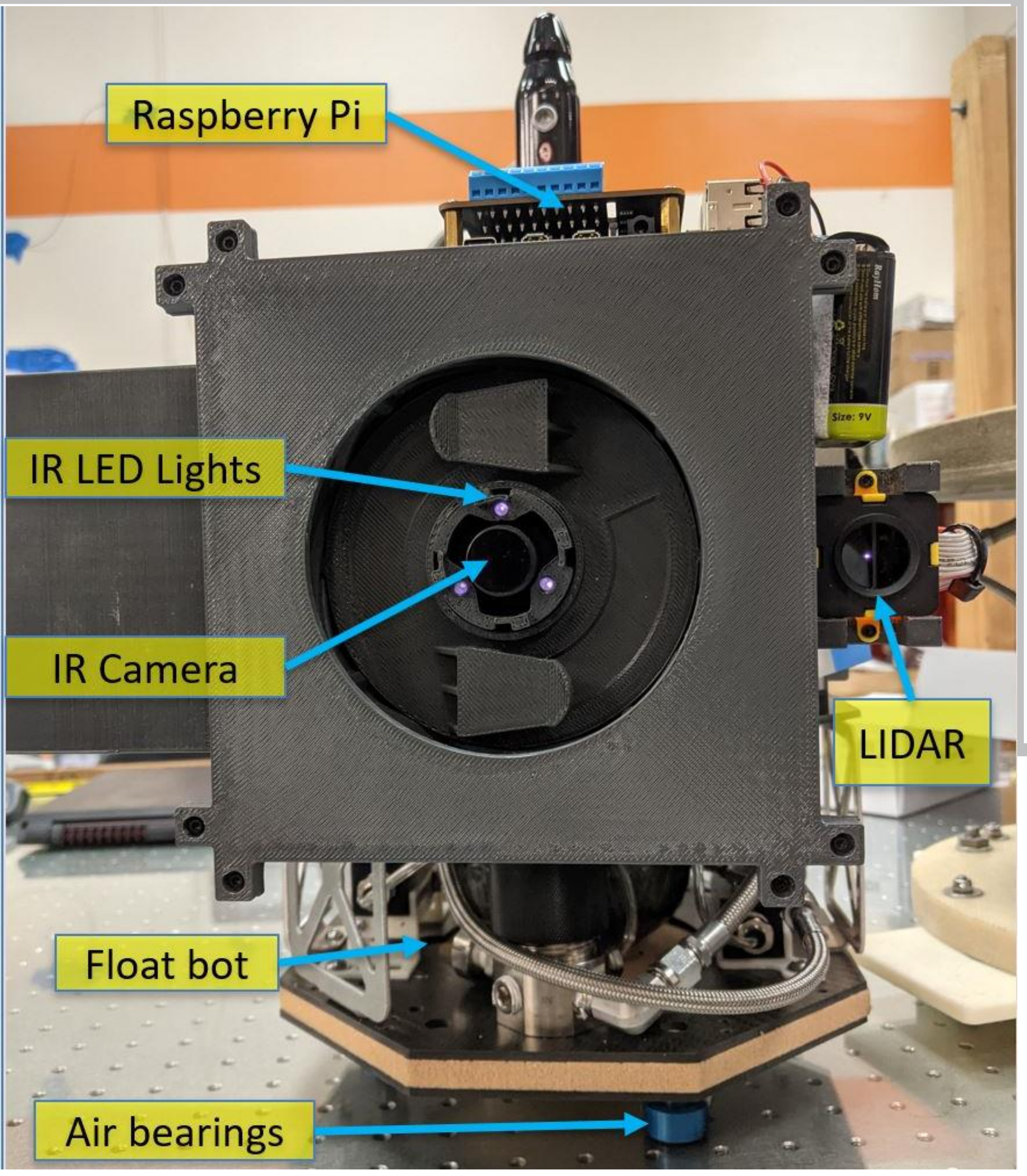
SWARMS - CLING

Principal Investigator: Adarsh Rajguru (355); Co-Investigators: James Smith (355), Bruno Quadrelli (347), David Barnhart (University of Southern California)

Program: FY21 SURP **Strategic Focus Area: Multi-robot Teams and In-Space Assembly**

Project Objective

Our objective is to combine technologies and capabilities for laying the foundation of adaptive reconfigurable monolithic and distributed space platforms. The team investigated techniques and architectures that allow physical aggregation / disaggregation, with realizable structural connections, and developed ubiquitous “rendezvous” methodologies that enable any type of swarm space elements to function safely. Our goals were to develop a standalone autonomous docking system for small satellites, develop the operational capabilities of a suite of Rendezvous Proximity Operations (RPO) sensors to aid with bearing and range knowledge for instructing the host and acquire capability for the product to transfer power, data and fluids across the docking interface. Our long term goal is to develop a flight qualified robust and reliable docking and undocking mechanism. The capabilities for CubeSats to enable more and more challenging science missions are quickly growing. The combination of these technologies and capabilities will provide a set of baseline designs and infrastructure that will enable a range of science-driven applications as well as place JPL strategically to be ready to effectively respond and win proposals as CubeSat opportunities are rolled out by NASA SMD.



Brief Background:

CLING stands for Compliant, Low Profile, Independent, Non-protruding and Genderless. It is intended for small satellites. It has approximately 8 degrees of-nominal compliance between mating surfaces and fits inside a 10 cm x 10 cm profile within a 0.5U volume. Current breadboard prototype has a 17 cm x 17 cm profile using hobby parts such as Arduino MEGA. It takes advantage of LED triangulation to align the host (satellites / CubeSats). We transitioned to the use of TriDAR for higher accuracy and reliability (LIDAR with IR Camera for target acquisition).

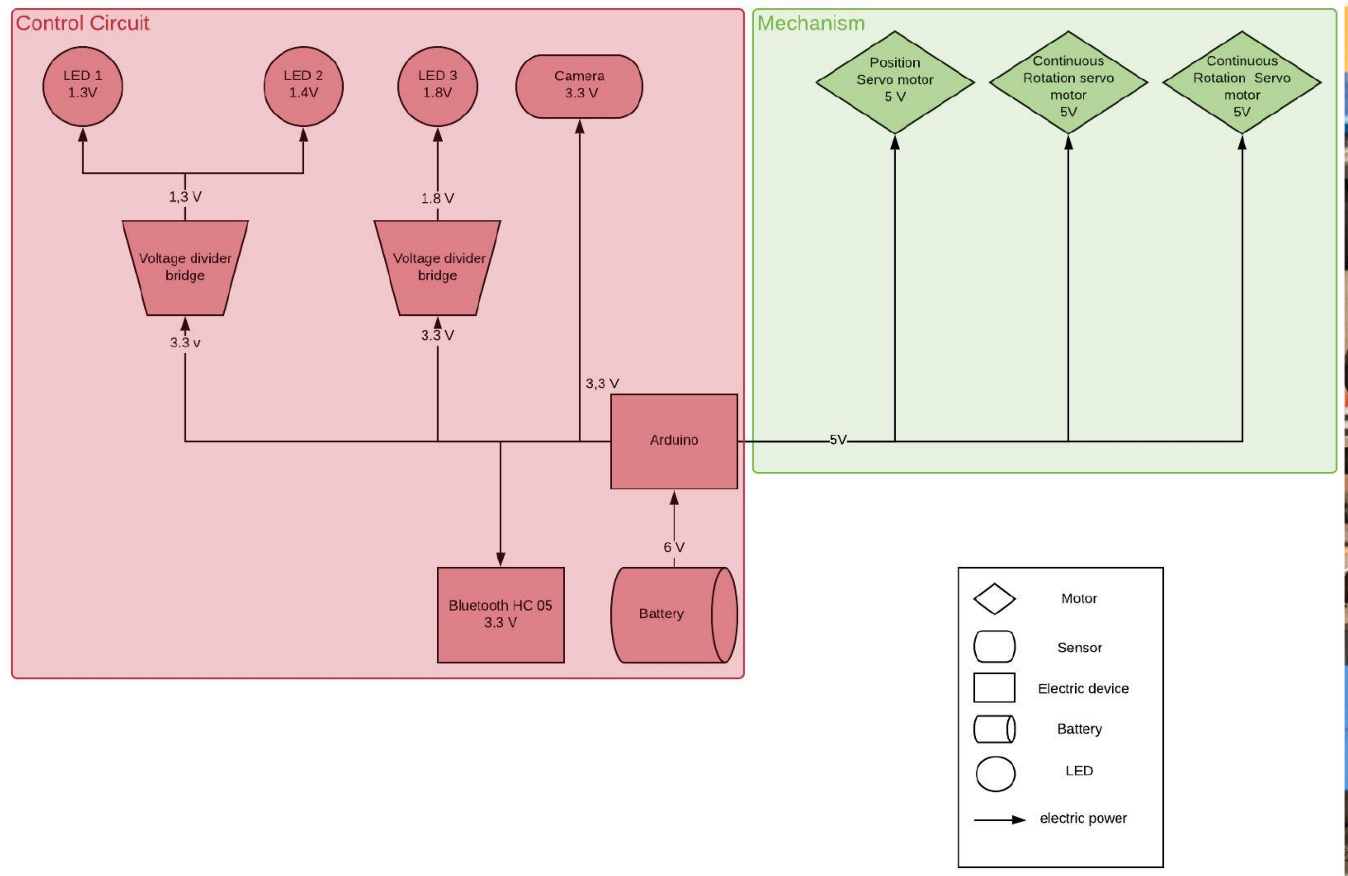
Our docking mechanism to assemble the spacecraft elements in orbit is called CLING (Complaint Low-profile Independent Non-protruding Genderless). It represents a focus on connectivity between different platforms and / or satellites. The device allows for physical modularity between different satellites in a potential cluster. The prototype concept was first developed for “modular robotics” [1, 2] to enable any size / shape device to interconnect, thus allowing multiple configurations. With the help of the SURP funding, it is being developed to provide mechanical and electrical connectivity, specifically for docking in space. The capability of data, power and fluid transfer adds novelty to this technology.

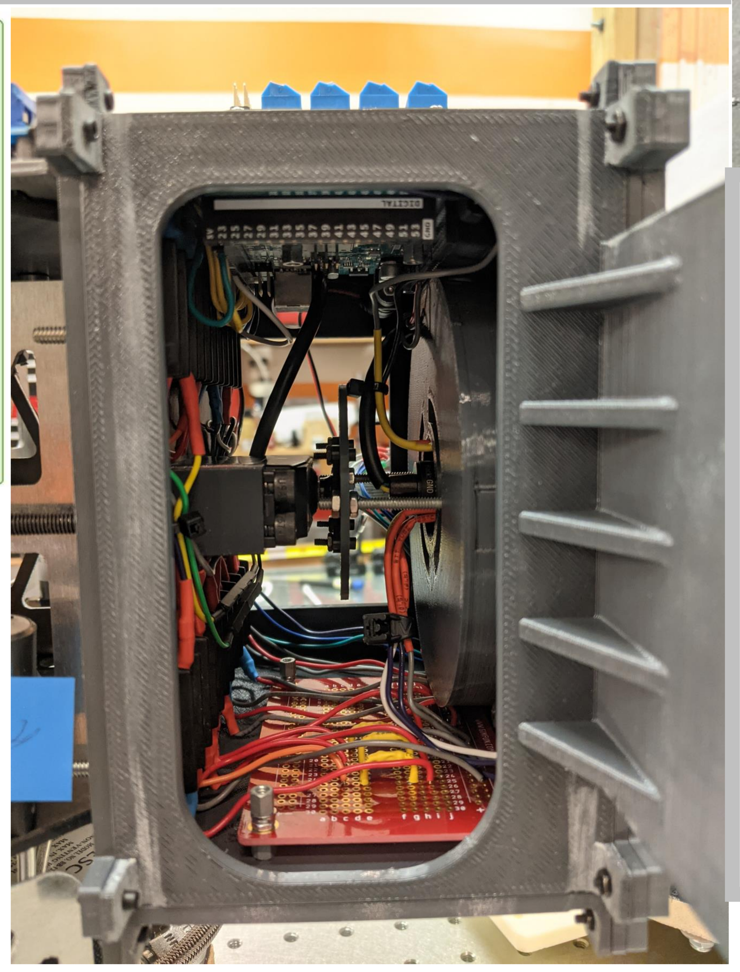
Approach and Results.

To increase the resolution of measurement from any instrument a large antenna reflector has to be deployed in orbit. In order to achieve this SWARMS is looking at integrating multiple CubeSats in orbit each with a piece of the antenna reflector. To achieve this integration in orbit USC’s CLING can be utilized. The latest CLING design and prototype made use of an IR LED based image processing system to gather information about its relative orientation on approach. It also uses a rotary encoder and reflectance sensors to realize its mechanical state, allowing successful interlock with another CLING to achieve docking / undocking. The mechanical design has undergone minor modifications to accommodate the new sensing system. The central guide has been hollowed out to provide a window for the IR Camera that would sit underneath the structure looking upwards. Small LED socket holders have been created on its outer surface to hold the IR LEDs that are used to help determine the orientation in an equilateral triangle. The top surface of the central guide is chamfered in order to increase the angle of detection. A docking procedure was coded for two CLING devices to connect per the following process flow on the USC SERC air bearing table:

The CLING devices are brought to about 30 cm using the overhead inertial system. They may or may not be aligned relative to each other. The Cameras on both devices scan to find the LED Triad on the other device. The information about the location of the LED triad, as seen by the camera, is used to generate orientation and motion control instructions. When the triads become visible to both the cameras, the CLING devices try to align themselves such that they point exactly opposite to each other. The distance between all the LEDs is calculated and compared against each other. Since the LEDs are arranged in a triad that forms an equilateral triangle. Hence, if the distances between the observed points are equal, then the devices are parallel to each other. The distance between the observed LEDs also helps to determine how far the devices are. Using this information, CLING platforms move, bringing them closer.

The devices come close to a predetermined distance and each device rotates their respective tine plates to the top. Because the relative positions of the tines and LEDs stays fixed, the positions of the tine on the other device can be determined based on the LED positions. Based on this observation, the tine plate on both devices rotate to make space for the other tines to come in during approach. The devices then come close to allow each other’s tines fall inside their rotation plane. The tine plates then rotate and both devices grab and interlock. The tine plates then retract back down inside each hub pulling the two CLING devices / platforms closer until they rigidize against each other’s central body, completing the docking procedure.





Significance of results / benefits to NASA / JPL

We have partnered with University of Nevada, Las Vegas (UNLV) and submitted a proposal to ISS National Lab for a TRL 6 demonstration inside the ISS. After the ISS demonstration is complete, the plan is to return the CLING and CuBEE devices back to Earth for thermal vacuum testing to accomplish TRL 7 status. For TRL 8 demonstration we intend to make a follow-on proposal to the ISS National Lab to launch a single 3U CubeSat from ISS. The 3U will be composed of two docked 0.5U docking system payloads each connected to a 1U CubeSat. After deployment from the ISS they will demonstrate undocking, creating positive separation beyond the RPO sensor range of the CLINGs, before flying back to dock again. As of today we have accomplished TRL 4. We have developed a breadboard prototype and demonstrated an end to end closed loop autonomous operation of CLING on air bearing platforms. We assembled two float bots and mounted 1 identical CLING to each of them. the autonomous operations included 1 CLING instructing it's host to acquire, approach, dock, and then undock with another CLING on the separate float bot. The test was successful helping us to TRL4. The sensor system in each CLING to communicates with any other CLING. CLING module transmits range and attitude information from another CLING to its host spacecraft or platform. Automatic sensing and actuation when two CLING devices get close to autonomously engage and allow for soft to hard docking transition. Finally, electrical, data, and fluid transfer capability provided via the interfaces.

CLING Features

- Fixed structure “product” that has all electronics, mechanisms and operating capability into a single 1U form factor.
- The sensor system in each CLING to communicates with any other CLING.
- CLING module transmits range and attitude information from another CLING to its host spacecraft or platform.
- Automatic sensing and actuation when two CLING devices get close to autonomously engage and allow for soft to hard docking transition.
- Electrical, data, and fluid transfer capability into the CLING housing via the connecting pins.

(1) **C**: Compliant – it can dock under relatively high positioning errors in all directions.
(2) **L**: Low profile – several CLING units can be installed on multiple faces of a spacecraft without any significant impact on size.
(3) **I**: Independent undocking ability – in case of failure, each module can disengage the docking on its own.
(4) **N**: Non-protruding – In passive mode, there are no protrusions and the motion is not limited.
(5) **G**: Genderless – there are no fixed male / female configurations, hence both of the modules in a pair are the same.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

PI/Task Mgr Contact
Email: Adarsh.Rajguru@jpl.nasa.gov

Clearance Number:
RPC/JPL Task Number: SP18024