

AUTONOMOUS SPACE PROCESSOR FOR ORBITAL DEBRIS ADVANCED DESIGN PROJECT IN SUPPORT OF SOLAR SYSTEM EXPLORATION

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Abstract

This paper is regarding a project in the Advanced Design Program at the University of Arizona. The project is named the Autonomous Space Processor for Orbital Debris (ASPOD) and is a NASA/Universities Space Research Association (USRA) sponsored design project. The development of ASPOD and the students' abilities in designing and building a prototype spacecraft are the ultimate goals of this project. This year's focus entailed the development of a secondary robotic arm and end-effector to work in tandem with an existent arm in the removal of orbital debris. The new arm features the introduction of composite materials and a linear drive system, thus producing a light-weight and more accurate prototype. The main characteristic of the end-effector design is that it incorporates all of the motors and gearing internally, thus not subjecting them to the harsh space environment. Furthermore, the arm and the end-effector are automated by a control system with positional feedback. This system is composed of magnetic and optical encoders connected to a 486 PC via two servo-motor controller cards. Programming a series of basic routines and sub-routines has allowed the ASPOD prototype to become more autonomous. The new system is expected to perform specified tasks with a positional accuracy of 0.5 cm.

Introduction

The subject of orbital debris has been reaching the spotlight since SkyLab's degenerating orbit put the world on alert as to where the debris that survived reentry would touch down on Earth. These problems have not gone away and are currently affecting today's space missions, as was demonstrated when Discovery's crew in September of 1991 and Atlantis's crew in November of 1991 had to alter their orbits in order to avoid a piece of space junk. The actual debris had a trajectory that would intersect NASA's four-mile safety envelope for shuttle missions. These events are a good indication of the growing trouble caused by orbital debris. Table 1 is a short outline of the types of problems caused by orbital debris.¹

Table 1 Several problems with orbital debris

- | |
|---|
| 1. Loss or damage to satellites and spacecraft by collision with debris |
| 2. Interference with astronomical observations on Earth and in orbit |
| 3. Accidental reentry of satellites and other space hardware |
| 4. Interference with scientific and military experiments |
| 5. Spread of nuclear materials in orbit and on Earth |
| 6. Potential explosions of unused fuel |

Presently there are over 7500 pieces of orbiting debris of sufficient size to cause a disaster similar to that of the Challenger. Furthermore, there are countless numbers of untraceable pieces of smaller debris that are capable of causing enough damage to a satellite to make it inoperable. The kinetic energy related to orbital debris is the significant problem. Table 2 is a representation of the possible effects from orbital debris collisions at a velocity of 10 km/s (22,369 mph, i.e., kinetic energy).²

Table 2: Comparisons of kinetic energy of debris and collision effects

Particle Size (Diameter)	Effects
< 0.01 cm	Surface erosion
< 0.1 cm	Serious damage
0.3 cm at 10 km/s (32,630 ft/s)	Bowling ball at 60 mph (88 ft/s)
1.0 cm aluminum sphere at 10 km/s	400 lb safe at 60 mph

These small pieces of debris have also been responsible for small craters in the space shuttle's windows on several missions, thus requiring the windows to be replaced after each mission at a cost of approximately \$50,000. Most recently, the new shuttle Endeavour received a small crater in one of its windows which was determined to be caused by a small piece of debris. This is a direct result of placing satellites into orbit without considering what to do with them or their rocket boosters after their useful life has expired. Figure 1 is an illustration of the artificial orbital population.³

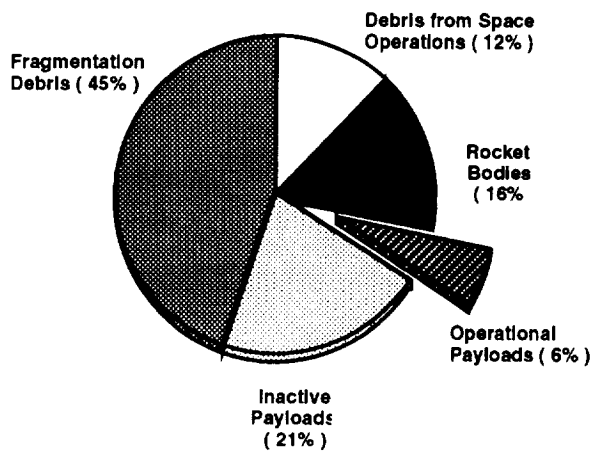


Fig. 1 Orbital population (Dec. 1989)

This figure shows that only 6% of all the artificial objects in orbit are functioning satellites. The rest of the objects are considered orbital debris. The table below shows the major elements of orbital debris.¹

Table 3: Elements of orbital debris

<ul style="list-style-type: none"> • Deactivated spacecraft or satellites • Spent rocket stages • Paint flakes • Fragments of rockets and spacecraft • Engine exhaust particles • Spacecraft rocket separation devices • Spent Soviet reactors • Intentional break-up of orbiting payloads
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There are many myths regarding the seriousness of the debris problem previously mentioned. Some such myths include:

1) The major problem posed by orbital debris is the inability to track accurately the trajectory of the smaller pieces. [This is in part true; the smaller pieces are the reason for concern. However, it must be realized that the larger pieces through orbital collisions and explosions of excess propellant are the cause of the smaller pieces of debris.]

2) The problem of space debris will not be significant until the year 2000. [Why wait until the problem becomes serious in order to search for viable solutions? Furthermore, it can take about 10 years to develop a space craft from conception to production; thus there is no better time to start than the present.]

3) The body of knowledge about orbital debris is not well defined; thus more studies are needed to learn more about the problem. [This is an unfounded rumor. In fact, the majority of the larger pieces of debris are currently being tracked by the Space Surveillance Network (SSN) which is operated by Department of Defense. Also there are databases that have information about the large debris (i.e., trajectories, velocities, mass, geometry, etc.).]

Fortunately, students at the University of Arizona under the guidance of Dr. Kumar Ramohalli have been able to see through these myths and are now concerning themselves with a means to solve this problem. The concept of an Autonomous Space Processor for Orbital Debris is the answer to sweep up the problem of orbital debris. The two major goals of the ASPOD spacecraft are to deal with the orbital debris problem (by processing the trackable large pieces of debris before they have a chance of becoming small, untraceable projectiles that potentially could cause a lot of damage) and to utilize the resource (i.e. the debris) that is already in orbit (by using the materials from the debris to produce or build new device that will serve a purpose). The goal of ASPOD is to process large pieces of debris. The approximate number of objects and their total mass are shown in Table 4.²

Table 4 Approximate number and size of artificially-made orbital debris

Object Size	Number of Objects	Percentage of Objects, %	Total Mass	Percentage by Mass, %
> 10 cm	7,000	0.2	3,000,00 kg	99.97
1 - 10 cm	17,500	0.5	1,000 kg	0.03
< 1 cm	3,500,000	99.3		

Although objects over 10 cm in size constitute less than 1% of the number of objects in orbit, they contribute to over 99% of the total mass of orbiting objects.

Another misconception is that in the vastness of space, it is virtually impossible to rendezvous with orbital debris and that the propellant requirements to do so are too great. This is not true. In fact, a study conducted by the University of Arizona in 1989 identified several specific inclinations in which a majority of the large debris exist (see Figure 2).³

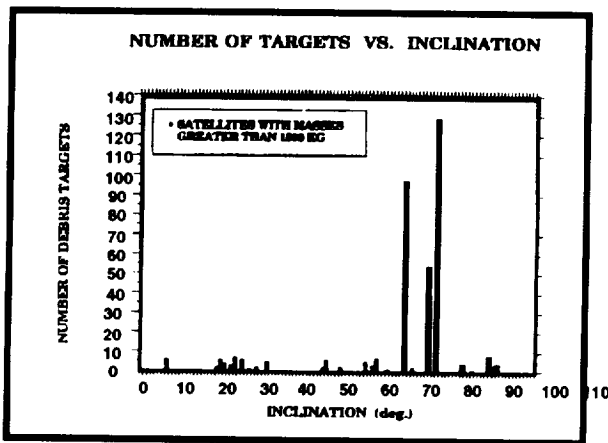


Figure 2: Distribution of orbital inclinations

Mission feasibility studies have shown that one of the envisioned spacecraft could process at least five of the large pieces of debris with reasonable propellant requirements. This is accomplished by taking advantage of nodal regression differences and the use of classic Hohmann transfer.³

ASPOD's Basic Mission Profile

The following is the overall mission scenario:

1. Launch from booster or Space Shuttle.
2. Use propulsion and programming to enter orbit and rendezvous with target debris.

3. Rendezvous with debris and use programming and one of two computer-controlled robotic arms to retrieve debris.
4. Programming selects the proper placement of second robotic arm to grip the piece to be cut off.
5. Both arms then move debris into the focal point of solar cutting device (solar cutter is an array of mirrors and Fresnel lenses).
6. After the piece has been cut, the second arm places the piece in storage bin. The process (from 4 to 6) is repeated until whole debris is placed in storage bin.
7. Programming instructs ASPOD to rendezvous with next target debris (steps 3 to 7 are repeated until all target debris has been processed).
8. ASPOD has then three options depending on retrieved payload i.e., orbital debris:

- a) rendezvous with Space Shuttle where debris will be downloaded and returned to earth. ASPOD will then be refueled and given new instructions and new target debris.
- b) rendezvous with future Space Station where debris will be downloaded and remanufactured for other uses.
- c) burn up on reentry into atmosphere.

This project was initiated in 1987 and has become an integral part of the Advanced Design Program at the University of Arizona over the past several years due in part to an increased interest in the problem of orbital debris and the continued funding of NASA/USRA. Moreover, the ASPOD project has met with great support over the years from both the University of Arizona and the surrounding community, resulting in numerous appearances in both local and national newspapers and news broadcasts.

Progress

Since 1987, the ASPOD project has maintained a steady level of progress, each year enhancing the former year's design along with incorporating necessary additional systems into the satellite to ensure that it will be truly be autonomous when completed. In this respect, the prototype

(test-bed) has excelled from the basic concept of a debris retriever to that of an integrated machine capable of maneuvering a piece of debris with a robotic arm through a focal point of a solar array that has utilized a solar tracker to align itself with the sun in order to maximize its cutting potential.

Consistent with the USRA philosophy, a new group of undergraduates was involved with the ASPOD project this year. This year's team consisted of 14 undergraduates and two graduate students with varying majors and interests. A complete list of these and past students can be found in the Appendix.

Arm

The ASPOD design group was tasked with designing a second robotic arm for the ASPOD satellite. Improvements that were required included a greater increase in reliability, a lighter structure, higher stiffness, drive system simplification, and a high degree of controllability. The arm's improvements must be accomplished while maintaining the original arm's degrees of freedom and rough link lengths.

The design group that undertook this project included Paul Chinnock, George Williams, Peter Wegner, and Curt Bradley. Paul Chinnock was responsible for the design of a light, rigid structure of high reliability and easy to manufacture. George Williams was charged with drive system design. The drive system was required to be light, consume low energy, be very reliable, and fulfill motivation needs for the loading conditions specified. Peter Wegner needed to engineer the control system with a closed loop feed-back control using encoders. In addition the system needed to be light, to be very accurate, and to work in close conjunction with a remote computer for precise position control. Curt Bradley needed to design a support frame on which to mount the arm and straddle the mirror frame. Within the support frame design area, the arm's base needed to be positioned to maximize its usefulness.

The first semester consisted of brainstorming and iterative paper-based design. The design (see Figure 3) was finalized, and parts were ordered for manufacturing and assembling in the Spring semester. Throughout the manufacturing process, further simplifications were made to the individual pieces to shorten machining time. The entire two-semester project was packed with educationally rewarding experiences.

The arm is designed with linear ball-screw-to-ball-nut drives for high efficiency, reduced stresses at the axles, simplicity, and lightness. The arm's structure is built of

composite links and aluminum joints. The base is designed to travel a full 360 degrees of rotation and therefore uses a gear and chain assembly. Links are preloaded to increase stiffness. The arm's end has been designed to accept the arm end-effector.

The linear drives have preloaded ball nuts that eliminate play induced by wear and tear on the arm. The ball-screw-ball-nut linear actuator exceeds the first arm's drive system in reliability, reduced play, simplification, lightness, and reduced stresses. The arm's drive motors are DC brushless and offer torque for acceleration and deceleration for placement speed of 90 degrees per minute. The arm has been demonstrated at much higher speeds. Lagrangian dynamics was used to determine the torques required for all conditions. All three motors are the same and have 195 oz. of continuous torque.

The control system uses optical encoders to position the arm to an accuracy of 1 centimeter when loaded and unloaded with a 1-pound load. A 486 computer with two three-channel control boards is used for control. The controller boards convert the computer's digital signals to analog signals for the motors. The boards' output signals are amplified to the DC motor's requirements for input by two amplifiers. The controller cards, in addition to translating signals, have built-in stability programming for set bandwidths. The channels on the boards each have position, velocity, and acceleration registers. The optical encoders offer 270,000 pulses for a joint's entire range of motion exceeding accuracy requirements.

The Base Support Frame has carbon-graphite composite links preloaded with centered bolts and joints made of aluminum. The structure exceeds strength requirements and stiffness specifications. The deflection under double the load requirement (2.2 lbs) and worst torque position is 6.35 mm including arm and base structure linked.

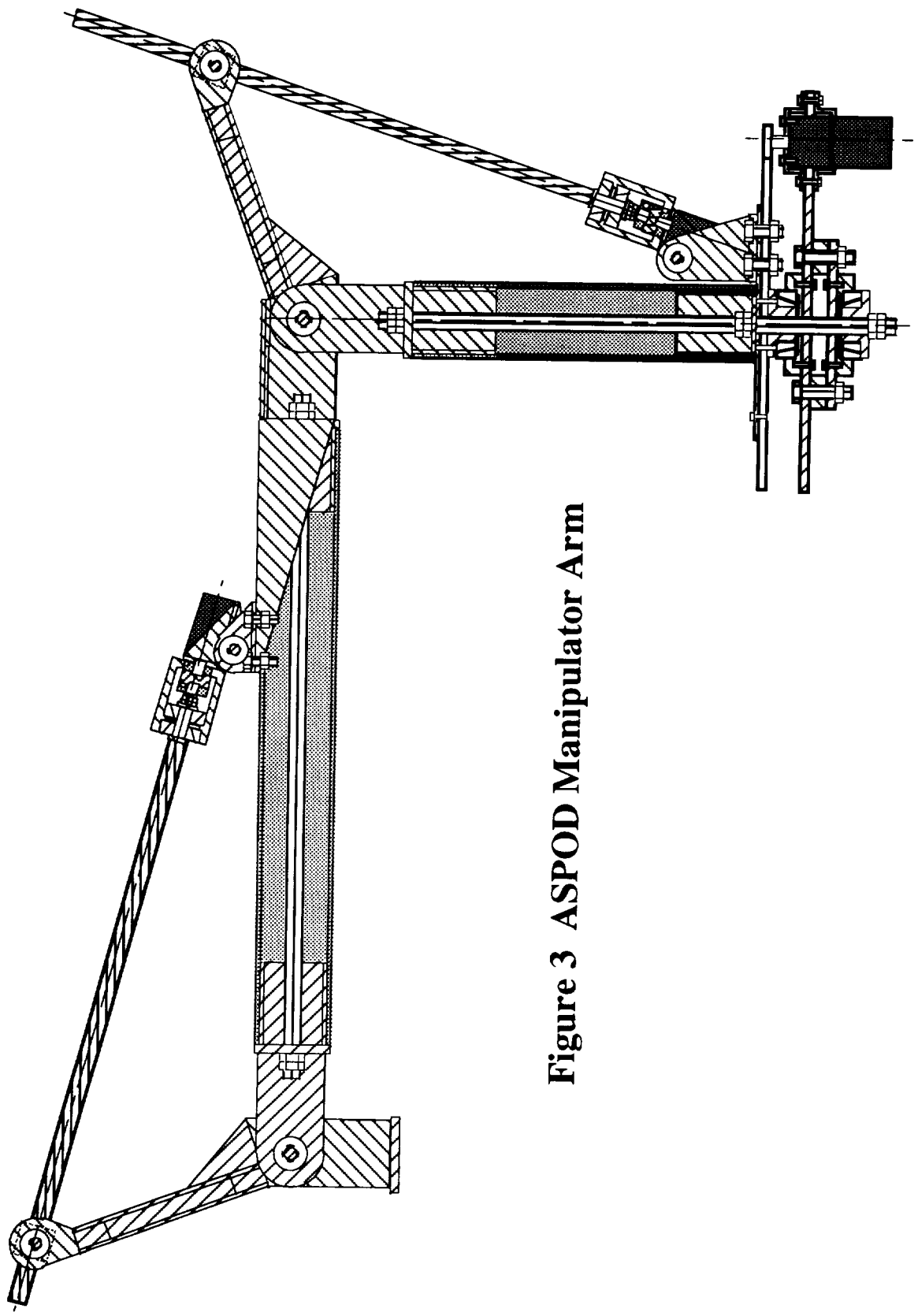


Figure 3 ASPOD Manipulator Arm

End-Effector

Operating in conjunction with the ASPOD arm is the end-effector. The end-effector was designed as part of the ground-based working prototype for one of the twenty-first century's advanced space systems. The following were the original specifications to be met by the Autonomous Space Processor for Orbital Debris end-effector system.

GRIPPING ABILITY: The end-effector must be able to grip various sizes and shapes. It is proposed that it be able to pick up an object with a maximum weight of 1 lb. and that the jaws open 5 inches.

DEGREES OF FREEDOM: The design will have three degrees of freedom. The gripper will open and close. The "wrist" joint will rotate and the "elbow" joint will be a pinned hinge joint.

MASS: A maximum total weight of 10 lbs has been set for the end-effector and its components. This will lower the torques it must overcome while being tested on Earth and decrease the weight that will need to be lifted to orbit.

SPEED: A suitable range for the operation of the effector will be from 1/16 to 3/16 inches per second (in/s). The wrist will rotate in the range of 2 to 8 revolutions per minute. The elbow joint will move as slowly as necessary to keep acceleration at a minimum.

SENSORS: Encoders in joints will be used to relay rotation positions.

MOTORS: The end-effector and arm will be powered by 12-24V DC motors. Individual motor sizes will be determined by the torques they are required to produce.

COMPATIBILITY: The end-effector will be mounted on the robotic arm which is also under development. Cooperation with the robotic arm group will insure that the designs are compatible.

DRIVE SYSTEMS: A system of gears, drive screws, and chains will be used to relay torques from motors to joints.

TOLERANCES: Because of the high degree of accuracy required, machining tolerances of 0.002 inches must be adhered to on all load-bearing members.

Achieved Design Specifications

The exact specifications for the ASPOD end-effector system are shown below.

GRIPPING ABILITY: The end-effector is able to grip objects of various sizes and shapes. It produces a

gripping force of approximately 8 pounds with a maximum opening range of 5 inches.

DEGREES OF FREEDOM: The end-effector design incorporates three degrees of freedom. The gripper opens and closes along a linear track. The "wrist" joint rotates more than 360 degrees in either direction. The "elbow" joint is a pinned hinge joint that moves through an angle of 220 degrees.

MASS: The end-effector weighs a total of 9.2 pounds. This meets the 10-pound limit set in the original design specifications.

SPEED: A suitable range for the operation of the hand will be from 1/16 to 3/16 (in/s). The wrist and elbow joints rotate between 6 and 8 revolutions per minute. This minimizes the inertial acceleration.

SENSORS: Magnetic encoders attached to the end of the motors are used to relay rotation positions.

MOTORS: The end-effector is powered by three motors. A 360 oz-in 12-V DC motor powers the elbow joint. The rotational joint is run by a 670 oz-in 12-V DC motor. And a 200 oz-in 24-V DC motor powers the gripper.

COMPATIBILITY: The end-effector is attachable to the parent robotic arm, which in turn works with the rest of the systems on the ASPOD vehicle.

DRIVE SYSTEMS: For all three degrees of freedom, power is transferred from the gear motor through shaft couplers and drive shafts. For the gripper and bending joints, a series of gears is used to relay power. But the rotational motor transfers torque by direct drive.

Beyond the basic quantitative constraints, the design team also followed a set of qualitative constraints or goals. The main concepts addressed by the design are efficiency, reliability and flexibility. To make the design "efficient" the prototype is representative of an uncluttered "common sense" assembly. The reliability of the end-effector components implies protection from failure and accidents, but also easy repair if an accident should occur. Finally, since the ASPOD system is still in the optimization stage of development, the end-effector is designed to be flexible with respect to changing performance needs. The result of careful design and analysis is shown in Figure 4. In this figure several general design features can be seen as examples of efficiency, reliability, and flexibility.

Notice the efficient layout of the components of the design. The twisting joint is situated before the bending joint. This arrangement better utilizes the capabilities of the bending joint. If the position of the joints were reversed,

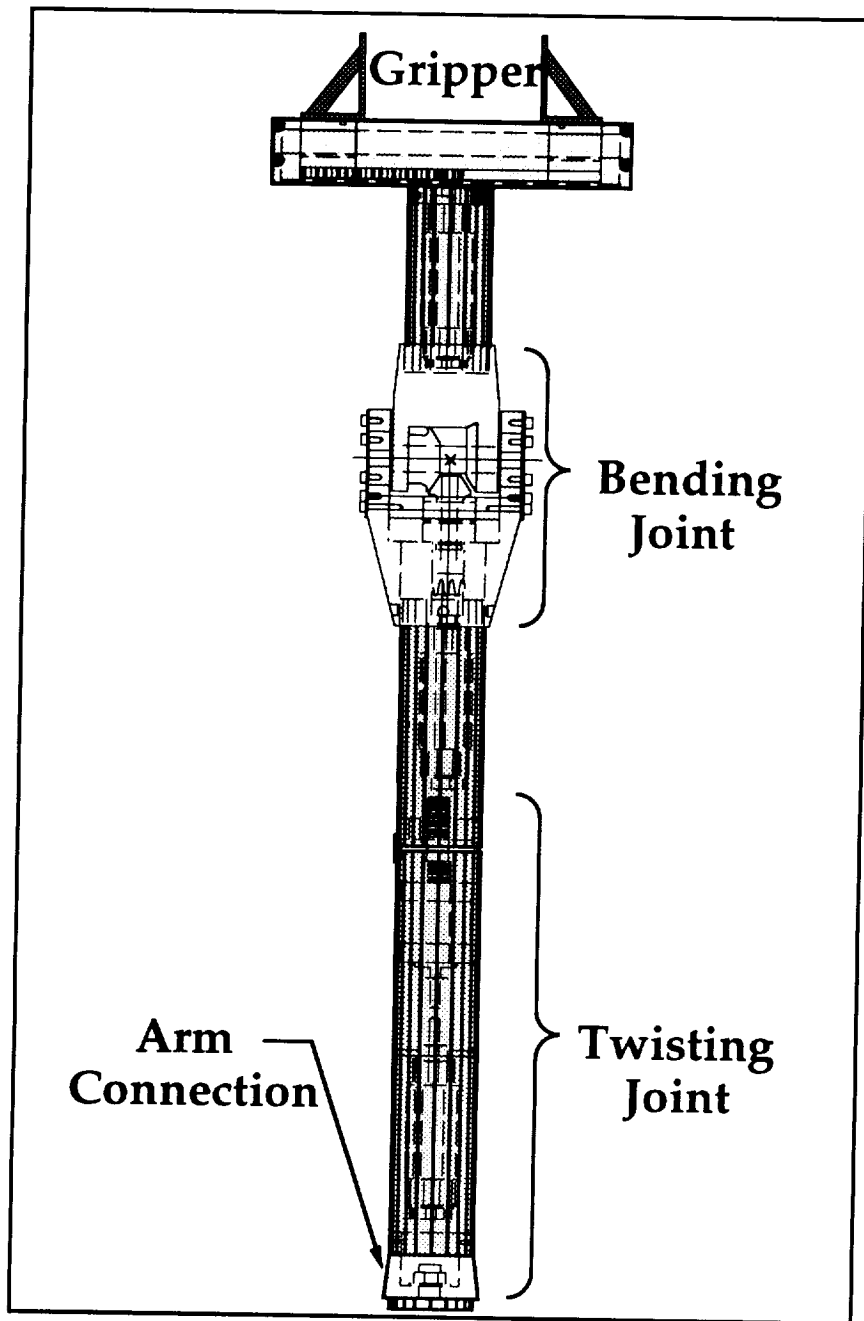


Fig. 4 ASPOD End-Effector

the bending joint would be redundant with the rest of the arm joints. Also, the selection of compact, high torque gear motors manufactured by "Micro Mo" allowed the designers to place the motors at each joint inside the aluminum support tubing. The internal motors are protected from the environment, while the short distance to the applied joint eliminated the need for complex drive systems. Along with the motors, all of the gearing and most of the wiring are enclosed for protection. The result is an efficient, uncluttered design.

The design layout also contributes to high reliability. High precision fits and internal mountings reduce gear wear while protecting parts. Since the motors are mounted to the joints in assemblies of simple parts, the joints and parts are easily disassembled and repaired in case of a problem.

The design of the assemblies also allows for easy redesign or configuration changes. This flexibility reduces the need for major redesign iterations. The linear gripper utilizes removable fingers on the jaws. This allows jaw redesign and implementation in a matter of minutes rather than longer, more costly periods of time. In addition, since the motors are in single assemblies with their driven joints, switching from the twisting joint first, bending joint second configuration to the opposite arrangement is accomplished in half an hour.

One of the most dramatic aspects of the flexible design is the control system. The control system allows the operator to program a desired output into the terminal. The computer-based control system then calculates the specific system requirements, provides the system commands, and moves the system to the desired state while checking for errors. This process starts at the computer terminal. The user specifies a move using one of the programming methods available. The controller card inside the computer converts the logical command to a voltage command and sends the command to the appropriate axis via the connection card. The power amplifier converts the output signal to an appropriate motor input command signal. While the motor is in a control mode, the controller card reads the encoder output, comparing the output to the desired position. The controller card will move the motor to the desired position and keep it there until another command is given. The major components used in the control system are the actuators, the feedback sensors, the interface hardware, the controller card, and the computer-based instructions.

The actuators used for the arm and end-effector are Pittman and Micro Mo high torque gear motors. The motors used for the bending and the twisting joint require a twelve volt

power output, while the gripper and arm motors require twenty-four volts. The controller card offers a convenient method for adjusting the output signal. Gain and offset potentiometers are supplied for each axis and can be adjusted for a desired output.

In the ASPOD Arm-Effector design, the actuators are all DC motors requiring an analog output from the controller card. Attached to the motors are the feedback sensors. In the case of the three Micro Mo motors, the feedback sensors are magnetic encoders. Magnetic encoders were chosen because they were cheaper and more readily available as an integral package from the manufacturer. The Pittman motors utilize BEI optical encoders reading off the output shaft. The encoders provide two square wave signals 180 degrees out of phase which are decoded into a number of counts per motor revolution. The position of each joint is then determined from a reference. This information is then used to command the motor.

In the control system the encoders and the motors do not interface directly to the controller card. First, the controller connects to a wiring interface card which in turn connects to the power amplifiers and the encoders. The interface card was supplied by Servo Systems with the controller card. The power amplifier circuits were constructed by the design team.

The power amplifier circuits were designed around a National Semiconductor LM12C operational amplifier. The circuit involves two power supplies powering a common bus. Each power amplifier circuit draws power off the bus to distribute to the appropriate motor. Each power amplifier circuit is interfaced between a motor and a control axis on the controller card.

The controller card is the main processor of the control system. The Omnitech Robotics MC-3000 card is a 3-axis controller card designed around three Hewlett Packard HCTL-1000 motion controller IC chips. Two MC-3000's are sufficient for the six axes of control required for the arm and end-effector. Although several control modes are available, the trapezoidal profile mode is being used. Trapezoidal mode is ideal for robotic applications because it offers reasonable velocity and acceleration control with positioning control. An acceleration/deceleration and a maximum velocity are specified by the user. When the card receives a position command, it accelerates the motor until maximum velocity is reached or until the motor is halfway to the desired position. Then the motor is decelerated at the programmed deceleration. After the motor is decelerated, the card checks for position, and adjusts to the programmed value.

Although a decoding program was provided by Servo Systems, a better user interface was desired. The goal was to have a program that fulfilled three objectives. The program should be easy to use, powerful, and, of course, should be able to run the robot arm through fixed routines. Originally the "C++" programming language was chosen for the program. However, it was later decided to use "Turbo Pascal 6.0." Turbo Pascal is easier to learn and compiles more quickly, significantly lessening development time. Turbo Pascal also came equipped with extra libraries for windows and mouse interface programming. These libraries were not included with C++.

To make the control program easier to learn and use, the program was designed to be menu-, window-, and mouse-driven. A window-based menu-driven program arranges methods and commands in a logical system. This interface allows new users with little or no computer experience to learn program basics in less than an hour. In the case of the menu commands, pressing the "Alt" key and the highlighted letter will open that sub-menu. Once the sub-menu is open, a command in that sub-menu may be executed by pressing the key corresponding to the highlighted letter. An alternate, easier method for choosing commands is by using the mouse. With this method, the mouse is used to move the cursor to the desired sub-menu, the right mouse button is "clicked" (depressed and released) opening the sub-menu. Then the right mouse button is clicked while the cursor is over the desired menu item. This procedure will execute the desired menu command. Some commands offer yet an additional method for their use. When each sub-menu is open, some of the commands have key sequences adjacent to them against the right hand side of the box. These key sequences are known as "Hot-Keys". By executing the Hot-Key sequence on the keyboard, the desired command can be effected without having to use the menus. Within this structure, three general control methods are available to adapt to the varying needs of the operator. These methods are a menu-executed trapezoidal command, a programmed set of routines, and direct keyboard or "hand " control.

By using the mouse or keyboard commands to go through the menus the operator can execute a trapezoidal command. A trapezoidal command implies that the maximum velocity and the acceleration/deceleration are specified by the user. When this method is used the position versus time profile is in the shape of a trapezoid. The menu-executed trapezoidal command is advantageous when testing moves in order to build a routine. To see what will happen when a command is executed, enter the test values and execute. If the effect is not desired, return the arm to the original position and try again. By testing commands like this the user can come up with a programmed routine.

Once the user compiles enough commands, the full featured file editor can be used to construct a command file. A command file is constructed by placing the necessary commands (one per line) in a list with any needed values on the line following. To show how these commands might be used, an example routine is shown below.

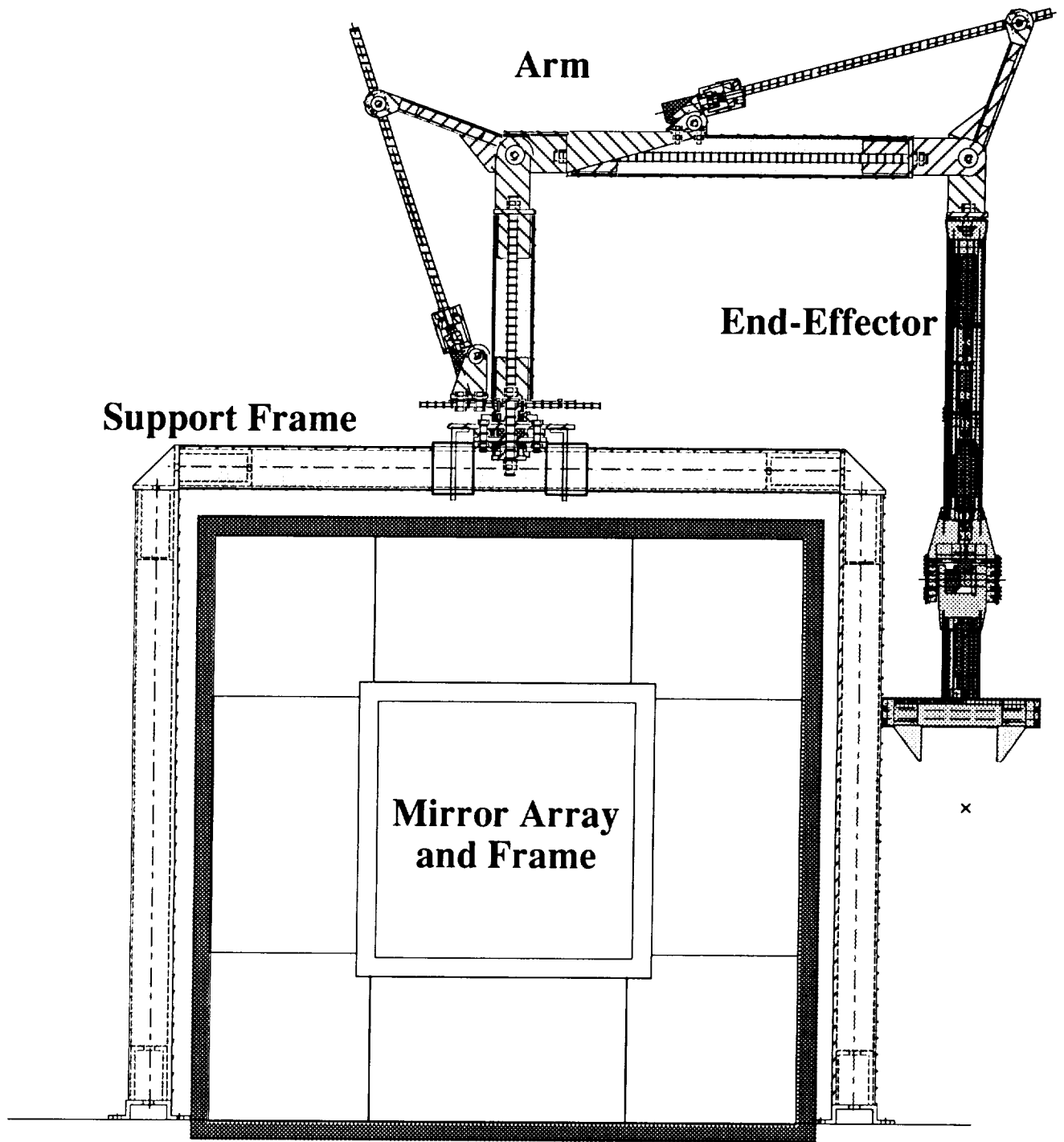
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set_base
776
reset
clr_act_pos
set_gain
10
set_zero
240
set_pole
40
set_timer
40
set_max_vel
127
set_accel
70
set_final_pos
10000
trap_mode
delay
2000
set_base
778
dac
255
delay
2000
dac
127
reset
set_base
776
reset
quit

```

The routine shown above operates the twisting joint of the end-effector and the gripper. After setting the zero, pole, gain, and other parameters, the twisting joint will turn 10,000 encoder counts at max velocity while the program delays for 2000 units (about 400 units per second). Then the gripper will close at full voltage for another 2000 units of delay. Finally the gripper voltage will be set back to zero, and both axes will receive a hard reset. Routines like this are easy to design and test using the file editor inside the controller program.

Figure 5: Robotic Arm, Support Frame, and End-Effector Configuration



Another alternative to trapezoidal commands and command routines is straight keyboard commands. Occasionally, the trapezoidal command mode is not the most convenient method for moving the arm. For this reason a set of "Hot-Keys" has been assigned to positive, negative, and zero voltage out commands for each axis. A list of these commands is located under the Commands menu. To move an axis, the user hits the "Escape" key until the "All axes have been reset" message is displayed. Then the Hot-Key sequence corresponding to the desired motion is hit. The joint should move. Once the axis has moved to the desired point, the user hits the home key to stop the motion. The home key will only stop the last axis to be activated by a voltage out command.

Conclusion

The progress of ASPOD is highly encouraging with several large steps made in both the integrated system and the overall design approach. One major advancement in the development is an additional robotic arm which is capable of working with the existing arm in order to accomplish the tasks that are needed in the removal of orbital debris. This arm is built with a more stable linear drive system and the use of composites as an effort to decrease the weight of the arm itself. The main characteristic of the end-effector design was that it incorporated all of the motors and gearing internally, thus not subjecting them to the harsh space environment. Furthermore, a control system was developed in order to control the arm and end-effector. The total configuration of the arm, support frame, and end-effector is shown in Figure 5.

The future plans are to control both arms in tandem from a computer in order to move the debris into the focal point of the solar cutter. In this respect, a computer code is being written to tell the arms to perform certain functions with a single command from the comm-linked operator.

References

1. Orbiting Debris. A Space Environmental Problem. Office of Technology Assessment, September 1990.
2. Space Debris a Potential Threat to Space Station and Shuttle. General Accounting Office Report, April 1990.
3. Ramohalli, Kumar, et al., Advanced Design For Orbital Debris Removal in Support of Solar System Exploration, USRA Summer Conference, June 1991.

From Sept. 1987 to June 1992, more than 60 students, ranging from high school to graduate students, have participated in the ASPOD program at the University of Arizona.

Student Participation:

1987 - 1988

Graduate Students: David Campbell, Scott Reid

Undergraduate Students: Donald Barnett, Bryan Cindrich, Steve DiVarco, Catherine Dodd, Velda Dykehouse, Robert Flori, Reid Greenberg, Joseph Manning, Jim Matison, Ruzila Mohkhirhadi, James Poon, and Zenophen Xenophontos.

1988 - 1989

Graduate Student: David Campbell

Undergraduate Students: Jeff Brockman, Bruce Carter, Leslie Donelson, Lawrence John, Micky Marine, Dan Rodina.

1989 - 1990

Graduate Student: David Campbell

Undergraduate Students: Dan Bertles, Micky Marine, Ramon Gutierrez, Joseph Huppenthal, David Nichols, Mohamed Saad, Carlos Valenzuela.

1990 - 1991

Graduate Student: Micky Marine

Undergraduate Students: James Bartos, James Colvin, Richard Crockett, Kirby Hnat, David Ngo, Jennifer Putz, James Shattuck, Lee Sword, Sheri Woelfe.

Pre-University Students: Angela Mcfadden, Jennifer Hamilton, Brenda Lundt.

1991 - 1992

Graduate Students: Dominique Mitchell, Brett Taft

Undergraduate Students: Curt Bardley, Sheila Caoile, Paul Chinnock, Greg Hart, Todd Jacobson, Bjoern Kutz, Dave Lye, Matt McCutchen, Angela Mcfadden, Ted Parvu, Mohamed Saad, Glen Sonnenberg, Peter Weginer, George Williams.

Pre-University Students: William Dalby.