Project Name: SCENARIO

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Introduction: In the development of an orbital satellite, it is sometimes necessary to include one or more moving parts in the design. However, as there is no friction or drag in space, any movement in the robot will cause a change in attitude and position. The SCENARIO project, Simulated Control ENvironment for Active Robots In Orbit, intends to simulate the free-floating behavior an orbital robot will experience in space. This project is centered around the development of two identical planar, three degree of freedom systems, which will serve as a proof of concept for future projects with higher degrees of freedom. The system will contain the following subsystems:

Robotic Platform
The Robotic Platform will contain the 3-DOF planar manipulator necessary to move the Planar Space Robot through all necessary poses during the simulation.

Data Acquisition
The Data Acquisition system will gather all sensor data at a high frequency for use in the Software subsystem.

Software
The Software subsystem will contain the control law and the user interface for the machine. The control law will regulate the motors of the Robotic Platform.

Planar Space Robot
The Planar Space Robot subsystem will move independently of our Robotic Platform, and will represent an experimental space robot in its design cycle.

Design Requirements:

1. Robotic Platform

1.1. The Robotic Platform system shall simulate free-floating movement for the Planar Space Robot.
The Planar Space Robot shall move as if on a frictionless surface. The Planar Space Robot should not be able to observe external forces such as friction and drag. It is the task of the Robotic Platform to simulate this movement.

1.1.1. The Robotic Platform shall maintain the position of the center of mass of the PSR within 1 cm of its desired position while no PSR movement commands are being transmitted.
To simulate free-floating movement, it is imperative that the PSR robot conserve its velocity and momentum. While the PSR is stationary, there should be no drift resulting from a change in linear velocity or momentum.

1.1.2. The Robotic Platform shall maintain the position of the center of mass of the PSR within 2 cm of its desired position while PSR movements commands are being transmitted.
To simulate free-floating movement, it is imperative that the PSR conserve its velocity and momentum. While the PSR is moving, the trajectory of its center of mass should very closely resemble the desired trajectory of the model.

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1.1.3. *The Robotic Platform shall maintain the orientation of the body of the PSR within 5° of its desired orientation while no PSR movement commands are being transmitted.*
To simulate free-floating movement, it is imperative that the PSR robot conserve its angular velocity and momentum. While the PSR is stationary, the angular drift should be as close to zero as possible.

1.1.4. *The Robotic Platform shall maintain the orientation of the body of the PSR within 7° of its desired orientation while PSR movement commands are being transmitted.*
To simulate free-floating movement, it is imperative that the PSR robot conserve its angular velocity and momentum. While the PSR is moving, its angular trajectory should very closely resemble the angular trajectory of the model.

1.2. The Robotic Platform system shall include a CR-H2010 series Hirata manipulator.
The HIRATA has been purchased and allocated for this project. It is capable of manipulating a load in a three degree of freedom workspace.

1.3. The Robotic Platform system shall operate in a three degree of freedom environment.
The Planar Space Robot should be allowed to move in two orthogonal linear directions with respect to the Robotic Platform. The Planar Space Robot should be allowed to rotate about a third axis, orthogonal to its axes of movement.

1.3.1. *The Robotic Platform shall have a defined x-axis.*
This axis is represented by the longer translational joint of the HIRATA manipulator.

1.3.2. *The Robotic Platform shall have a defined y-axis orthogonal to its x-axis.*
This axis is represented by the shorter translational joint of the HIRATA manipulator.

1.3.3. *The Robotic Platform shall have a defined z-axis orthogonal to its x and y-axes.*
This axis is represented by the vertical rotational joint of the HIRATA manipulator.

1.3.4. *The Robotic Platform shall allow the central mounting point of the PSR to operate within a 49 cm by 28 cm rectangular plane.*
The rectangular plane defines the dexterous workspace of the Hirata manipulator, where the limits of the x-axis are 0 cm and 49 cm, and the limits of the y axis are 0 cm and 28 cm. These measurements provide a margin of safety to prevent damage to the Hirata.

1.3.5. *The Robotic Platform shall allow the body of the PSR to rotate at least 360° about the z-axis.*
The PSR system is mounted to the shaft of a Maxon DC motor. To simulate free-floating motion, it is necessary for the PSR to be able to rotate about the z-axis.

1.4. The Robotic Platform system shall be actuated by three 250W Maxon RE65 DC motors and encoded by three Avago HEDS 5540 A15 encoders.
These motors and encoders have been purchased and allocated for this project.

2. Data Acquisition

2.1. The Data Acquisition system shall have the ability to send recorded encoder values, forces, and torques from sensors to a computer.
The Data Acquisition system will retrieve data from sensors and send them to a computer where it will be processed and used for control.

2.1.1. *The data sensors used shall include, at a minimum, 13 shaft encoders, 13 decoders, and a torque-force sensor.*

Three shaft encoders, three decoders, and the torque-force sensor will be used to acquire data from the robotic platform. Five shaft encoders and five decoders will be used on each PSR to acquire motor data.

2.2. The Data Acquisition system shall acquire data from the sensors at the highest possible frequency.
The sensor data must be retrieved at a high enough frequency for controlled movement of the links.

2.2.1. The Robotic Platform shall acquire data and control movement of the PSR base at a frequency of no less than 1000 Hz.
For force-feedback control of the PSR, a period of 1 ms has been selected for the maximum delay in system response.

2.2.2. The PSR shall acquire data and control the actuators at a frequency of no less than 100 Hz.
Control of the PSR isn't required to be as fast as on the robotic manipulator. 100 Hz shall be sufficient to control the actuators and obtain data via wireless communication.

2.3. The Data Acquisition system shall use an ATI Mini-40 torque-force sensor to observe torques and forces on the Planar Space Robot.
To properly simulate a free-floating environment, the use of a torque-force sensor will be required to measure the external and internal forces acting on and within the Planar Space Robot. This sensor has been purchased and allocated to this project.

2.4. A motion capture system shall be used to record the task-space coordinates of the Planar Space Robot while it is on the air bearing table.
For system verification, it is necessary to compare our experimental system with an already-validated system. A motion capture system will allow for accurate tracking and recording the task space coordinates of the Planar Space Robot's motion on the low-friction air bearing table.

2.4.1. The motion capture system shall record positional data of the PSR operating on the air bearing table at a minimum frequency of 30 Hz.
The motion capture data will only be recorded for comparison between the motion of the two PSRs, not used in real time for control, so it can be acquired less frequently.

3. Software

3.1. The Robotic Platform system shall have a control system that replicates free floating motion.
To simulate free-floating movement, each degree of freedom will need to be controlled. The output of each motor and particular sensors should be used in a feedback loop to control motor input. The control will be achieved in the Software subsystem using sensor information from the Data Acquisition system.

3.2. The system shall have a user interface to move the Planar Space Robot and set experimental parameters.
To be useful as a tool for simulation, the user should be able to specify an experimental duration and other test parameters for the system. In addition, the user should have the ability to send movement commands to the Planar Space Robot via the software interface.

3.2.1. The user interface shall allow the user to choose the individual joint angles and momentum wheel angular velocity of the PSR.
The user will be able to send individual motor commands to the PSR to perform smaller tests or for demonstration purposes.

3.2.2. The user interface shall allow the user to select a pre-created movement profile for the PSR to complete.

These movement profiles will include the joint-space or task-space trajectory or position commands necessary to move the PSR in a predetermined way. This way, identical motion can be produced in each PSR.

3.2.3. *The user interface shall allow the user to input an experiment duration of no more than 120 s.*
For repetitive movement profiles, the user may wish to run the experiment for a specific amount of time. The experiment duration will not exceed 120 s in order to ensure experiments are not in danger of using too much air and altering the air bearing cushion characteristics.

3.2.4. *The user interface shall display a warning when an invalid parameter is entered, and the invalid command shall not be sent to the PSR.*
The software will not allow the user to send commands that would move the links or motors beyond physical limitations.

4. Planar Space Robot

4.1. The Planar Space Robot system shall consist of two discrete Planar Space Robots which have identical dynamic properties.
These two robots will be identical in mass and distribution of mass. They will have the same actuators and will behave in the same way given the same system inputs. Each will be mountable to the Robotic Platform.

4.1.1. *The two Planar Space Robots shall have a maximum of 2% difference in mass parameters.*
Quantities relating to total mass and distribution of mass may not exceed a 2% variation from one PSR to the other.

4.1.2. *Each Planar Space Robot shall have a maximum mass of 100 kg.*
The overload force in the Z axis of the ATI Mini-40 torque-force sensor is 2400N, which in Prescott, Arizona corresponds to 245 kg. A PSR mass of 100 kg should not be necessary, but would still be safe for operation on the robotic platform.

4.1.3. *Each Planar Space Robot shall have a maximum momentum of inertia about the Z axis of 3.18 kgm^2.*
This number is derived from the maximum Z-axis torque measureable by the ATI Mini-40 torque-force sensor, and the maximum acceleration generated by the PSR attitude actuator.

4.1.4. *Each Planar Space Robot shall exert a maximum torque of 1 Nm about either the x or y axis of the torque-force sensor.*
This is the maximum X-Y torque measurable by the ATI Mini-40 torque-force sensor at the highest resolution setting.

4.2. The Planar Space Robot system shall include a minimum of four physical links.
The system should be complex enough to excite the torque-force sensor, and provide useful experimental data.

4.2.1. *The PSR shall have two arms with a minimum of two links each.*
Each link will contain a DC motor acting as an actuator. Wires will run from each DC motor back to the main body of the PSR which will contain a microprocessor.

4.3. The Planar Space Robot system shall have an actuator for attitude control.
The addition of a spinning disc to the Planar Space Robot allows the robot to regulate its own orientation. The disc adds an additional degree of freedom to the Planar Space Robot and further excites the torque-force sensor.

4.3.1. *A momentum wheel shall act as an attitude control actuator.*

The momentum wheel will be a disc mass mounted to a DC motor. It will remain spinning during operation, and its angular velocity will be changed to induce a change in angular momentum and orientation.

4.3.2. *The attitude control actuator shall be able to induce an angular acceleration of* $\frac{\pi}{10}$ *rad/s*^{2}

This acceleration will allow the PSR to accelerate to π rad/s in 10 s.

4.4. The Planar Space Robot system shall use an on-board battery to power its on-board electronics.

The system must accurately recreate the conditions the Planar Space Robot would experience in an orbital scenario. Cables leading from the Planar Space Robot would introduce external forces.

4.4.1. *The PSR shall use a 12V battery to drive the DC motors and microprocessor.*

12 V will be sufficient to operate the DC motors, which will require the most power and the highest voltage supply of any component on the PSR.

4.5. The Planar Space Robot system shall have wireless communication capability with the PC workstation.

The system must accurately recreate the conditions the Planar Space Robot would experience in an orbit scenario. Cables leading from the Planar Space Robot would introduce external forces.

4.5.1. *The wireless communication system shall communicate across a minimum range of 10 m.*

This measurement is the maximum distance between the PC workstation and the air bearing table in the ERAU Prescott Robotics Lab.

4.5.2. *The wireless communication system shall transfer a minimum of 12 kb/s.*

This number is derived from the amount of data required to transmit the motor shaft information at the required PSR control frequency of 100Hz.

4.6. The Planar Space Robot system shall consist of at least one robot with functional air bearings.

At least one Planar Space Robot will be placed on the air bearing table, and fitted with air bearings to simulate a frictionless environment. In order to make the air bearings function, the Planar Space Robot will also require a compressed air tank, regulator, and air tubes to feed the air bearings.

4.6.1. *The PSR shall have a total of three air bearings.*

The air bearings will be mounted on the main body of the PSR and spread out in a triangular formation.

4.6.2. *The operational air pressure of the air bearings will be regulated to between 60 and 80 psi.*

The air pressure supplied to the bearing will be sourced from a ½ gal pressurized tank mounted on-board the PSR. A regulator will be implemented between the tank and the bearings to maintain a pressure between 60 and 80 psi. This is the manufacturer-specified operating range of the bearings.

Attributions:

Tasks	Team Members				
	Andy Worthington	Tym Anderson	Lorenzo Lucchese	Maddy Markham	Lucas Vasconcelos
Introduction			X	X	
Robotic Platform	X		X	X	
Data Acquisition	X	X		X	X
Software	X	X			X
Planar Space Robot (PSR)	X	X	X	X	
Presentation		X			X
Formatting			X		
Editing	X	X	X	X	X
Attributions	X	X	X	X	X
Revisions	X	X	X	X	X