Galactic Autonomous Twin Operational Robotic Arms (GATOR Arms)

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Abstract

With the growing number of satellite constellations and CubeSats in Low Earth Orbit (LEO), the emerging field of In-Space Servicing, Assembly, and Manufacturing (ISAM) promises to revolutionize how existing satellites are repaired, assembled, disassembled, and recovered while in orbit. The space environment is harsh with extreme temperature fluctuation, radiation, and orbital debris collisions that can often damage core satellite functions and components without warning. Therefore, ISAM is necessary to conduct satellite repairs in orbit, which would largely reduce launch costs while increasing the total lifetime of the damaged satellite. One method of making in-orbit satellite repairs consists of advanced dexterous robotic manipulator arms using tools to fix damages. Many of the currently produced and tested robotic manipulator arms designed for use in harsh space environments have a high cost of production, which does not allow for mass scale adoption, and are not well-suited for satellite repair, repositioning, and recovery in LEO. To address these problems, this paper aims to discuss the design and implementation of cost effective, autonomous, dual interchangeable robotic arms with six degrees of freedom (6-DOF) for ISAM.

The system features a vision sensor that performs object recognition and tracking to enable autonomous repair tasks, while a storage attachment secures a set of detachable, interchangeable tools. The manipulator's grasping function, driven by a high-torque motor, handles operations such as fastener driving and drilling, and the arm's joints are powered by ultra-high vacuum capable stepper motors with optical differential rotary encoders for precision in six degrees of freedom. A depth-sensing camera attachment provides robust inspection capabilities. This compact, cost-effective design is built to operate efficiently over a mission span of two to four years. With these factors included our design for dual interchangeable robotic arms for satellite repair, repositioning, and recovery aims to help revolutionize the field of ISAM.

Introduction

The growing fields of ISAM and RPOC have been propelled by several recent satellite missions in the last two decades. AFRL launched XSS-10 in 2003. Northrup Grumman made strides with their Mission Extension Vehicle (MEV) in 2021. Upcoming missions include DARPA's Robotic Servicing of Geostationary Satellites (RSGS) and NASA's On-orbit Servicing and Manufacturing-1 (OSAM-1). Each mission has focused on servicing satellites with robotic arms and demonstrating gains in multi-body satellite control. However, these robotic arms are large with high costs and little modularity; there are currently no small-scale robotic arms for ISAM and RPOC that can be equipped to rapidly maneuvering spacecraft (<100 kg). With the increasing use of small satellites, it is necessary to develop a novel autonomous robotic arm system architecture that is modular, small-scale, and long-lasting for harsh space, lunar, and Martian environments to enable complex missions such as ISAM, RPOC, and space sustainability and debris removal. Galactic Autonomous Twin Operational Robotic Arms (GATOR Arms) will be the first of its kind small-scale, autonomous twin robotic arms with modular, interchangeable end effectors. The original GATOR Arms were made with the idea of having them on a Venus Class satellite, but they will be further designed to mount on any small satellite in the future.

Fig. 1: Venus Class Satellite that the GATOR Arms are designed to be mounted to for this mission.

The arms have six motors that allow six degrees of freedom of motion and rotation of the end effector.

The arms will have a tool arm interface that provides mechanical and electrical coupling to the modular end effectors. This is shown fully in Figure 2 There will be a tool holder that can securely hold detached tools and grippers until later usage. The system will have cameras and sensors built into the base, arms, and hands to provide real-time feedback on the position, orientation, and location of the arms and surrounding objects. For example, the arms could locate a nearby Rubik's cube, approach and grab the cube, then manipulate and solve it with a real-time data feedback loop. The design will leverage off-the-shelf parts as much as possible to meet an eight-month timeline. An orbital flight will raise the system's TRL and validate core capabilities in the harsh space environment, including precise manipulation and actuation, end effector exchange and use, autonomous capabilities, and dynamics modeling. Successful trials will accelerate operational readiness for future missions and support a new commercial ecosystem for ISAM and RPOC.

Fig. 2: Full model of Venus class satellite with both robotics arms and hand along with tool holders

Design Overview

6-DOF Arms and Grippers

The two modular arms, known as GATOR Arms, will have 6 degrees of freedom in motion which will be powered by 6 motors for each arm. The base material for both arms will be Aluminum due to its ease of machinability, relatively low cost, and high range of working temperatures. In addition, a separate motor will be used in the had section of the robotic arm to operate the tools of the robotic arm and in order to grip objects with the hand. The rotation from the motor will not only power the tools but it will also actuate the grippers of the hand to move in and out. The motors used for the design will be an ultra-high vacuum (UHV) 4118S-04P Hybrid Stepper Motor paired with a DM332T digital stepper driver, a TMC5160 stepper driver for precise motor control, and an E5D optical differential encoder for precise motor position tracking. This 4118 NEMA 17 motor was chosen due to the high torque it is able to provide relative to its size.

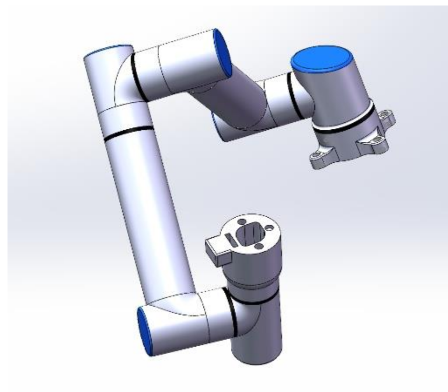

Fig 3: SolidWorks CAD model of the arm disconnected from the bus and the tools.

The gripper of the arms is designed to hold cubes or rectangular prism with a face of 10cm by 10cm which is designed that way so that the arms will be able to securely latch onto or hold CubeSats or CubeSat sized objects. Below in Figure 4 shows a model of the arm that was created to demonstrate the gripper portion's ability to hold cube like objects.

Figure 5: View of the 3D printed hand prototype gripping a 70 mm cube to display its ability to grip small CubeSats.

Figure 5 also shows another view of the 3d Printed prototype gripper that was constructed. This along with Figure 4 demonstrates the arms capability to extend and retract its grip by rotating the topmost portion shown in Figure 5. The 3d printed model of the hand of the robotic arms bring the hand model from a TRL2 to a TRL3 by displaying a working limited prototype of the hand.

Figure 5: Bottom top view of 3D printed hand at a different claw position to show grip movement capabilities.

Camera System and Data Handling

The Camera system of the GATOR Arms is what allows the arms to have spatial awareness and detect damaged areas of the satellite in need of repair. It also allows the arms to identify which tools will need to be used to make the repair. It will also be used in detecting the arms in relation to each other, so no collisions occur while the arms are repairing or updating the satellite's hardware. Due to the paramount importance of the camera to the robotic arms sustained operations the Lynx4MP-70 camera displayed in Figure 6 to best used for both arms. The Lynx Camera is built for accurate visual imaging in LEO and can accurately image the area up to 39 meters at a 550km orbit. Since most CubeSats and small satellites orbit Leo this camera will work well for the current planned objectives of GATOR Arms. In addition, the Lynx4MO-70 is commonly used in docking and rendezvous procedures so its ability to perform in similar application to the current objectives is already verified. The Cameras will then be calibrated to accurately measure the distance of the arm from the satellite and the other arm. The camera for each arm must be calibrated for this purpose and then with the help of a Machine Learning Algorithm will be able to identify damaged areas and the procedure the arms need to follow.

Figure 6: Image of the camera that is planned to be used with the robotic hand for a visual reference.

Automated ISAM operations, 3D scanning and inspection do not require real time downlinks, observers, or full-time operators. Due to this mission commands and instructions will be uploaded and initiated remotely. Uplink and downlink bitrate of approximately 1kbps and 1 Mbps, respectively will be observed during normal engineering operation. Data from tools (tactile sensors, cameras) and stepper motor encoders will be serialized for transmission through the rotary connectors to the computer housed in the bus. The Data transmitted will be as limited as possible to ensure the cost of the continuous operation of GATOR Arms is kept down.

Table I

Operation	**Uplink**	**Downlink**
Emergency	500 bps	10 kbps
Normal / Engineering	1 kbps	1 Mbps
Special	1 Mbps (memory reload)	5 Mbps (mission data)

Thermal

The operating temperature ranges of each component were considered to ensure the operations under LEO conditions. From the temperature conditions of the components and the temperature ranges expected in the satellite’s orbit, a thermal analysis was conducted to determine the insulation needed to stay within the operating range. The operating temperature ranges of the components are shown in Table II.

Table II

Components Temperature Ranges	
Robotic Arm Material (Aluminum)	-80 to 200C
Arduino Nano Every	-40 to 85C
Nvidia Jetson Orin Nano computer	-25 to 80C
TMC5160 stepper drivers	-20 to 75C
4118S-04P Hybrid Stepper Motor	-20 to 50C
Raspberry PI Zero 2 W Temp range:	-20 to 30C
Nema 17 Stepper Motor High Prec.	-10 to 90C
DM332T Digital Stepper Driver	0 to 65C
BigTechtree Octopus V1.1	0 to 50C

The temperature ranges that the satellite will experience in orbit was determined by the System Tools Kit (STK) program with the orbital parameters tested from ISS Zarya 25544. These parameters are similar to the expected orbital parameters of our satellite in LEO. A period of 1 year was used to determine the temperature range the satellite will endure. From STK the determined temperature range is –81.3 to 25.8 Celsius. Since the orbit's lower end temperature is less than all the components used on the satellite, thermal insulation is needed to get the temperature in a range that allows the operation of all components. Different insulation materials were considered for our satellite. The materials considered were Polytetrafluoroethylene (PTFE), Multilayer Insulation Coating (MIC), and Aluminized Kapton. The prices of each material were considered with PTFE being the cheapest at $3-5 per square meter, the MIC and Aluminized Kapton being about the same price around $50 per square meter. PTFE is the cheapest option by far, but this material is subject to eroding in LEO as it could be eroded by Atomic Oxygen. "Existing studies showed that Teflon could be eroded by AO (Atomic Oxygen) in LEO but with a lower erosion yield than most of other spacecraft materials. However, its erosion yield increases in long-term flight experiments, which might be caused by synergism of several environmental effects" [1]. PTFE is subject to erosion in LEO orbit, but PTFE can be considered for short term space operations. For our satellite, MIC will be used as the insulation material, where further thermal analysis and testing will be done to estimate how much insulation is required to ensure safe operations.

Tools and Tool Holder

Figure 7 shows the hand of the Gator Arms along with all of the custom-built tools that are designed to be easily held by the hand. IN figure 6 from left to right is a drill tool, a wrench tool, the hand, screwdriver, and another camera separate from the positioning cameras that will be used for inspections. This camera tool is separate from the positioning cameras and its main purpose will be to perform inspections of the work done by the robotic arm.

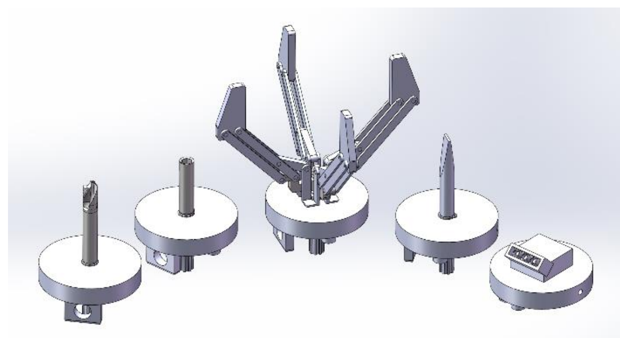

Figure 7: 3D model of the robotic arm and all of the of modular tool examples that the arm is capable of manipulating and completing operations using.

Each tool is optimized to be held by the hand of GATOR Arms to ensure maximum efficacy when performing the tasks relating to each tool. The tool holder will be used to hold all of the different tools for the robotic arm. The tool holder is specifically made to allow the arm an easy way to replace tools and securely put them back. The tool holder shown in Figure 8 is key to ensure the GATOR Arms are a fully modular system

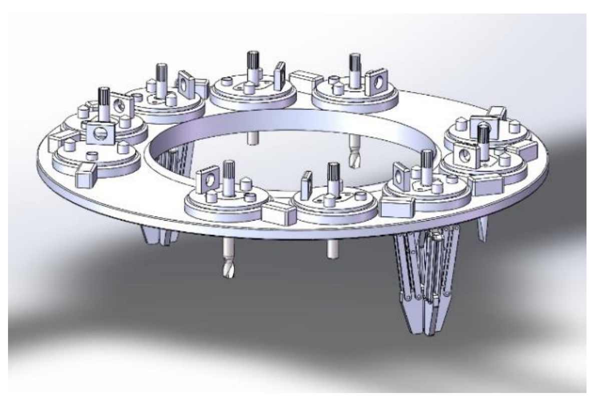

Figure 8: 3D model of the tool holder which will house all 10 tools for the robotic arm.

Failure Analysis

The maximum load experienced by the robotic arm under expected operating conditions will be a ½ inch drilling operation in aluminum. This operation has an optimal drilling force (P) of 50 lbf [2] at a maximum extension of the arm (L) of 30 in, which results (from (1)) in a moment (M) of 1500 inch pounds at the base. The maximum tensile stress (σ) caused at the base by this moment can be calculated with (2), where c is the outer radius of the frame and I is the moment of inertia of the cross section of the tubing calculated with (3). In (3), D_i and D_o are the inner and outer diameter of the tube, respectively. The moment of inertia for the aluminum tube at the base is $0.95889\ in^4$, resulting in a maximum tensile stress of $2.346\ Kpsi$. This stress does not exceed the yield stress of aluminum, which is $40\ Kpsi$ [2]. [3].

$$M = P * L \tag{1}$$

$$\sigma = \frac{M * C}{I} \tag{2}$$

$$I = \frac{\pi ({D_o}^4 - {D_i}^4)}{64} \tag{3}$$

In addition, solar proton radiation was also an aspect that was taken into account. Most electrical components are affected by a solar proton after a dosage of 1000 rads (Si) [4]. However, with a thickness of 0.1 inches of aluminum the radiation dosage absorbed is on the scale of 100 rads (Si) in LEO over a period of 3 years [5]. This means that the GATOR Arms electrical components will likely be safe in LEO for the planned 4 year long mission duration at least from solar protons.

Robotic Arm Dynamics

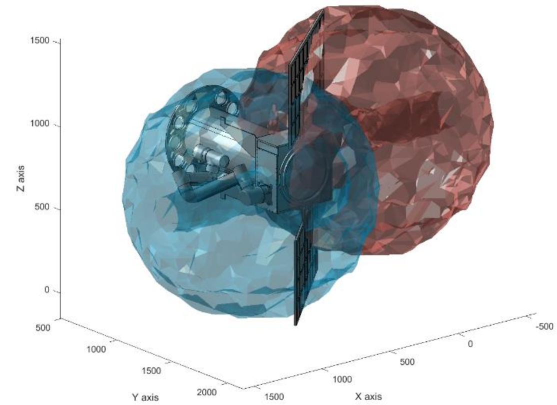

Figure 9: Forward kinematic analysis of the range of motion for both arms.

The Arm design and geometry were compared to other similar arms to validate the geometry of the robotic arms in use by analyzing the respective work envelopes of the different arm configurations. The work envelopes were generated in MATLAB by utilizing a basic forward kinematic analysis to iterate throughout the angle ranges for each revolute joint in the configuration [6], to provide a point cloud of the different locations about the origin the robotic arm could service. Additional MATALB programs were implemented to convert the points clouds into a boundary covering the points cloud to create a work envelope for the robotics arms and contextualize the work envelope by displaying it around the models of the satellite and the arm itself.

The current arm design utilized showed the maximum overlap between the two arms' work envelope amongst the designs tested. This criterion was immensely important given the mission requirement for cooperation between the two arms would necessitate maximum overlap between their envelopes to allow them to work together effectively, as shown in the figure below. For future work developing programs to calculate precise angles ranges for each revolute joint that maximizes the work envelope to aid in the selection of optimized electromechanical equipment like the servomotors. Developing inverse kinematics methods and implementing ML models to allow the arms to autonomously conduct action items.

Manufacturing Procedure

Robotic Arm

The robotic arm will be primarily constructed of 6061-T6 aluminum. The base hub will have its mounting plate CNC machined from aluminum stock and will be otherwise constructed of aluminum tubing. The base hub will have the 3-inch frame tubing welded orthogonally to its side with a rotary electrical joint and stepper motor mounted to rotate the first arm link.

The first arm link will be manufactured using aluminum tubing cut into the necessary length, with two more lengths of tubing welded orthogonally to the primary length, parallel to each other. The two smaller lengths of tubing function as housings for the stepper motors and more rotary electrical joints.

Between the first arm link and the second arm link, a motor joint will be constructed of two short lengths of aluminum pipe. The longer length will house a motor and rotary electrical connector, while the shorter is welded to its side at 90-degrees to connect to another link. This joint is nearly identical to the motor joint on the other end of the second arm link.

The second arm link will be similarly constructed with aluminum tubing cut to length and welded in the correct orientation. The second arm will be constructed differently from the first in that one end is connected concentrically to the motor joint, while the other end is welded to a shorter length of tube at 90-degrees. The shorter length houses the next stepper motor pack and rotary electrical connector.

The second arm link is connected to the wrist motor joint. This joint is nearly identical to the other motor joint, but with a long side that is manufactured slightly longer to accommodate the motor housed within.

The wrist motor joint will be connected through a rotary electrical connector to the wrist, which will be CNC machined to accommodate the specific features required for the tool changing process. A solenoid will be fastened to this wrist to allow for retention of the tools, a stepper motor with a spline shaft coupling will be mounted inside the wrist to power the tools, an a spring loaded pogo pin connector will be used to transmit data and electrical power to and from the tools attached to the wrist. Each of these three components will be purchased off-the-shelf.

Robotic Hand and Other Tools

The robotic hand will have its base CNC machined from 6061-T6 aluminum stock to allow for the complex features required for tool changing and operation to be fabricated. This base will be nearly identical to the bases of all other tools with the exception of the first stage links, which will be welded to the base.

All other links allowing for the opening and closing of the hand, including the fingertips, ACME screw slider (CNC machined), and the ACME drive screw, will be manufactured with 304 stainless steel. The fingertips will feature mounting points for tactile sensors/grippers. The ACME drive screw will be welded to a spline drive shaft to actuate the hand using the stepper motor in the wrist of the arm.

Any other tool that functions using a rotational input (direct or indirect) can be welded to the standardized spline shaft and equipped with snap rings to construct a custom tool for use with the robotic arm. The snap rings retain the tool's translation along the rotational axis with respect to the off-the-shelf needle bearing that allows rotation of the tool for functionality.

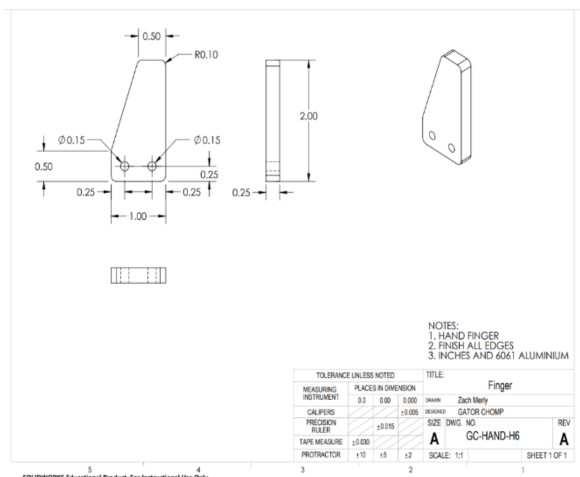

Figure 10: This is a part drawing of the fingertip of the robotic hand. Used as an example of the part drawings that will be used for manufacturing.

Tool Holder

The tool holder will be constructed of 304 stainless steel, water jet or plasma cut out of a large plate into the desired frame shape with holes cut for all 10 tools. Steel cuffs for tool retention will be welded to the frame, and mounting points for the tool retaining solenoids will be machined around each tool hole.

Proposed Mission Overview for Final Product

Flight Test

It is desired that GATOR Arms be integrated into a readymade satellite or platform that can accept data and transmit during frequent (but not necessarily continuous) passes. High data rate X-band is preferred but S-band is baselined. GATOR Arm's CONOPs aim to execute automated commands representative of those to perform repairs on orbit. Testing will be done in a "crawl-walk-run" approach to ensure safety of the host platform. To highlight a specific CONOP to be performed over multiple passes, GATOR Arms will, (i) "wave" automatically, (ii) grip its tools but not remove them, (iii) remove its tools but not perform operations and (iv) will move its arms with tools repairing an "imaginary" satellite. The operations can be verified via GATOR Arm's sensors and the host platforms attitude and power during tests, for which 1Hz is sufficient. This, and other repair-like maneuvers, will show the arm is sufficiently built to withstand the harsh, radiation, micro-gravity space environment. Once the flight test action are accomplished the GATOR Arms can than conduct a more serious trial detailed as Objective 1, 2 and 3.

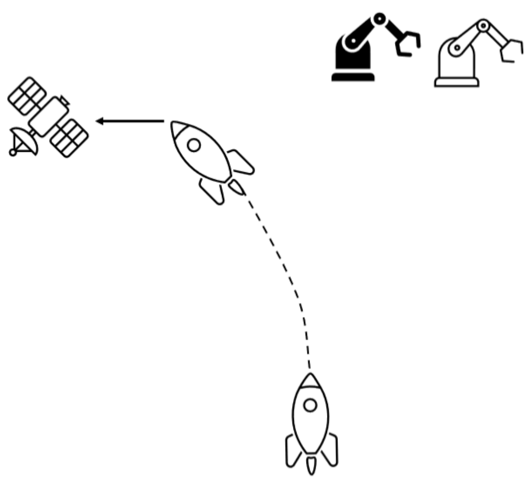

Figure 11: Flight test CONOP visual aid to show plan to get the satellite bus equipped with the GATOR arms and tools to LEO.

Specific requirements are (i) consistent 100W to the arm (or if not, a larger battery will be included in GATOR Arms), (ii) sufficiently large to handle arms of 100 cm length, (iii) support a mass of at least 50 kg. It is preferable if the host is around the size of a 6U-12U CubeSat and deployed to low Earth Orbit. This is to test the hypothesis that robotic arms can be hosted on a vehicle of equal mass for agile repair. Other vehicle mounting, such an ESPA port, is acceptable at reduced risk.

Objective 1 Drilling

The first Objective to test the readiness of the GATOR Arms during a test flight is to test whether the arms can accurately and precisely drill holes into a satellites surface, simulating an important aspect of a repair operation that could be done on a satellite. The task for this objective will be to drill four holes, all of the same diameter and depth, in a predetermined pattern using the drill in Figure 12. The proposed pattern is for the holes to represent the corners of a square with a side length of 2 inches, meaning the center of each hole will be two inches apart from the center of the other holes in the adjacent corners. This test aims to prove the arms' ability to complete a precise action repeatedly, as well as its stability when conducting a drilling maneuver.

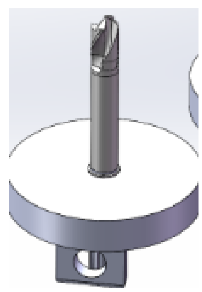

Figure 12: Closer look at 3D model of the drill tool.

To prove the working capacity of the GATOR Arms each hole must be drilled at the same depth and diameter. The arms will need to be thoroughly tested and calibrated before this objective occurs to ensure the maximum chance for it to succeed. The stability of the arm and drill must be tested while the arm is in the space environment to ensure the arm remains stable in microgravity and vacuum conditions.

The cameras mounted to the arms will send data back to us regarding the progress of the arms and the holes being drilled. This data will be sent as consistently as possible so if any problems occur an emergency stop may be placed on the arm. Once the holes are drilled images of the completed formation will be sent to verify the successfulness of the objective.

Figure 13: CONOP visual aid of robotic arm using drill tool

Objective 2 Screwdriver

Following the success of objective one objective two can begin. The second objective of the GATOR Arms is to successfully screw a plate onto the satellite surface that had holes drilled into it. This test objective will focus on the arms' ability to align and secure the plate over the previously drilled holes. The plate will be precisely manufactured one thousand of an inch (1 thou) to align with the holes that are planned to be mad in objective one with the screw being able to go through the plate holes and into the holes of the satellite.

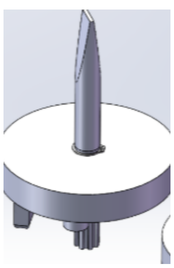

Figure 14: Closer look at 3D model of the screwdriver tool.

The first part of objective two will be for GATOR Arms to secure the metal plate and position it over the in-place holes. The screws will all be partially secured into the plate beforehand to ensure they are not able to float out. The main component of this test, “the screwdriver” will then be equipped by the arms and aligned with the grooves of each screw. Then torque will be applied to each of the screw to secure the plate onto the satellite.

This will test the GATOR Arms’ capability to apply an exact amount of torque. If the arms use too little torque and only turn the screw for a short amount of time the screw will be loose, and the plate will not be properly secured. On the other hand, if too high torque is applied the screws may be stripped or damage may be done to the satellite. In addition, one arm must always be used to secure the plate to the satellite until at least one of the screws is in place.

The successful completion of objective two will represent another step in proving the reliability of GATOR Arms. Once objective two is complete the ability of the arms to switch tool from the drill to the screwdriver and use both to successfully perform a simulated repair will be demonstrated. The Camera will consistently send visual confirmation that the objective is being completed properly and send visual conformations that the one last time when the objective is completed

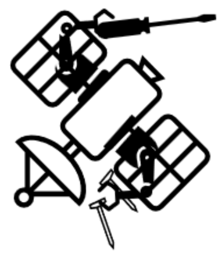

Figure 15: CONOP visual aid of robotic arm using screwdriver tool and nails

Objective Three Final Tool Equipping Check

This last test will focus on ensuring that each of robotic arms/hand will be able to equip all of the tool from the holder then place the tools back and equip another tool. This test is to ensure all of the tools do not have any issues when being equipped and that transitioning from one tool to another occurs smoothly and without damage. A picture will be sent each time a tool switch is completed to verify its success. This test will show that the arm is able to properly clutch each of the remaining tools and is the final objective for this proposed first mission. An objective further down the line would be for the GATOR arms to be able to clutch a CubeSat mid-flight. However, that will be done after more extensive fine tuning and verification that the arm works well performing simpler tasks in a space environment.

Risk Mitigation

Part of Gator Arms being a set of two arms is that it creates a redundant system. While the loss of one arm might result in the loss of certain capabilities of the system, other tests can still be performed if only one of the arms partially or completely fails. A way the arm can partially fail is the loss of one motor and a complete failure would be the loss of all motors. In this way almost all parts of the GATOR Arms system are designed in sets of two with two cameras and two computers as well. to ensure there is some redundancy in order to minimize the risk of the GATOR Arms system.

Budget

Prototype 1

Tables 3-6 represent an itemized budget for the Forst prototype of the GATOR Arms which will be worked on. Red boxes are dimensions not currently fully defined or harder to define in the context of a table. The Hands will be estimated to cost around a thousand dollars for prototype 1 as prototype 1 will not include tactile sensors

Table III

Arms	Dimensioning (in^3)	Cost	Count	Cost
Motors	N/A	$400.00	6	$2,400.00
Planetary gears	N/A	$500.00	6	
Rod 1	~85	$60.00	1	$60.00
Rod 2	79.8	$43.99	1	$43.99
Joint Connector	10.6	$10.00	2	$20.00
Rotational Casing	24.59	$19.23	5	$472.93
Base	28.08	$59.63	1	$59.63
Base Rot. Case	51.61	$34.33	1	$34.33
1 Arm total			23	$3,090.87
2 Arm TOTAL			46	**$6,181.74**

Table IV

Attachment Holder	Dimensioning	Cost	Count	Cost
Circular Holder	150	0	1	$0.00
Spline	4 ft long	$8.52	10	$8.52
Mounted Roller Bearing	N/A	$17.70	10	$177.00
Snap Rings	pack of 100	$13.63	20	$13.63
tool connection	2 foot, 3.5 diameter	$190.76	10	$190.76
Attachment Holder TOTAL				**$389.91**

Table V

Attachments	Dimensioning	Cost	Count	Cost
Wrench	N/A	$9.47	2	$18.94
Drill	N/A	$39.93	2	$79.86
Screw Driver	N/A	$8.52	2	$8.52
Camera	124.5 x 30.5 x 26.5	1700	2	$3,400.00
Attachment TOTAL				**$3,507.32**

Table VI

2 Arms	**$6,181.74**
Attachment Holder	**$389.91**
Attachments	**$3,507.32**
Hand	**$1,000.00**
Total Cost	**$10,689.06**

Planned Cost

The cost shown in Table 7 represents the planned cost to bring GATOR Arms all the way up to TRL 7. This includes University IDC costs, payment for student and faculty working on the project, and the cost of creating each prototype.

Table VII

Equipment- Low fidelity model	$2,500
Equipment - Thermal, Vacuum, and Vibrations Testing	$25,000

Equipment - 1st Prototype (exit criteria TRL 4)	$10,681
Equipment - 2nd Prototype (exit criteria TRL 5)	$13,750
Equipment - Engineering Model (exit criteria TRL 6)	$35,000
Travel	$10,000
Equipment -1st Prototype - Extra for Risk Mitigation	$10,000
Equipment - 2nd Prototype - Extra for Risk Mitigation	$13,750
Salaries (1 month PI time, 2 grad students, 9 undergrad students)	$188,114
Fringe	$11,656
Tuition (2 Grad Students)	$30,355
Indirect Costs (53.5%)	$112,227
Total	**$462,352**

Conclusion

In conclusion this paper proposes the development of a cost effective, interchangeable set of twin autonomous robotic arms represents a significant step forward in the field of In Space Servicing and Manufacturing (ISAM). The GATOR Arms make uses advance visual sensors, changeable tools, and a small-scale design to keep cost down ensure that the arms can conduct a wide range of repairs and have the potential to conduct recovery and repositioning operations in Low Earth Orbit. The arms will make use of current machine learning ability and autonomous systems in order operate effectively in space without constant commands. In addition, it will make use of UHV motors to survive the vacuum of space, and the arms will be surrounded by a layer of aluminum thick enough to provide sufficient shielding from radiation in most general cases in Low Earth Orbit.

The GATOR Arms hope to strike a balance between cost effectiveness and lifespan. The proposed lifespan of 4 years based on the material and motors is suitable for most missions and by sticking to lower cost materials like aluminum we ensure the cost of the arms is kept down. In addition, by ensuring our arms are more modular and smaller scaler than many previously designed robotic arms it can be more easily mass produced and adopted. This technology has the capability to increase the lifespan of satellites in orbit by making routine repairs and lower the number of times replacement satellites will need to be remade and sent back up through expensive launches.

This innovative approach and method to the development of robotic arms changes the way orbit servicing, repair, manufacturing, and maintenance is done. These arms hope to play a pivotal role in thew emerging field of ISAM and bring about a more cost-effective era of space exploration and satellite design.

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