University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

Proximity Identification, chaRacterization And Neutralization by tHinking before Acquisition (PIRANHA)

Approvals

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Nomenclature

PIRANHA	=	Proximity Identification, chaRacterization And Neutralization by tHinking before Acquisition
DCS	=	Debris Capture System
TBD	=	To Be Determined
DOF	=	Degree Of Freedom
SOSC	=	Space Operations Simulation Center
NORAD	=	North American Aerospace Defense Command
NASA	=	National Aeronautics and Space Administration
SpaDE	=	Space Debris Elimination
REDCROC	=	Research and Development for the Capture and Removal of Orbital Clutter
PACRAT	=	Progress and Advancement to Capture and Remove Aerospace Trash
LEOPARD	=	Low Earth Orbit Project for the Acquisition and Recovery of Debris
SVIL	=	Space Vehicle Integration Lab
LMCO	=	Lockheed Martin Company
ITLL	=	Integrated Teaching & Learning Program and Laboratory
CU	=	University of Colorado

1.0 Problem or Need (Problem Statement)

With space being the newest frontier for exploration and technology becoming reliant on satellites in orbit, a serious concern to space faring agencies is the amount of junk that is in orbit. Since the launch of Sputnik 1 in 1957, the amount of human induced orbital debris has been ever increasing. There are currently no active systems in use to reduce the amount of debris in orbit, but it is well known throughout the industry that in order to continue to explore and utilize space, action must be taken to start cleaning up space. Lockheed Martin Space Systems Company understands the orbital debris dilemma and is using this as motivation for funding the project outlined below:

This project will develop a test article, the Proximity Identification, chaRacterization, And Neutralization by tHinking before Acquisition (PIRANHA) subsystem integrated onto a preexisting orbital Debris Capture System (DCS), the Low Earth Orbit Project for the Acquisition and Recovery of Debris (LEOPARD), to be used in Lockheed Martin's Space Operations and Simulation Center (SOSC) testbed. The preexisting DCS is a mechanism that can store two pieces of simulated orbital debris (referred to as debris in the remainder of this document), but PIRANHA will further evolve its capabilities by introducing intelligence such that it can detect, think, and communicate. PIRANHA will detect debris within a 20m proximity of the DCS. PIRANHA will characterize the debris based on size and shape to determine whether the object can be captured based on the 10 – 40cm diameter constraint of the preexisting DCS. If the debris is within the size constraint, PIRANHA will output pointing and tracking directions to facilitate the acquisition of the debris by the DCS. PIRANHA will alert the simulated spacecraft bus if the debris appears to be within the size constraint of the DCS but has undetected extrusions prohibiting a successful capture. The outputs of PIRANHA will interface with a simulated spacecraft bus which provides propulsion and attitude control via a six degree of freedom (DOF) robot in the SOSC.

2.0 Previous Work

As space technology continues to advance, the number of orbital objects and the amount of potentially harmful debris increases. When pieces of debris collide, they create more debris, all of which are travelling at thousands of miles per hour. Debris as small as a speck of paint is capable of chipping the windshield of the Space Shuttle. The North American Aerospace Defense Command (NORAD) tracks nearly 40,000 objects, including satellites and debris, but there are millions of pieces in orbit currently. According to the National Aeronautics and Space Administration (NASA) there are three types of collision risks[1]:

- 10 cm and larger collisions: potentially catastrophic, but can maneuver to avoid (over 21,000 pieces being tracked)
- 1-10 cm collisions: too small to track, yet too large to shield against. Collisions can disrupt or disable a mission (~500,000 pieces)
- <1 cm collision: Debris shields are effective, non-shielded hardware suffers degradation or losses in a collision (in excess of 100,000,000)

Even if no further debris is placed in orbit, the amount of debris will continue to increase due to accidental collisions between debris. This is the Kessler syndrome, and it describes the cascading effect of existing debris creating more debris in collisions that go on to create more and more collisions. At a critical point, the cascading effect will be unstoppable and entire orbits will be unusable due to massive clouds of debris. This is an important factor motivating the need to reduce orbital debris.

Currently there are no systems in place to reduce the debris in orbit, and the only way to avoid collisions is to monitor all debris in orbit and maneuver spacecraft out of the way if there is a chance of collision. The ISS has to do this multiple times per year.

However, there are several proposed methods to reduce the amount of debris. The first is using ground-based lasers to vaporize the surface of debris[2]. The result of this pressure would be to slow it down, causing it to de-orbit faster and burn up in the atmosphere. Another solution proposed by NASA is called SpaDE (Space Debris Elimination). This project proposes delivering focused pulses of atmospheric gasses in the orbital path of a targeted piece of debris[3]. This would induce enough drag on the object to make it deorbit faster. The last solution to the problem is the capture and deorbit of debris by a spacecraft. The European Space Agency (ESA) has proposed a spacecraft called the RObotic GEostationary orbit Restorer (ROGER). This spacecraft would approach defunct satellites in geostationary orbit, grab them, and move them to a graveyard orbit[4]. It is important to note however, that none of these systems are in place, but have been discussed as possible orbital debris capture/mitigation systems.

Currently the U.S. Government requires companies to abide by the Orbital Debris Mitigation Standard Practices. This states that spacecraft and upper stages must have a mission design such that they are disposed of in one of the three ways: atmospheric reentry, maneuver to a storage orbit (this differs for LEO, MEO, and GEO), or direct retrieval[5]. Even though there are no current systems in place to reduce the amount of debris in space, it is of great concern to the government, and therefore the government requires these standard practices to help prevent the growth of this problem.

Three previous senior design projects have explored this concept. REsearch and Development for the Capture and Removal of Orbital Clutter (REDCROC) first explored the orbital rendezvous, capture and deorbit of debris by looking at a few different architectures of how to capture debris. REDCROC decided on an extendable cone with netting to capture the debris[6]. The senior design project Progress and Advancement to Capture and Remove Aerospace Trash (PACRAT) advanced this idea. This project further explored mission architectures for capturing debris, looking into methods such as nets, pods, harpoons and sticky darts. They also looked into deorbit methods, such as using a tether, drag sails, or a balloon, but ultimately this outside the scope of their project[7]. Low Earth Orbit Project for the Acquisition and Recovery of Debris (LEOPARD) DCS was the most recent senior design project to work on orbital debris mitigation. The project team was able to develop and build a storage unit that could open and close to capture up to two pieces of debris, up to 40 cm in diameter (a constraint derived from the dimensions of the DCS and illustrated in Fig. 1), and store them for deorbit[8]. More information on these senior design projects can be found in the archives of previous projects[9].

Figure 1. Heritage DCS and size constraint of debris due to DCS.

This year, team PIRANHA will move away from further developing a debris capture structure, and develop a system that can detect simulated debris, characterize it based on size and shape and provide telemetry to a testbed. PIRANHA will be a suite of sensors integrated with the preexisting DCS and will further evolve the design by adding intelligence. It will enable the DCS to detect and capture debris autonomously. An orbit debris scenario does not conclude with the capture of debris; however, designing and modeling the deorbit procedures are beyond the scope of this project. This work could be used and built upon for a future DCS that could be used offensively in areas where there is a high amount of debris. The spacecraft could be launched into an orbit in the vicinity of clusters of debris, and the DCS would be able to autonomously seek out and capture debris.

This would be beneficial in mitigating the problem of orbital debris. When an asset, such as the ISS, is deemed at risk by debris, a DCS equipped with an adaptation of PIRANHA could be deployed to proactively clean up the debris, before it comes close to the asset. Because of the large amount of orbital debris, this is not a viable solution to cleaning up the entirety of the debris in space, but it could reduce the risk of collision with current assets by protecting them before they are in the path of danger.

3.0 Specific Objectives

In order to satisfy the design problem, PIRANHA must be physically integrated onto the preexisting DCS, such that PIRANHA and the DCS form a unified test article for the SOSC testbed. PIRANHA must detect debris in a 20m proximity of the DCS and characterizes the debris based on size and shape. PIRANHA must assess the ability of the DCS to capture the debris based on the 10 – 40cm diameter size constraint of the DCS. PIRANHA must alert the DCS if debris is outside of the size constraint. PIRANHA must output information about the relative position and relative velocity of the debris. PIRANHA outputs must be converted to commands for the simulated spacecraft bus on how to maneuver the DCS to facilitate capture of debris. PIRANHA must interface with the SOSC 6-DOF robot and execute a simulated debris capture scenario, as well as a scenario where PIRANHA alerts the simulated spacecraft bus that the debris to be captured is outside the size constraint of the current configuration of the DCS.

Success Levels

- Level 1 – PIRANHA is mechanically attached to the preexisting DCS. PIRANHA can detect an object in a 20m proximity of the DCS and characterize the object based on size and shape. PIRANHA can assess the ability of the DCS to capture debris based on the DCS's size constraint. PIRANHA can detect extrusions during capture which cause the debris to occupy more than a 40cm diameter sphere.
- Level 2 – PIRANHA can output information about the relative position and relative velocity of debris in three dimensional inertial space to a simulated spacecraft bus. The PIRANHA outputs are converted into commands for the simulated spacecraft bus on how to maneuver the DCS to facilitate capture of the object using feedback control. PIRANHA will also satisfy Level 1.
- Level 3 – PIRANHA and the preexisting DCS can interface with the SOSC 6-DOF robot. PIRANHA can execute a simulated debris capture scenario, as well as a scenario where PIRANHA alerts the simulated spacecraft bus that the debris to be captured is outside the size constraint of the current configuration of the DCS. The scenario will begin with an object within

PIRANHA's TBD detecting proximity and culminates with the capture of the debris or alerting to the simulated spacecraft bus. PIRANHA will also satisfy Level 1-2.

4.0 Functional Requirements (FNC.X)

FNC.1 PIRANHA shall integrate with the preexisting LEOPARD DCS.

FNC.2 PIRANHA shall detect the presence of debris within 20m proximity of the DCS.

FNC.3 PIRANHA shall characterize objects based on their size and shape.

FNC.4 PIRANHA shall output relative position vectors (pointing and tracking telemetry) of the debris with respect to the DCS.

FNC.5 PIRANHA shall be testable via interface with the SOSC testbed.

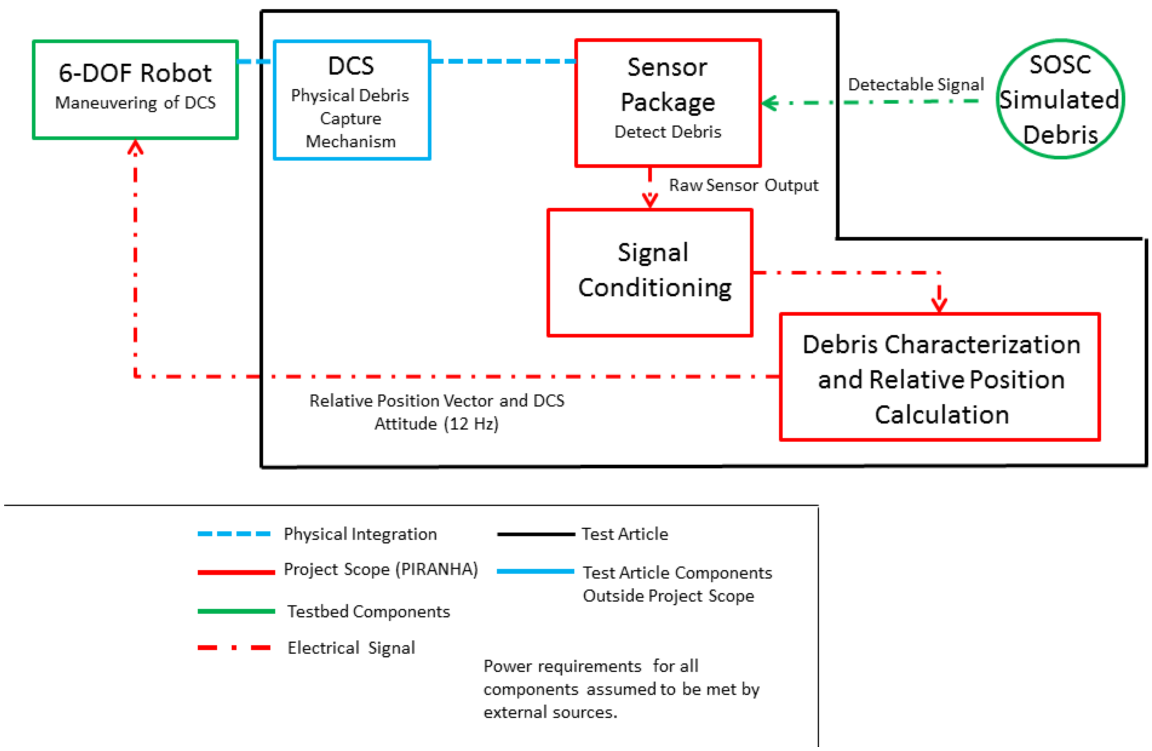

Figure 2: Functional Block Diagram of PIRANHA

Outlined in black in Fig. 2 is the PIRANHA instrument, the main focus of this project. It will be a test article to be used in the SOSC testbed, physically attached to the preexisting LEOPARD DCS which will be attached to one of the SOSC 6-DOF robots. A sensor package onboard will detect simulated debris, and PIRANHA will then filter the sensor output and subsequently characterize the debris. Characterization includes determining if the simulated debris is able to be captured, and its relative position and velocity with respect to the DCS. This characterization is the output of PIRANHA, and will be sent to command the 6-DOF robot.

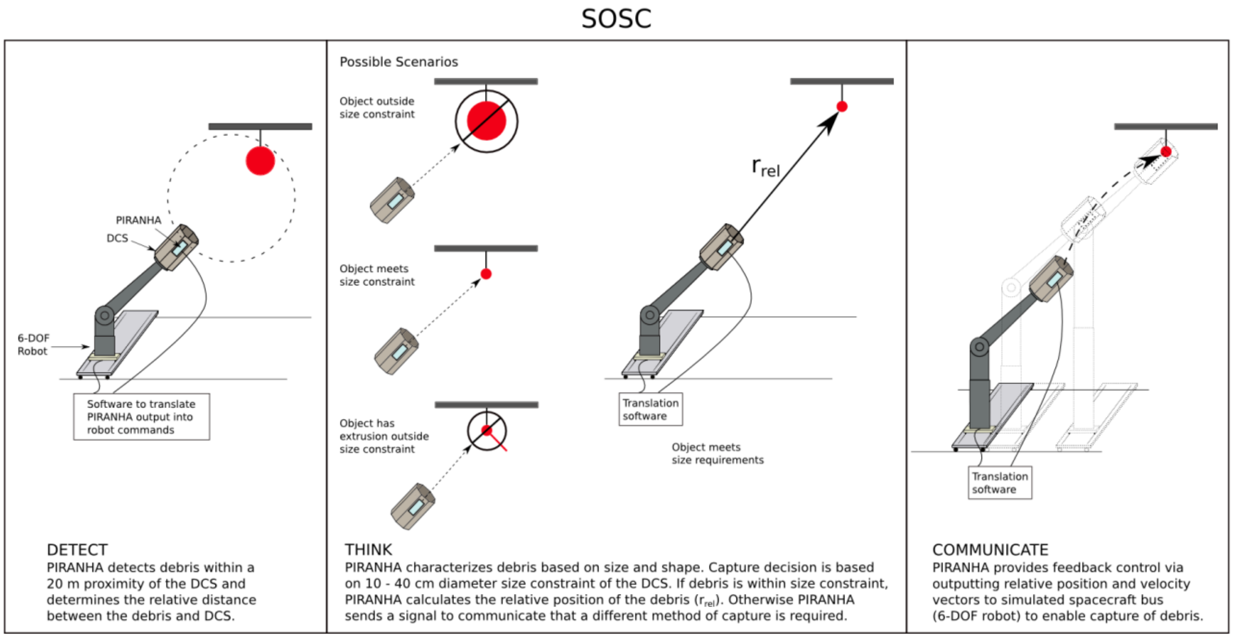

Figure 3: Mission CONOPS

The CONOPS diagram shown in Fig. 3 details the operation of PIRANHA in the SOSC. PIRANHA will be attached to the existing LEOPARD DCS on the 6-DOF robot and will detect an object within a TBD proximity of the DCS. PIRANHA will characterize the object based on its size and shape. If the object is within the 10 – 40cm size constraint of the DCS, PIRANHA will output position and velocity vectors of the debris relative to the DCS (pointing and tracking directions), which will be translated into acceptable commands for the robot. The robot will use these formatted commands to maneuver the DCS within the 3D space to capture the object. If the object is outside the size constraint or has an extrusion outside the size constraint, PIRANHA will not endanger the DCS by trying to capture the object.

5.0 Critical Project Elements (CPE.X.X)

Technical

CPE.1.1 PIRANHA must detect debris in a simulated space environment. Without the detection of debris, the remaining functional requirements cannot be satisfied and the design will not be a success. Additionally, the task of detecting debris is not trivial as no team member has direct experience in designing a system to perform in this manner.

CPE.1.2 PIRANHA must be capable of outputting commands at the rates and specifications required by the SOSC robot. Without properly formatted data at the correct transfer rate, the SOSC robots will not be able to simulate the propulsion required to maneuver the DCS to capture the debris.

Logistical

CPE.2.1 The PIRANHA team must tour the SOSC and Space Vehicle Integration Laboratory (SVIL) to have a full understanding of the constraints and interfaces that must be considered when utilizing these resources.

CPE.2.2 A software model must be supplied to Lockheed Martin and tested within the SOSC to insure PIRANHA can interface with the SOSC system. The test software model will verify that the design will meet requirements before operational testing.

CPE.2.3 The PIRANHA team must be able to perform operational testing at the SOSC. The test must be conducted using a 6-DOF robot. The operational testing is needed to validate the functional requirements are satisfied.

CPE.2.4 The preexisting DCS must be acquired from the Aerospace Engineering Electronics and Instrumentation Lab Manger, Trudy Schwartz.

Financial

There are no financial critical elements for this project.

6.0 Team Skills and Interests

Aaron Buysse - *Software Lead*: Aaron has a strong understanding of astrodynamics and control systems. He is experienced in MATLAB and Simulink, and is familiar with C/C++ and STK. Aaron has worked with interfacing and acquiring measurements from sensors in real-time applications during his internship at the Jet Propulsion Laboratory last summer.

Chad Caplan - *System Lead*: Chad has interests in astrodynamics including space navigation, celestial mechanics, and orbital determination. Chad also has knowledge and experience with data acquisition, and digital electronics, including interfacing sensors with microcontrollers, collecting data, and making real time decisions. He has additional expertise with electrical lab equipment and measurement devices, as well as programming in MATLAB and C/C++.

Matt Holmes - *Electric Lead*: Matt interned at Ball Aerospace and Technologies Corporation in Integration and Testing for the Ground Support Equipment group last summer. He has also worked in the Aerospace Engineering Electronics Lab fixing and improving various labs encountered throughout the curriculum. He is skilled in soldering and interfacing with various sensors and experienced in the utilization of measurement devices such as oscilloscopes and multimeters.

Colin Nugen - *Financial Lead*: Colin has experience in programming and simulations using MATLAB, Simulink, and STK. Colin is interested in project and engineering management, he also possesses a strong financial background and expertise in professional writing. While at CU, he has worked on a couple of satellites - a cubesat launched to 100 km, and a subsystem of DANDE.

Kevin Rauhauser - *Safety Lead*: Kevin is technically strong in electronics, and has practical field test coordination experience. Kevin works with the Research and Engineering Center for Unmanned Vehicles (RECUV) where he conducts UAV research and acts as pilot in command for UAV flights. The pilot in command is responsible for making sure field tests are conducted in a legal, safe manner. Kevin is also skilled in MATLAB and has some experience with heuristic path planning algorithms and C/C++ programming. Kevin is interested in test engineering, fluids, and aircraft design.

Ryan Slabaugh - *Project Manager*: During his military experience, Ryan trained and led a fleet of 13 Crew Chiefs in maintenance and flight operations of helicopters with 30 Marines under him. At San Diego Mesa College, Ryan was the President of the Society of Hispanic Professional Engineers (SHPE) chapter in 2011. Ryan was awarded “President of the Year” in the San Diego district by the professional SHPE chapter, as well as his chapter received “Outstanding Chapter of the Year”. Ryan’s previous leadership experience in the military, as well as within academia, provides him with well-rounded leadership skills that will be utilized in leading PIRANHA. Ryan also has extensive training and experience in software development. In May 2013, Ryan started an internship with Lockheed Martin’s Space Vehicle Integration Laboratory in which he works with MATLAB and Simulink on a daily basis. Additionally, Ryan works with STK almost as regularly as he works with MATLAB and Simulink. Ryan is looking forward to using his expertise and knowledge to incorporate Simulink’s auto-code generation capabilities into the design.

Rebecca Travers - *Mechanical Lead*: Rebecca has vast experience and knowledge with structural and mechanical work. Rebecca previously worked in a civil engineering internship where she performed structural analysis of dams and had an opportunity to participate in several on-site dam inspections. She was also employed as an intern in the summer of 2013 with Lockheed Martin where she gained experience with spacecraft structural and mechanical design, analysis, and testing.

Critical Project Elements	**Team member(s) and associated skills/interests**
5.1.1	Ryan Slabaugh and Matt Holmes – Experience in Aerospace Engineering Electronics Lab interfacing with various sensors Entire Team – ASEN 3300 experience with sensor communication, specifications, and signal conditioning.
5.1.2	Chad Caplan, Aaron Buysse and Colin Nugen – Interest in orbital mechanics and astrodynamics which will facilitate properly formatted data and reference frame conversions. Ryan Slabaugh and Aaron Buysse – Interest in software and optimization of developed code to meet SOSC data rate requirements.
5.2.1	Entire Team – Full team will be present for the tour of the SOSC & SVIL and will all be responsible for understanding the specifics involved with integration and testing in the facility.
5.2.2	Chad Caplan and Aaron Buysse – Interest in software and modeling in the required programs to verify that PIRANHA will work before it is tested in the SOSC. Kevin Rauhauser and Colin Nugen – Interest in test setup and planning. Interfacing with the SOSC correctly will be an integral part of this.
5.2.3	Kevin Rauhauser – Interest in test setup and planning. Plans to be the lead member organizing and coordinating SOSC tests. Matt Holmes – Internship at Ball Aerospace in the Integration and Testing group. Previous head of Integration and Testing on a Colorado Space Grant cubesat. Knowledge from both of these positions should help with designing for testability and test coordination. Ryan Slabaugh – Key coordinator between Lockheed Martin and the PIRANHA team for all testing opportunities. Rebecca Travers – Internship with Lockheed Martin doing structural engineering will help with mechanical interface and securing of entire system to SOSC robots.
5.2.4	Ryan Slabaugh – Coordination with Trudy Schwartz. Rebecca Travers – Background can be used to assess the state of the DCS and possible reinforce it for future use.

7.0 Resources

Critical Project Elements	Resources Needed	Resources Available
5.1.1	Sensor for detecting debris and facility to manufacture and test electronics	ITLL Lab Stations, Trudy Schwartz, Dr. Zoltan Sternovsky, LMCO Space Vehicle Integration Lab (SVIL), Matt Dean (SVIL manager), Sherri Ahlbrandt (LMCO Sensors/Electrical engineer)
5.1.2	Understanding of sensor integration, proximity orbit operations and attitude determination Ability to interface with SOSC	Sherri Ahlbrandt(LMCO Sensors/Electrical engineer), Dave Huish (LMCO GNC support engineer), CU faculty Dr. Steve Nerem, Dr. Hanspeter Schaub, Dr. Dale Lawrence LMCO Jeffrey Weber (project lead), Frank Moore (SOSC labs manager), SOSC engineers Dave Huish, Sherri Ahlbrandt, and Michael Drews, SVIL
5.2.1	Tour of the SOSC & SVIL	LMCO Jeffrey Weber, SOSC Personnel, LMCO Matt Dean
5.2.2	Software compatible with the SOSC 6-DOF robot	LMCO Jeffrey Weber (project lead), Frank Moore (SOSC labs manager), SOSC engineers Dave Huish, Sherri Ahlbrandt, and Michael Drews, SVIL
5.2.3	Operational testing in SOSC	LMCO Jeffrey Weber (project lead), Frank Moore (SOSC labs manager), SOSC engineers Dave Huish, Sherri Ahlbrandt, and Michael Drews, SVIL
5.2.4	LEOPARD DCS acquisition	Trudy Schwartz and Chelsea Welch

8.0 References

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