Charged particle detector
  - Detector modeling
- Telescopes
  - Telescope design
  - Multi element telescope design
- Interferometry
  - Spacecraft scale interferometry
  - Formation flight interferometry
- Remote sensing
  - Microwave sensors
  - Synthetic aperture
- Gravitation reference sensor
  - Electrostatic sensing
  - Optical sensing
  - Disturbance reduction
- Spacecraft and payload design
  - Orbital, altitude and attitude sensing and control
  - Optical payload design
  - Microwave and optical communication links
- Constellation flight
  - Space gravitational wave detection
  - Navigation
  - Space internet
- Mission examples
  - CubeSats
  - ISS
  - Hubble, SNAP & JWST
  - TESS & Kepler
  - GRACE & GOCE
  - LTP & LISA
  - GPS and navigation formation flights

Textbooks

"Spacecraft Sensors" by Mohamed Abid
Wiley 2006. ISBN-13: 978-0470865279

"Space Physics: An Introduction" by C. T. Russell, J. G. Luhmann, R. J. Strangeway
Cambridge University Press (2016) ISBN-13: 978-1107098824

"Space Mission Engineering: The New SMAD" Eds. By James Wertz, David Everett and Jeffrey Puschell, Microcosm Press (2011) ISBN-13: 978-1881883159

"Optical Payloads for Space Missions" Eds. By Shen-En Qian
Wiley 2017. ISBN-13: 978-1118945148

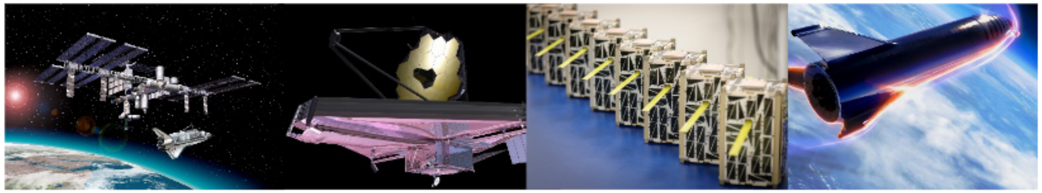
ECG716 Space Systems

ECG716 (New)

Space Systems

Summer III, July 11- August 12, 2022
Mondays, Tuesdays, Wednesdays, 4:15 pm – 6:45 pm, Remote Learning

Professor Ke-Xun Sun
Department of Electrical and Computer Engineering
Please email Ke-Xun.Sun@unlv.edu to request instructor permission



New Undergraduate and Graduate Courses for Training Future Advanced Workforce in Space Science and Engineering

Space is an open frontier for human. Space industry is a substantial and growing part of US economy, but yet in Nevada. To train the future Nevada workforce in space and engineering, we are developing a systematic curriculum. We welcome participation from all undergraduate and graduate students, including students from underserved and underrepresented groups. We are recruiting a GA in teaching and research. (The effort is jointly supported by Nevada Space Grant and UNLV.)

Course Contents

Space systems and spacecraft design overview. Subsystems such as bus, payload, communication, navigation, power, attitude control, propulsion, protection, and ground operations. Space qualification. Spacecraft assembly and verification. Constellation flights with multiple spacecraft. CubeSats. Mission studies. Emphasize optical, microwave, and radiation investigations. Applications in remote sensing, earth observation, high precision flights, space quantum links.

EE415/ECG615 Spacecraft and Payload Engineering

EE415 / ECG615 (New)

Trial offered as EE495/ECG695-1002 Fall 2023

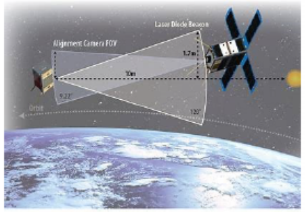
Spacecraft and Payload Engineering

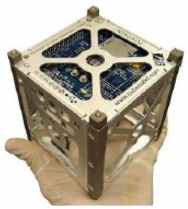
Hybrid In-Lab and Remote Learning

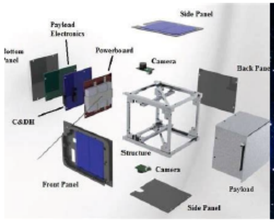
Tuesdays 5:30 pm – 8:00 pm Lectures, Thursdays 5:30 pm- 8:00 pm Labs

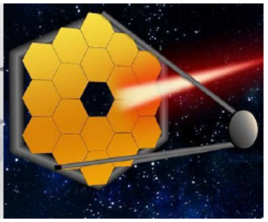
Professor Ke-Xun Sun

Department of Electrical and Computer Engineering









Cultivating Space Engineers in Classroom and Laboratory

The special topics course expands classroom lectures into laboratory projects. Lectures will be on both general space engineering principles and specific techniques as needed in the flight projects. The laboratory activities will be on system and subsystem design, hands-on building, programming, testing flight hardware such as power system, avionics, optical sensors, interfaces, satellite structure. Ground simulation using platforms created by UNLV previous course work. Students are engaged in large team projects and be encouraged to deliver on time. Students will meet with the instructor and work in both lectures and laboratory regularly.

Course Catalog Data

Mixed classroom and laboratory sessions on spacecraft and payload engineering. Space system design overview. Multi degrees of freedom ground test platform. Optical and vision sensors. Avionics. Computer control for rendezvous and proximity (RPO) operation. Mechanisms for space construction. Simultaneous Location and Mapping (SLAM). Flexible constellation flight. Quantum payloads in space.

3 Lecture credits.1 Lab credit.

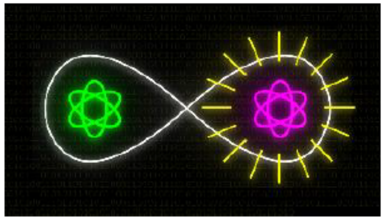
EE411/ECG611 Intro. Quantum Space Science

EE495/ECG695-1003 (upcoming EE411/ECG611)

Special Topics in Quantum Space Science

Spring 2023, Lab & Lecture Hybrid Learning
Tuesdays 5:30 pm- 8:00 pm Lecture (TBE B178) & Laboratory (TBE B311)
Thursdays 5:30 pm – 8:00 pm Laboratory (TBE B311)

Professor Ke-Xun Sun
Department of Electrical and Computer Engineering



A New Undergraduate and Graduate Course for Space Science

Earth is surrounded and impacted by space. Understanding space science and utilizing the immensity of space will greatly facilitate human life. In 2022, Nobel Physics Prize was awarded to Clauser, Aspect and Zeilinger for quantum entanglement experiments, and explicitly mentioned quantum satellite, which distributed quantum key from space to two continents, and realized secure quantum communications over 7,000 km. The future long distance secure communication is being shaped in space. Every communication engineer should know about these latest developments.

In the first offering in Spring 2023, the course will include an introduction to quantum mechanics and electromagnetics, thus self-contained. Please email Ke-Xun.Sun@unlv.edu for instructor permission --- if you have not taken EE310 Principle of "Solid State and Optoelectronics" and/or EE330 "Engineering Electromagnetics"

Course Contents

Review of mechanics, quantum mechanics, electromagnetics, and optics. Survey of space environment, spacetime, special relativity, general relativity, gravitational wave. Space experimental verifications. Applications to GPS navigation. Entangled photons and space distribution for secure communication. Space quantum links. Projects on science payload instruments. Hybrid remote and in person sessions.

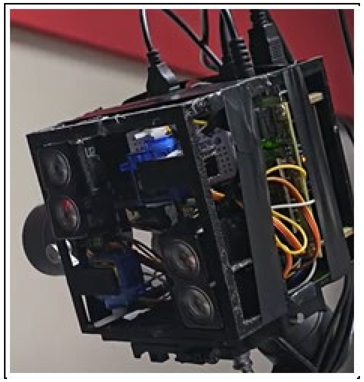
Mixed remote lectures & in-person lab sessions. 3 credits. Including 1 lab credit.

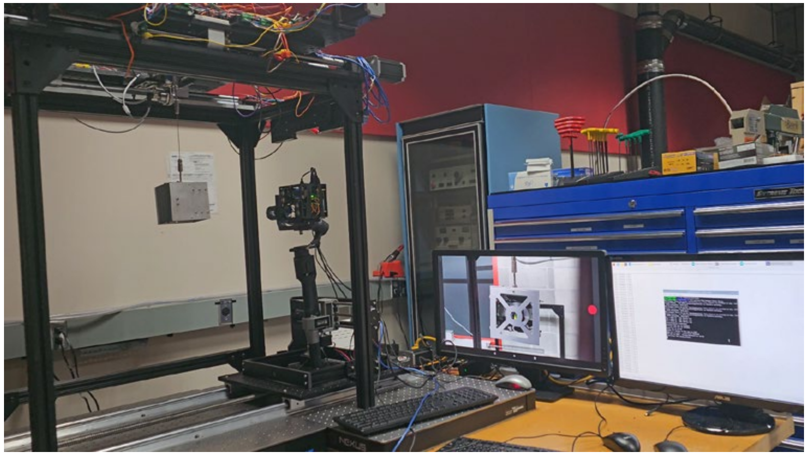
Students Participation

- 16 Undergraduate and Graduate Students
- Most students are from under represented groups
- Multi discipline academic background:
  - Electrical Engineering
  - Computer Engineering
  - Computer Science
  - Mechanical Engineering

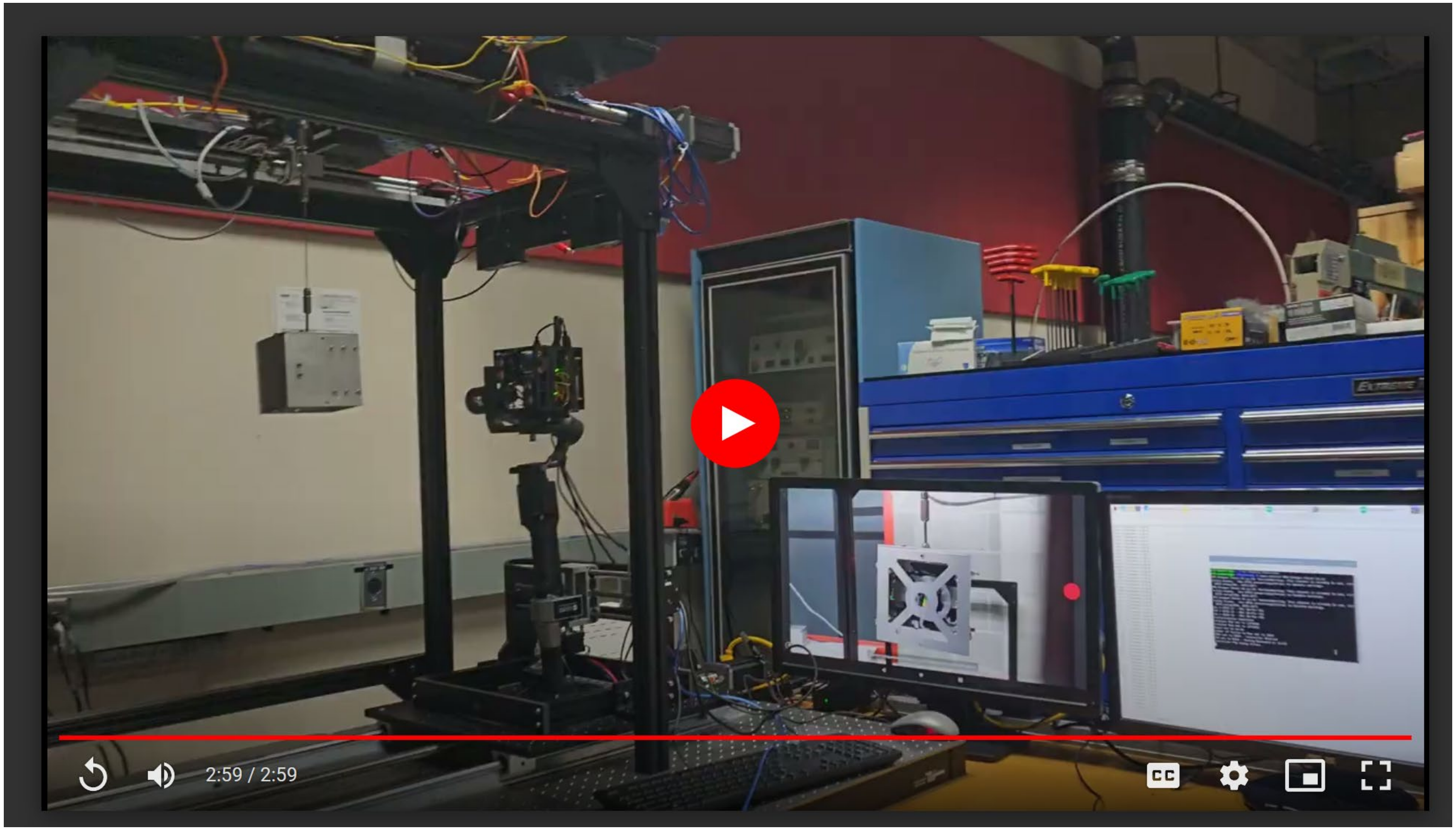
Outstanding Achievements

- CubeSat Test Platforms
  - Version 0: 6 DOF (translation and angular motions)
  - Version 1: 12 DOF for constellation testing
  - Version 2: Suspended microgravity platform
- Snapdragon SBC programming
  - Optical sensing
  - Motion control
- Optical Imaging and Tracking
- LiDAR distance measurement
- Release / Reassembly mechanism
- Power electronics

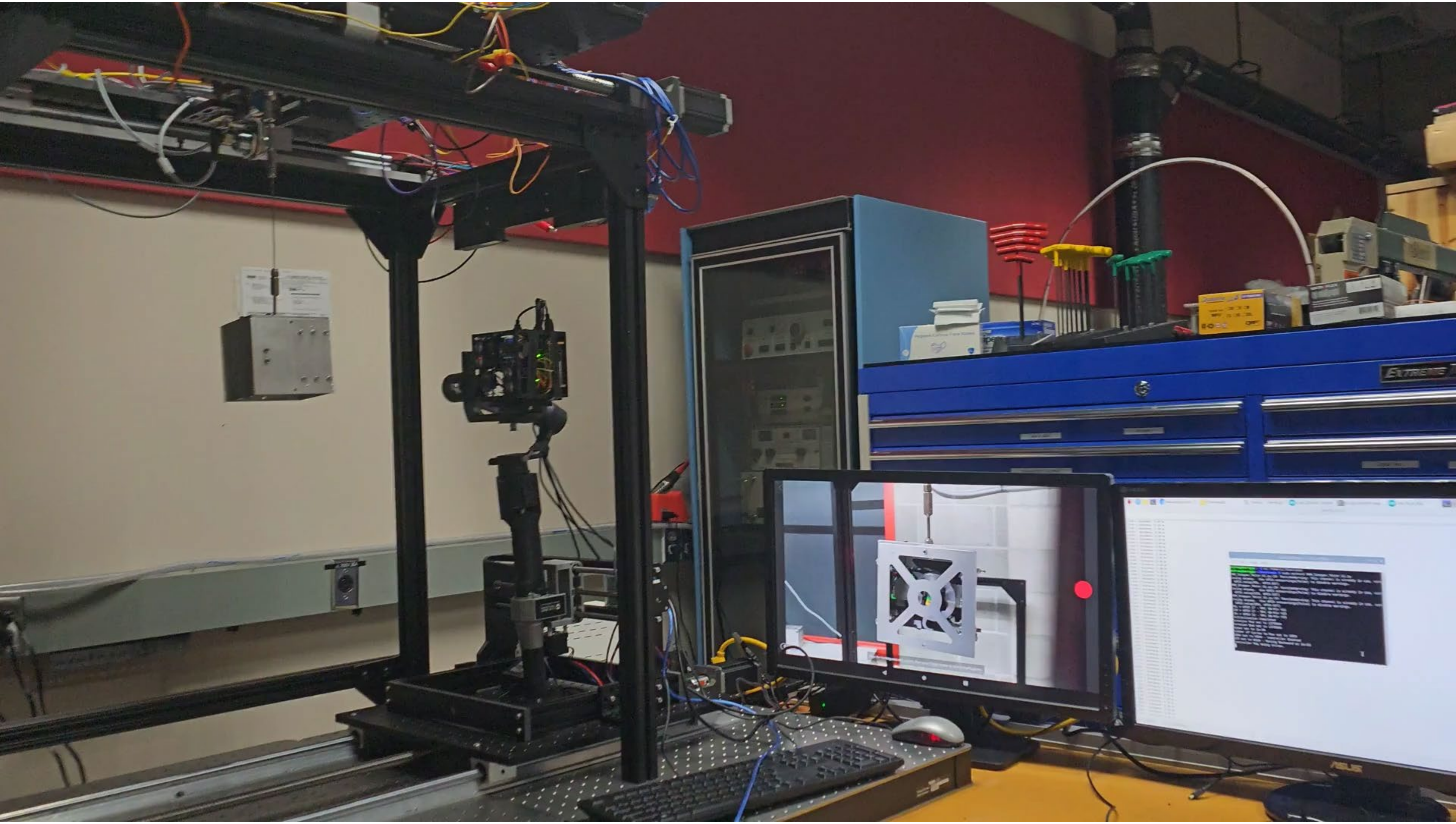




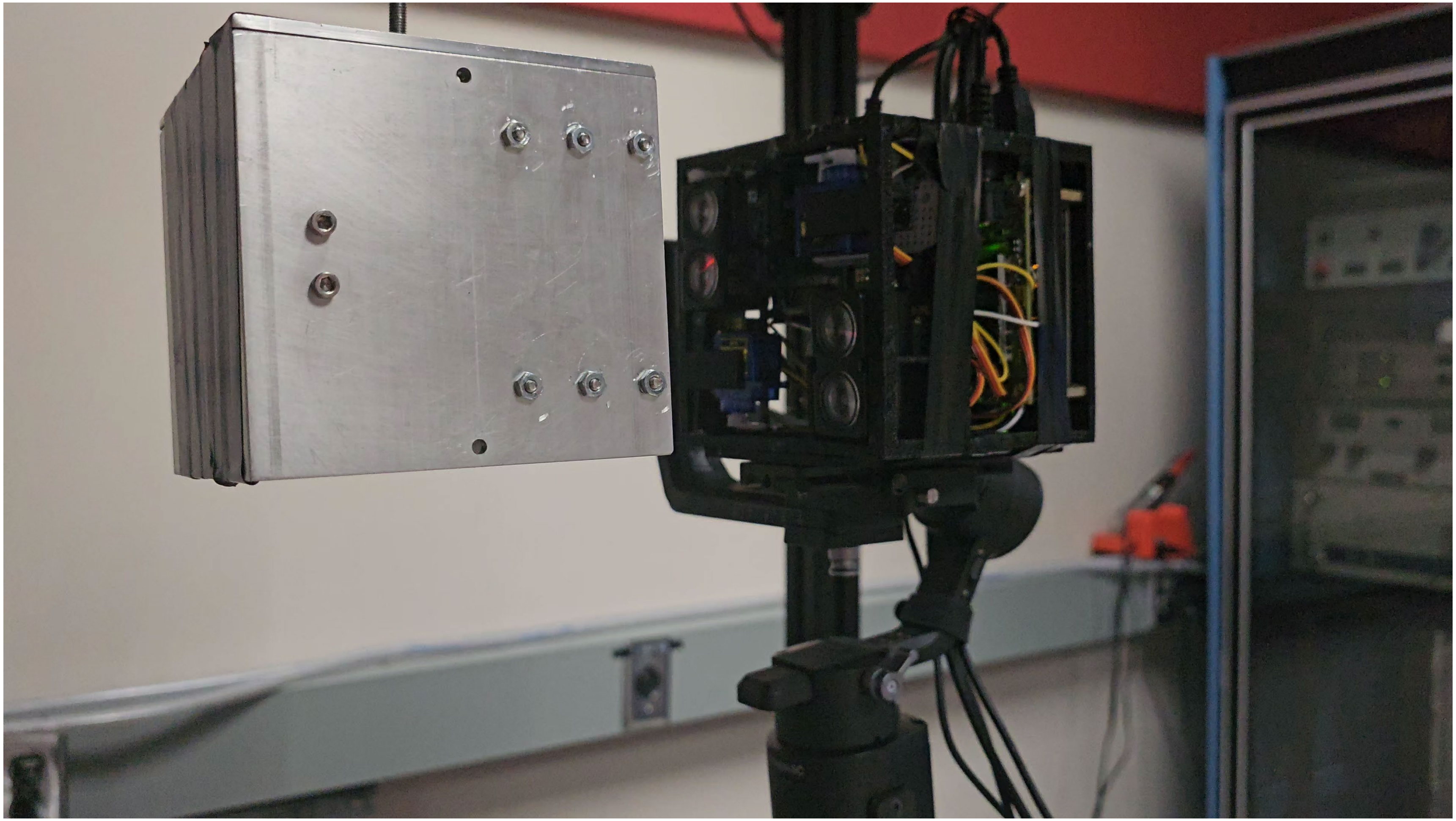
Optical Imaging and CubeSat Tracking



Optical Imaging and CubeSat Tracking



Closed Proximity Release / Reassembly for CubeSat Constellation Flight



Constellation Cube Satellite Avionic Systems Test Platform

Daniel Valdes, Brandon Munguia, Kainoa Solidium, Ke-Xun Sun

University of Nevada, Las Vegas

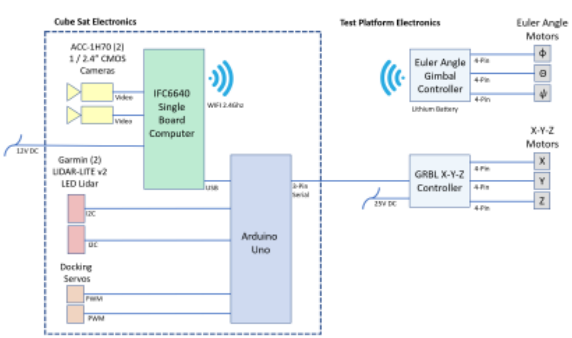
UNLV UNIVERSITY OF NEVADA LAS VEGAS

ABSTRACT

Constellation Cube Satellites require a wide suite of integrated avionic systems for constellation flight. By use of a Test Platform, critical segments can be developed, programmed, and physically tested individually on the ground before space flight. Optical systems including cameras and LIDAR are used as inputs to drive "navigational system" XYZ translation and Euler angle motors based on preprogrammed functions. Functional testing includes optical tracking, distance detection, navigational flight controls, and rendezvous docking sequencing. This work provides the University of Nevada Las Vegas with means to progress Cube Satellite research.

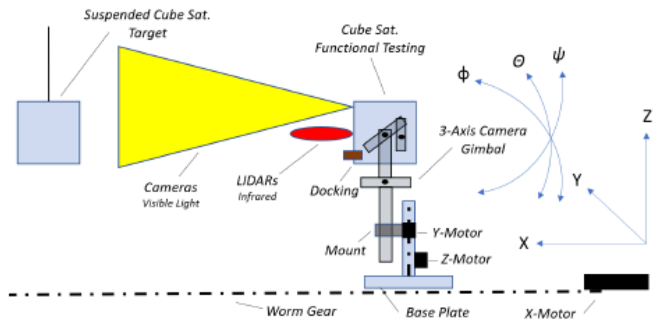
OBJECTIVES

- Single Board Computer – IFC 6640 (Linux, Android 9)
- Chassis Prototyping
- Optical Tracking
- LIDAR Distance Detection
- Arduino Interface
- 3-Axis Camera Gimbal Control
- XYZ – Translation Control
- Docking



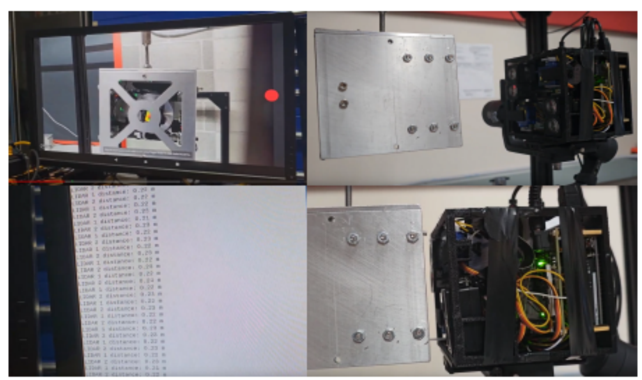
METHODS

The approach used to develop proof of concept systems are integrating working consumer systems. The XYZ translation motion is derived from a 3D printer assembly and a GRBL Controller. The Euler angle motion is provided by a 3-Axis camera gimbal and DJI Ronin Software. Central computer, IFC6640, handles image processing and interfaces to all systems on the Cube Satellite. An Arduino Uno is used to drive GRBL controllers.



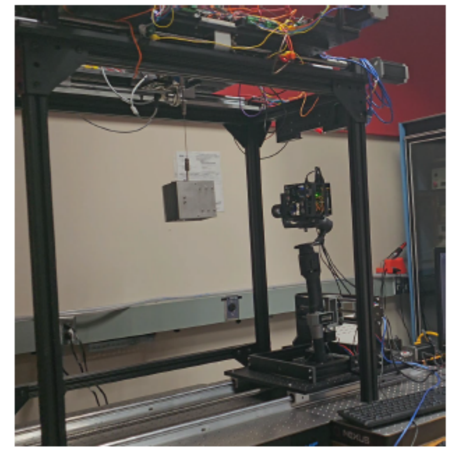
RESULTS

The team was successfully able to develop, program, and test all critical avionic systems collimating to a docking sequence with test mechanical servos. Successful tests of optical tracking and LIDAR distance detection have been achieved up to 2 meters. Successful docking sequencing has been observed at 100-millimeter LIDAR accuracy.



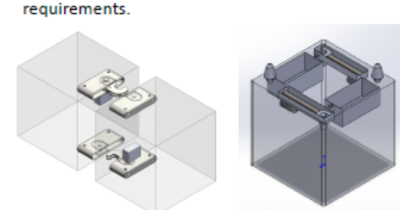
CONCLUSIONS

Further Cube Satellites developments are now possible at UNLV thanks to a functional integrated test platform. Further planed functionally include dual docking Cube Satellites and system specific calibration tests. Additional pieces of equipment, sensors, and systems will be easily integrated to current setup.



FUTURE

Integrated docking mechanisms will be the next system added to the test platform. This will require specific functional programming and reporting requirements.



ACKNOWLEDGEMENTS

NASA/Nevada Space Grant Curriculum Development

Optical Imaging, Object Tracking, and Motion Control Using a Snapdragon Single Board Computer on a CubeSat

Howard R. Hughes College of Engineering, Department of Electrical and Computer Engineering
Brandon Munguia Torres, Kainoa Solidum, Daniel Valdes, Dr. Ke-Xun Sun

ABSTRACT

CubeSat constellation flight can facilitate space quantum link experiment and multi-view space observations. Optical imaging, object tracking, and motion control are critical in CubeSat constellation formation and operation as well as Rendezvous Proximity Operations (RPO) and release / reassembly among CubeSats. These complex optical sensing and operations require substantial computing power onboard the CubeSat.

We have adopted a NASA-suggested Snapdragon Single Board Computer (SBC). We have identified and a matched camera. The system is running under Android operating system, allowing use of a variety of available software and hardware. In addition, an LED-based LiDAR was selected to measure the distance between CubeSats for more accurate RPO and release / reassembly operations. We have used a 3D printer to build a new prototype CubeSat to accommodate the SBC and all sensors.

For experimental demonstration, we mounted the CubeSat on our motorized 6-degree-of-freedom CubeSat test platform developed earlier in our lab. Another CubeSat is suspended on our microgravity test platform and set into swing motions. We successfully demonstrated high resolution optical imaging using the Snapdragon SBC and the onboard camera. We further demonstrated both angular and linear motion tracking of the swing object.

We have made important progresses in developing CubeSat constellation flight, space quantum links, and multi-view space observations.

This work is supported by NASA/Nevada Space Grant.

PROJECT GOALS

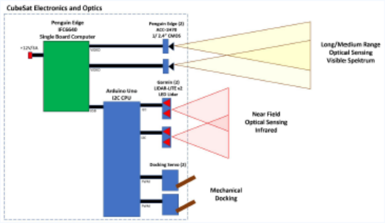
- Utilize only Commercial Off-The-Shelf (COTS) Components
- Rely solely on IFC6640 Single Board Computer (SBC) for data processing
  - Optical imaging
  - Object tracking
  - Motion control
- Fit optical system to meet 1U requirements (10cm x 10cm x 10cm)

COMPONENTS

- Penguin Solutions IFC6640 SBC
- Penguin Solutions ACC-1H70 Camera Modules
- Garmin LIDAR-LITE v4 LED
- Arduino UNO REV3

METHODOLOGY

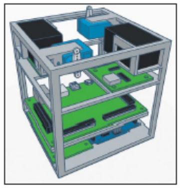
A simple PCB was constructed to run power and signal to the docking motors and LIDAR modules to the same location, limiting the number of wires and points of connection required within the CubeSat. The pushbutton to test the motors is simply to check proper motor function. Engagement of the docking system is contained within the same code to run the two LIDAR modules. The ACC-1H70 camera modules are connected to the IFC6640 with 41-pin ribbon cables supplied by the manufacturer.

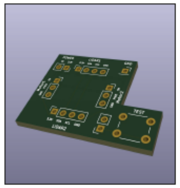


For testing and ease of application, the motors and LIDAR modules are currently connected to an Arduino, with the LIDAR verifying and supporting data collected from the camera modules.

The IFC6640 came from the manufacturer with the Android 4 operating system, however preliminary testing proved this system to be limited and insufficient. Android 9 was flashed onto the board for programming, enabling the construction and downloading of programs required for the CubeSat's optical sensing capabilities, including the software necessary for the CubeSat to communicate with the gimbal to perform object tracking in its current state.

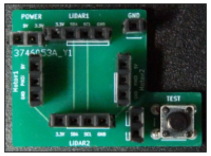
While initially testing the SBCs ability to perform object tracking via connection to the Gimbal stabilizer, it was found that the system required a nearly complete CubeSat chassis to be sturdy enough for accurate data acquisition. To combat this, a preliminary chassis design was developed to contain each of the optical system's components for testing purposes.



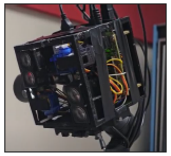


** Design solely for testing purposes.

RESULTS

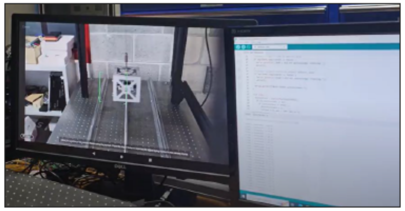


PCB for LIDAR and servo motor connections



Close-up of optical system in 3D printed cube

Pictured above is the setup of the CubeSat mounted on the gimbal. Below displays the tracking software (left) and the LIDAR readings (right).



CONCLUSIONS

The IFC6640 is a powerful SBC that is more than capable of performing optical sensing. Experimental successes in optical imaging, object tracking, and motion control prove the IFC6640 to be a viable option to supply the processing power necessary for safe and successful Rendezvous Proximity Operations, and docking / undocking procedures. Use of single board computers in CubeSat applications will prove vital in continuing research developments.

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CubeSat Constellation Release/Reassembly

Angelo Alberto, Kayla De Soto, Alfredo Garzona, and Ke-Xun Sun

Department of Mechanical Engineering and Department of Electrical and Computer Engineering, University of Nevada Las Vegas

Abstract

CubeSat constellation flight will facilitate many astrophysical missions, such as inter-satellite quantum link experiments, and multi-view asteroid observations. CubeSats can be deployed as an assembly into the targe space region, then be released into a constellation. CubeSats can be reassembled again into one module after completing inter-CubeSats experiments or distributed observation, and then be redeployed for next experimental and observational tasks.

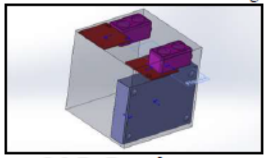
We are developing CubeSat release / reassembly mechanisms for this exciting goal. Two designs have been investigated as to make CubeSat constellation deployment possible. The first design is a vertical mechanism while the second design is a horizontal mechanism. These configurations will accommodate various payload configurations, and leave room for optical sensing instruments.

Design Goals

- Meet 1U CubeSAT Requirements
  - Must fit within 10cm x 10cm x 10cm Envelope
- Lock two 1U units together w/o power consumption
  - Incorporate Dual Gender/Genderless system to enable versatile CubeSAT
- Provide error compensation in the event of misalignment during docking sequence
  - Develop self-alignment design permitting up to 0.25" misalignment
- Withstand Anticipated Loads in Practical Application
  - Anticipated load is 10 kgf in tension pulling two units apart
  - Design to FOS 2.0 on loaded parts
- Fit Around Necessary Electronic Sensors and Cameras
  - Packaging study completed using geometry data from electronics/optics team
  - Design leaves maximum space in center of unit for payload

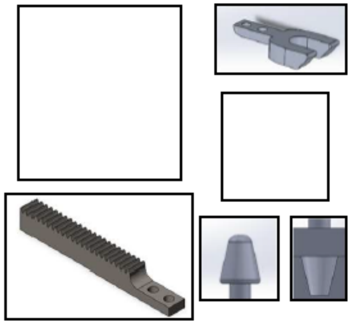
Initial Packaging Analysis

Initial packaging analysis revealed the amount of volume optic and electronic components occupied and helped set a constraint on available volume for the release/reassembly mechanism. After performing packaging analysis, the space available for docking was determined to be 2cm away from the edge of the CubeSat face with depth to be determined by mechanical mechanism chosen for the design



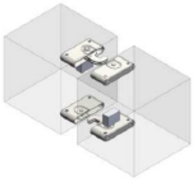
CAD Designs

Horizontal Clamping Design



Design Feature	Benefit of Design
Worm Gear	• Transforms Rotational Motion to Linear Motion in Rack • Can't drive rack while locking servomotor in case rack pushes back • Utilizes common profiles easily available off the shelf
Rack	• Receives input from worm gear to actuate U-Clamp • Can't drive servomotor as worm gear acts as lock • Utilizes common geometry available off the shelf
Male Pin/Female Receptacle	• Compensates for error in alignment during docking sequence • Receives U-Clamp to lock CubeSat units together
U-Clamp	• Clamps on to base of Male Pin to Lock Cube Sat units together • Ramped Tips allow for successful docking despite pins not being fully seated • Simple mechanism easily fabricated

Vertical Sliding Hook Design



Design Feature	Benefit of Design/Feature
Hook	• Locks two CubeSats together • Driven by Riding Pin • Easily fabricated simple design • Self-aligning along one axis
Cam	• Shaft w/ eccentric cutout for servomotor enables custom designed motion • Protruding profiles allows for Rotational and Linear motion in riding pin which is mounted to hook
Riding Pin	• Converts rotation of cam to linear and rotational motion of hook • Not available off the shelf, but easily fabricated

Future Work

The designs shown above are in the midst of fabrication via 3d printing. Once designs have been printed, they will be mounted in a CubeSat alongside electrical and optical equipment for live testing of the docking procedure. This testing will involve the use of the lab's internally developed microgravity test bench For testing, both designs will be 3d printed and tested on the team's microgravity test bench. On this test bench is where the limits of the error correcting features of both designs will be fully evaluated.

Conclusion

The horizontal clamp design and vertical sliding hook design are promising mechanisms that will enable new developments in miniaturized space experimentation. Both designs successfully meet goals of fitting in a 1U unit and fit in the space available when packaged with electronic sensors and cameras. Both designs also feature genderless components so that any two 1U units can reassemble to each other. Design goals of permitted error compensation and reliability in surviving loading scenario will be verified in the testing phase.

Power Electronics for CubeSAT Constellation Flight

Sam Ramey, Dr. Ke-Xun Sun
Department of Electrical and Computer Engineering
University of Nevada, Las Vegas

Abstract

CubeSat constellation flight will facilitate many astrophysical missions, such as inter-satellite quantum link experiments and multi-view asteroid observations. CubeSats can be deployed as an assembly into the targe space region, then be released into a constellation. CubeSats can be reassembled again into one module after completing inter-CubeSats experiments or distributed observation, and then be redeployed for next experimental and observational tasks.

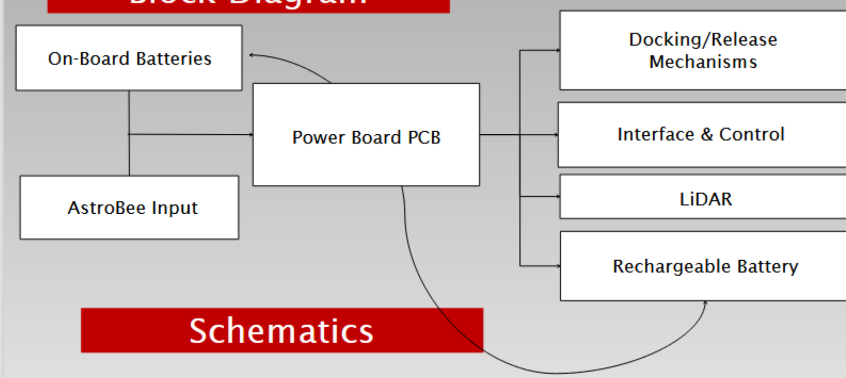
Research Objectives

- Power Electronics for the CubeSAT Constellation Flight will operate with a 2W/5V power input and feature multiple USB-style outputs.
- Outputs will support on-board electronics such as dual-motor control support for docking relays/release mechanisms, and LiDAR.
- Recharging of on-board power supply in a reliable manner

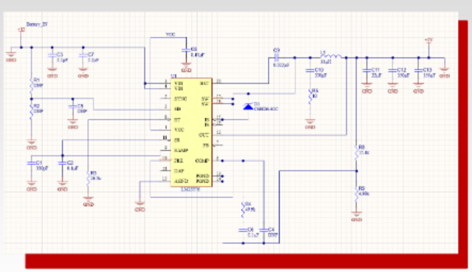
Methods

- Operational using 2W/5V power source
- Included protection circuit w/LED notification of blown fuse
- USB outputs for dual-motors, Optics, & LiDAR
- Two alternative power inputs were designed
    - Rechargeable Li-Ion batteries
    - Recharging using NASA AstroBee flying robotic system during docking

Block Diagram

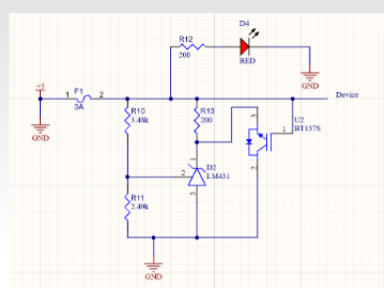


Schematics



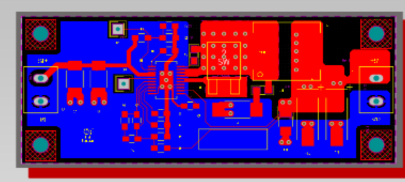
Power Schematic

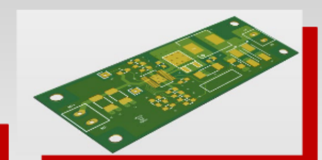
Protection Schematic



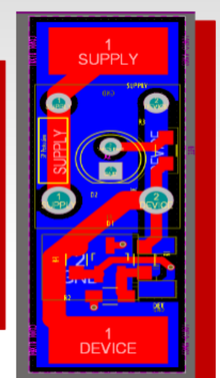
PCB

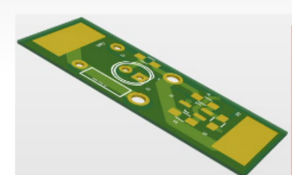
Power PCB





Protection PCB





HOWARD R. HUGHES
COLLEGE OF ENGINEERING

Achievements and Outlook

- Developed a set of undergraduate and graduate space science and engineering courses
- Attracted students from multi disciplinary academic background and diversified groups
- Substantial progress in CubeSat constellation flight
- Aiming quantum science space missions