Avoiding Space Robot Collisions Utilizing the NASA/GSFC Tri-Mode Skin Sensor

Final Technical Report
NASA Grant No. NAG5-1468

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11/15/91-12/14/92
submitted to
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

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Contents

Chapter 1

Introduction

1.1 Precision contact operations

A capacitance based proximity sensor, the "Capaciflector" [Vranish92], has been developed at the Goddard Space Flight Center of NASA. We had investigated the use of this sensor for avoiding and maneuvering around unexpected objects [Mahalingam 92]. The approached developed there would help in executing collision-free gross motions. Another important aspect of robot motion planning is fine motion planning.

Let us classify manipulator robot motion planning into two groups at the task level: gross motion planning and fine motion planning. We use the term "gross motion" where the major degrees of freedom of the robot execute large motions, for example, the motion of a robot in a pick and place type operation. We use the term "fine motion" to indicate motions of the robot where the large dofs do not move much, and move far lesser than the minor dofs, such as in inserting a peg in a hole. In this report we describe our experiments and experiences in this area.

Fine motion planning is crucial for task completion. A task we are currently looking into is robotic servicing of the Hubble Space Telescope (HST). The robot is expected to open a tool box (designed for HST servicing), identify the correct tool, service the HST, return the tool to the tool box, and close the box. Major parts of such problems fall within the domain of fine motion planning.

We classify the type of robotic applications that we have studied as "precision robotic contact operations in the presence of positional uncertainty". We describe the key words in the following paragraphs.

1.1.1 Contact Operations

The term "contact operation" is used to describe tasks where the robot end effector is required to touch, grasp, mate or in any other way contact an object within its workspace. This class of operation has special significance in space (zero gravity environment). Objects to be manipulated will be always be fastened to a massive object (such as a satellite or the space station). Hence any positioning error implies force build up in the robotic system. Success of the operation would finally depend on the system compliance. Furthermore, each robotic operation has to begin with and/or end in a contact operation. Hence the study in this area is warranted.

1.1.2 Precision Contact

The adjective "precision" signifies the intentional nature of, and the very low contact forces developed during the process. In satellite capturing and servicing, low contact forces are essential to avoid wobbling the satellite. This is achieved by precisely positioning the end effector over the area of contact, and approaching the area with very low velocities.

1.1.3 Positional Uncertainty

Thermal expansion of objects, robot flexibility and manufacturing/ assembly tolerances limits the accuracy with which one can predict the locations of parts in the workspace. This is referred to as "positional uncertainty".

We have worked on two tasks within this domain.

- Berthing of a module (Multiple Mission Servicer) on a satellite (Extreme Ultra Violet Explorer), and
- Opening the Hubble Space Telescope tool box.

Chapter 2

Precision Contact Operations

2.1 The Manipulator Tool as a Sensor

The positional uncertainty issue is tackled with sensory information feedback. Vision and other line-of-sight type sensors are limited by occlusion problems, especially when the end effector is close to the object to be manipulated and is in cluttered environments. Tactile sensors are inappropriate because of the low contact force requirements. We therefore use proximity sensors.

The "Capaciflector" (*Capaci*tive Re*flector*) is a capacitive sensing element backed by a reflector element which is driven by the same voltage as the sensor to reflect all field lines away from the grounded robot arm, thus extending the range of the sensor. This approach is an extension of the technique used in instrumentation systems where a shield or guard is used to eliminate stray capacitance.

The sensing and shield elements can be thin metallic sheets. Hence the Capaciflector provides a unique opportunity to *sensitize the end effector or the tool point* without altering its dimensions significantly. (The electronics can reside elsewhere on the robot.) In fact, the tool itself can be made the sensor[1]. The robot then acts as a probe which can sense the contact area, and as a manipulating mechanism. This unique feature opens possibilities of accomplishing many tasks not possible before!

The tool point can be used (and has been used in our experiments) for

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[1] We found that this was counterproductive for our application. The tool was such a powerful sensor that it could not distinguish the features in the contact area.

scanning the contact area. The scan can assist in identification of objects, verification of target, and alignment of the end effector. At the final stage, raw sensory information can be analyzed to complete the soft contact operation. Details are provided in the following sections.

2.2 Berthing of the MMS

The sample satellite servicing scenario we looked at is attaching the Multiple Mission Servicer (MMS) onto the Extreme Ultra Violet Explorer (EUVE) satellite. We used a Robotic Research Corporation (RRC) robot to manipulate the MMS. A Light Servicing Tool (LST) was attached to the end of the RRC, which holds the MMS and mates the MMS to the EUVE.

The MMS is a rectangular parallelopiped box. It mates with the EUVE satellite, the mating surface being the largest one. Let us call this the front face of the MMS. The MMS has two screws projecing out of the front face, one at the center of the top and bottom edges. These screws mate with internal threads on the mating suface of the EUVE, thus securing the MMS to the satellite. There is an aluminum cone around the mating internal threads for guiding the screw towards the threads. There is a hole running from the back face of the MMS to the back of the screw. This gives the LST access to turn the screw.

In the initial set up, the LST nut runner is inserted through the MMS, and is locked onto the back of the screw. Sensors are placed on the front face of the MMS and over the LST to make the two mating faces parallel to each other, such that a translation along the z axis of the end effector would bring the two screws inside their respective cones.

Once the two faces are brought to this configuration, the MMS is moved along the end effector z axis until the screw touches either of the cone. Then force feedback is used to push the screw in until both the screws are inside their respective holes. The nut runner then rotates the two screws in sequence for the final mating operation.

2.2.1 Planning hierarchy

We had described a system planning architecture in [Mahalingam 92]. We had described that a Local Path Planner (LPP) will be commanding the robot, based on the information it receives from the sensors and the world model. Here we give a further hierarchical breakdown of the LPP, and describe how the Capaciflector information has been used at these levels.

We assume that high level planning, such as obstacle negotiation, will get the robot end effector in the vicinity of the mating zone. As we descend the planning hierarchy, the planning scope decreases and less information needs to be abstracted from the sensory information.

For perfectly inserting the screw in the cone, the longitudinal axes of the cone and the screw must be aligned. Then insertion would be achieved by translation along the common axis. Hence we tackle the rotational and translational alignment problems separately. Sensors are placed on the MMS at various locations. These are used to make the face of the MMS and the mating surface on the EUVE parallel to each other.

When the end effector is sufficiently close to the mating zone, raw sensory data can be sufficient for accomplishing the task. For inserting the screw in the hole, for example, we know that the screw sensor (when moving in a plane parallel to the base of the cone) will send a minimum signal when it is at the center of the cone. We use this basic fact to first center the screw over the cone. Then the screw is inserted inside the cone until the capacitance value reaches some threshold value. The operations of centering and inserting is repeated in sequence until a maximum allowable threshold is reached. Powell's n-dimensional minimization routine is used for finding the center of the cone. The sensor is stable enough for this operation.

This algorithm was tested out on two platforms. The first one was on a T3 robot with a mockup of the mating surfaces, the second one was on the actual hardware described in the above section. We were able to insert the screw in the cone without touching the sides consistently.

Another approach attempted was to determine the rotational and translational errors in one go by imaging techniques. This is described below.

2.2.2 Imaging with the Tool

Let the tip of the screw be the sensor. Let us assume that the screw is above the cone, near its center. The screw is moved in a rectangular grid in its XY plane. The voltage reading (corresponding to the capacitance) is noted at the grid points. The corresponding distance value is computed (from a calibration curve) for each point. A surface can be fitted to this data. We call this surface the "image" of the cone, and we call this process of obtaining data as scanning.

The purpose of imaging is to align the screw axis with the cone axis. First, we need a reference image to determine the positional accuracy. We obtain an image *a priori* with the screw initially lined up with the cone axis. This position of the screw is called the "ideal position", the frame attached to this position the "ideal frame" and the image the "ideal image".

We assume that at the beginning of the insertion task the screw is above the cone and near its center. The cone is scanned at this instant. We call the resulting image the "actual image", refer to the position of the screw as the "actual position" and the frame as the "actual frame".

Our task is to identify the error between the actual and desired positions. If the desired and the actual images are not identical, we know that there is an error in the positioning of the screw. To determine the error, we apply a known transform to the ideal frame, to get a "test frame". We compute the image that would be obtained in this frame, which is called the "test image". We correlate the test and actual images, and converge to a solution.

There are two simplifying assumptions made in the computation of the test image which pose limitations to this approach. First, we use a line of sight model of the sensor in the computation. However, the Capaciflector in some sense integrates the distances to all the conductive particles in the area. Second, the sensor is assumed to be "looking" at the ideal image.

Two surface fitting techniques were tried out. First, we fit a tesselated surface (triangular elements) to the data points. Convergence took about five minutes, the absolute error in orientation determination was approximately 3 degrees. This was unacceptably high. Second, we fit a 2d spline surface to the data. It took an unacceptably long time to converge in the first data set. This investigation has been postponed for a later time.

2.3 Opening the HST Tool Box

The immediate objective of this task is to open the HST tool box, shown in Fig. 2.1. The proposed gripper design which is in the process of being manufactured is shown in Fig. 2.3. It is a basic split-rail parallel jaw gripper, with one of the fingers split into two. The latch has to be opened by removing the pip pin, and lifting the latch up. The pip pin can be only be removed by depressing the tip and pulling the pin out. The split in the finger accomodates the stem of the pip pin, the other finger is to be used to depress the tip. To open the door, the latch has to be opened, a safety brake lever has to be depressed and the door pulled open.

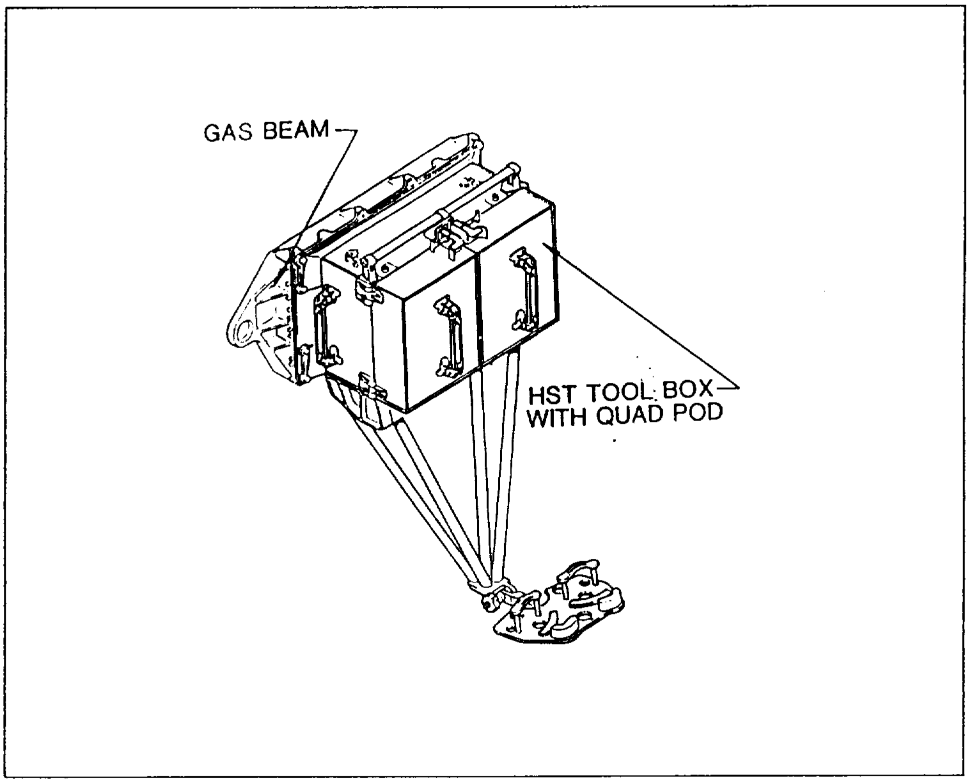

Figure 2.1: The HST Tool Box

The first subtask we are working on is opening the latch on the top of the tool box, shown in Fig. 2.2. The planning hierarchy used here is exactly the same as in the berthing operation. The development is being done on a seven dof RRC arm.

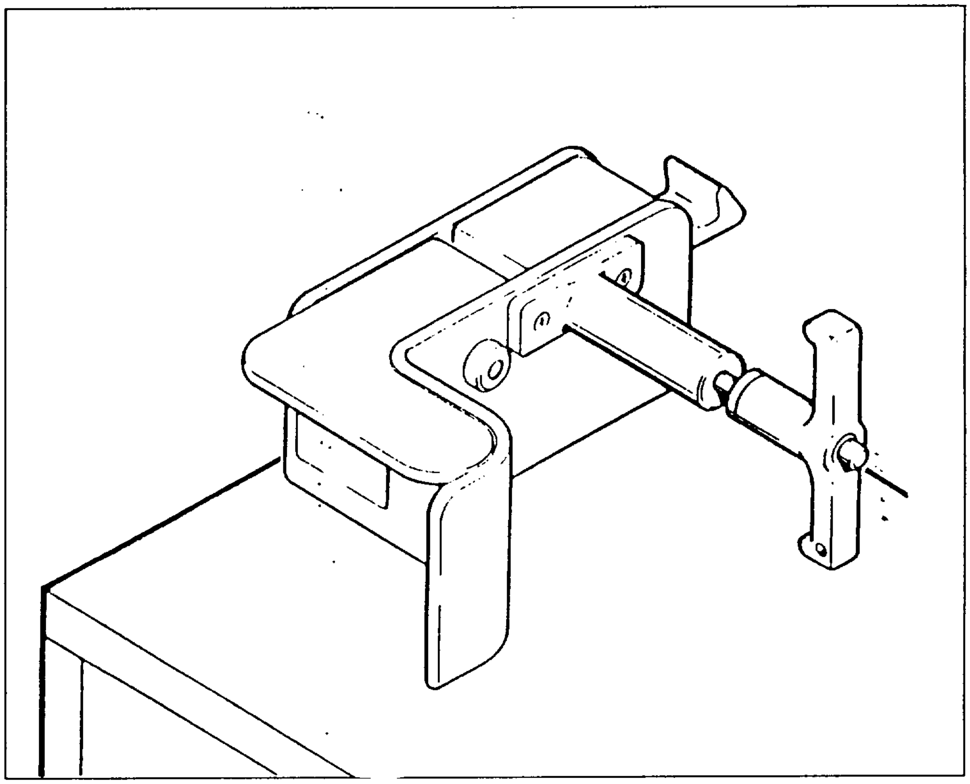

Figure 2.2: Tool Box Latch Details

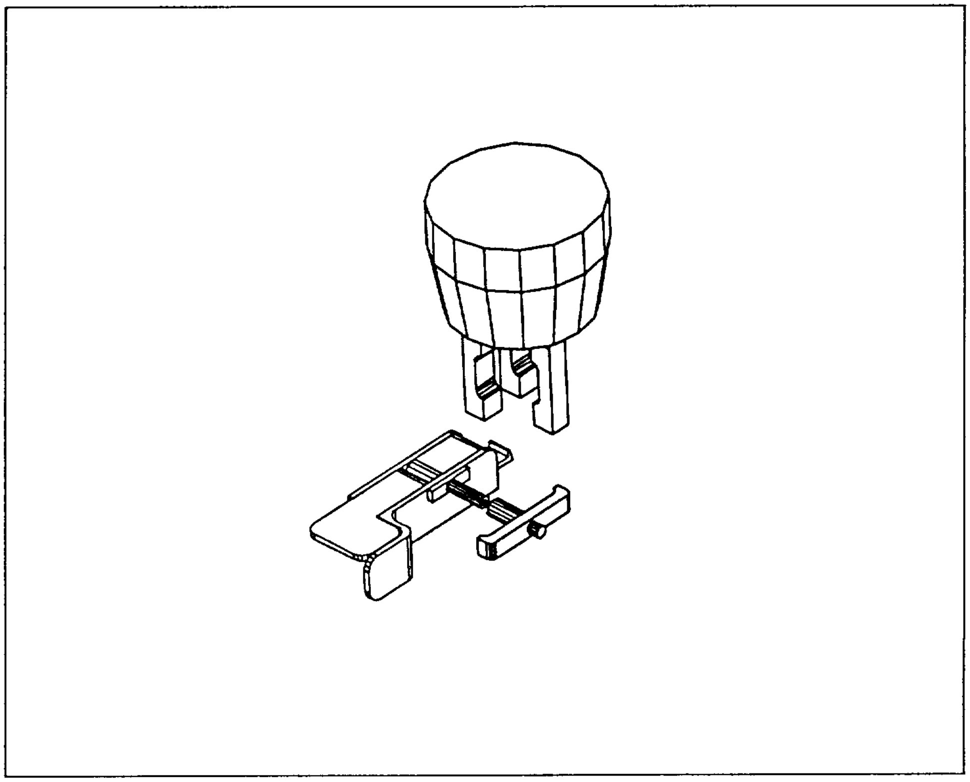

Figure 2.3: Gripper Details

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