Functionality of robot FRIEND for manipulation and maintenance in space

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Abstract

This paper deals with the functionality which space robot FRIEND can perform in the space missions. At the phase of earth prototype, the research is analysing its functionality. The light structure, its great flexibility, its possibility to perform different tasks (maintenance, recovery, subassembly) make the robot as a tool for space.

The Friend robot is designed to complete space structure maintenance missions and, in particular, those inherent in the International Space Station. This paper demonstrates the method used by the Friend robot to grasp an object or carry out an operation once an obstacle has been overcome and points out the methodology to assembly parts in the space structures, like ISS.

1. Introduction

The robot FRIEND (Flying Robot with Intelligently Ended Nursery Dexterity), as reported in References from 1) to 9), is dedicated to the maintenance of space stations. Its lightness, flexibility, adaptability, easy control and telecontrol may perform tasks like a friendly usable system for space stations.

The functions of the robot FRIEND appear strong in front of the applications, which mat cover a large field. Maintenance of the space station, from the external side, is a topic element for the future of reliability and safety of the life in the space.

This paper presents two aspects which must be examined deeply in the design of the robot end effectors and arms, and in the development of software. The topics are the motion on the truss with the obstacle avoidance and the assembly of large elements in the space. The dexterity of the robot FRIEND is clear.

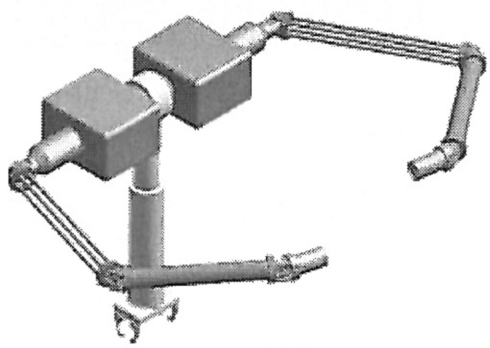


Fig. 1 Scheme of robot FRIEND 4

2. Motion of the robot FRIEND on the space station

In order to move, the robot will "walk " on a special beam until it has reached the point where maintenance is necessary. The robot is able to carry out the requisite operation, i.e. a typical machine tool operation or a more complex manoeuvre.

The procedure follows two different routes according to the type and geometry of the obstacle. There are two obstacle categories : an obstacle is either particularly long or reduced in length. The first category involves a transit strategy above the obstacle whilst the second category envisages a lateral transit strategy.

3. Transit over the obstacle

This strategy can be used for an obstacle that has an indefinite length with, however, the type of height that can be overcome through maximum extension of the docking arm telescopic joint. By using this strategy only one arm can access the work area, whilst the second is used to increase system stability. The robot

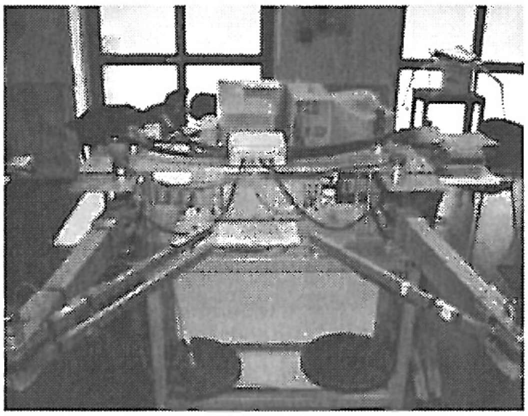


Fig. 2 Prototype of robot FRIEND in Robotics Laboratory, Politecnico di Milano

approaches the obstacle, by moving along the beam structure, "step-by step ".

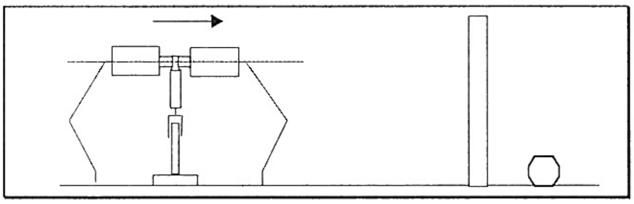


Fig. 3 The robot "walks" along the beam in the direction of the obstacle

The optimum distance at which the robot will stop when faced with an obstacle can only be calculated with precision by simulating all the operations that the robot must carry out.

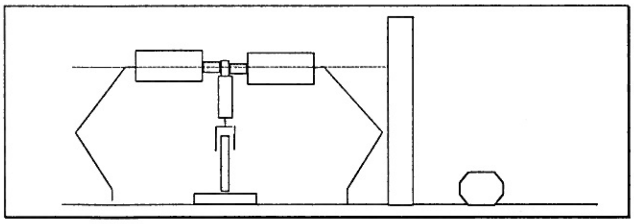


Fig. 4 The robot positions itself as closely as possible to the obstacle compatibly with the "step" strategy and docks on the beam

In order to avoid operation interference, distance can be reduced at will in order to maintain a small gap between the robot and the obstacle.

The robot is now berthed, by means of the docking arm, to the structure along which it moves. If so required, the second arm can be used as a point of additional anchorage. The arm that will be used to

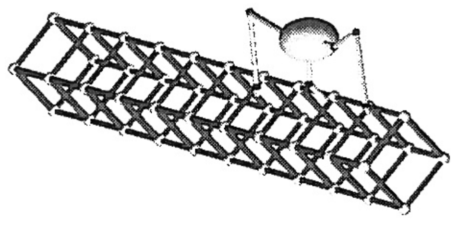


Fig. 5 Motion of the robot FRIEND on the truss

carry out this operation lies in a "horizontal" plane. The robot now takes an additional step to approach the obstacle. This step differs from the classic one because it is made with a single arm. The docking arm detaches itself from the structure and is lifted up. The arm that remains berthed subsequently moves the links in order to allow for body. translation.

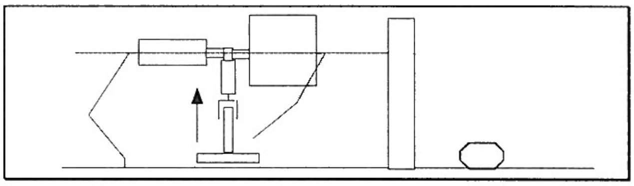


Fig. 6 Detachment and lifting of the docking arm

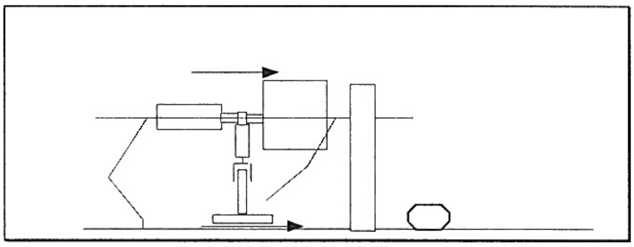


Fig. 7 Performance of a special step using only the left arm, to obtain the closest possible access to the obstacle

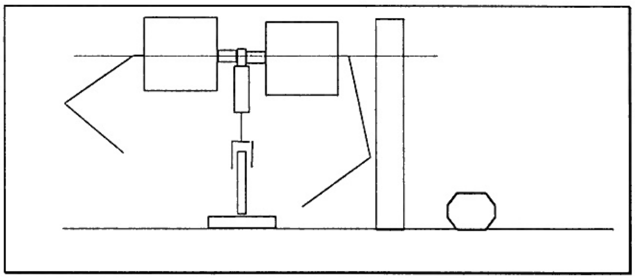


Fig. 8 Binding with the docking arm, unbinding of the left arm

Once the position nearest the obstacle has been reached, in order to raise its body plane and arms above the obstacle, the first thing that the robot does is to raise itself by using the telescopic joint on the docking arm.

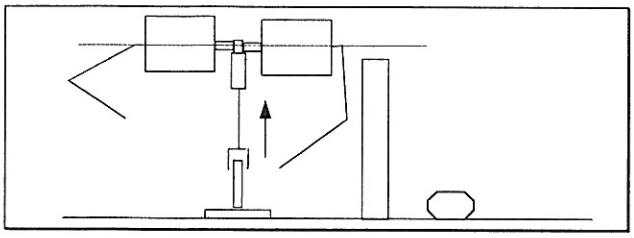


Fig. 9 Lifting of the robot on the telescopic joint of the docking arm

The robot is able to fully extend the arm that will be used to pass beyond the obstacle (please note that at this point the arm moves along a horizontal plane).

In order to approach the point where the operation will be carried out, the robot must make one rotation around the transverse docking axis.

The robot can now move the third arm link in order to reach the requisite point (please note that the arm will now move in a vertical plane).

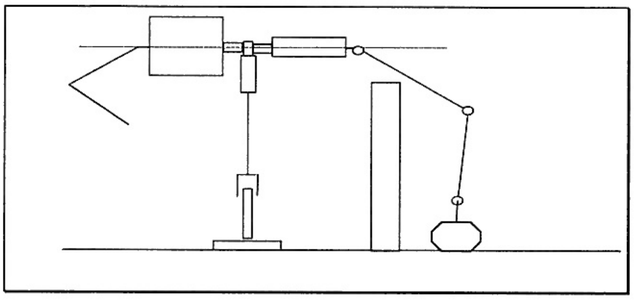


Fig. 10 To ensure alignment with the object, the robot uses the articulated linkage and spherical wrist

In the event of the grasping point not being found in the arm plane, there are two ways of reaching it. The first is to move the articulated linkage, thus compensating for the increase in the distance by using the third link movements. The second is to carry out a rotation around the transverse docking axis, counter-rotate the spherical wrist and correct the distance using the third link movement. The first option is preferable; fewer movements are used and the whole operation is simplified.

4. Lateral transit

This Sequence is undertaken when length dimensions are more compact, comparable or smaller to robot body dimensions. This means that one or both arms can grasp the selected object by passing laterally to the obstacle. The great advantage of this sequence is that both arms can be used simultaneously. This sequence can be developed in two ways. The first envisages the robot positioned perpendicular to the obstacle, whilst the second sees the robot parallel to the obstacle. Use of the first option prevents use of both arms, whilst with the second this becomes feasible. The first option ensures that the robot is positioned perpendicular to the obstacle, at a distance that allows for the movement of the arm. The arm is moved by using all three links and passes along the side of the obstacle in order to access the selected object. Subsequent movements may include linkage movement on the guideline, transverse rotation on the docking axis and orientation of the spherical wrist. Use of the second option means that the robot is placed frontally to the obstacle whereby use of the arm links, bring them beyond the obstacle.

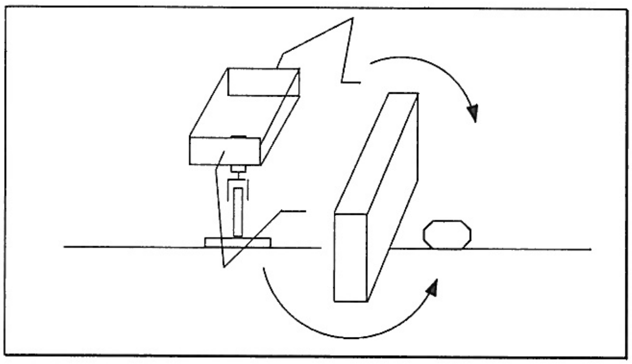


Fig. 11 Bypassing of the obstacle using one or two arms

In this way, both arms are situated beyond the obstacle and can operate simultaneously .

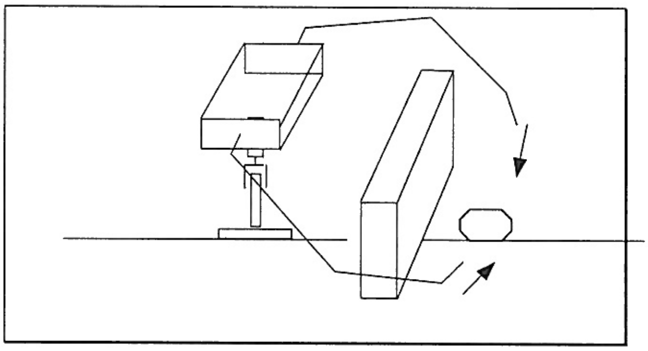


Fig. 12 Approaching a hidden object

If, at the end of the operation, it is necessary to grasp an object and bring it to the body of the robot, two different removal strategies are available. If the object is small, it can be grasped by a single arm; on the contrary, where extraction is in question, the same method used at the beginning can be followed, bearing in mind the new increased bulk. If the object is bulky and needs to be grasped with both arms, the extraction strategy is more complex. The robot can lift itself up by moving the telescopic joint of the docking arm, until the tip of the obstacle has been surpassed and the object has been brought to its body thanks to the movement of both arms.

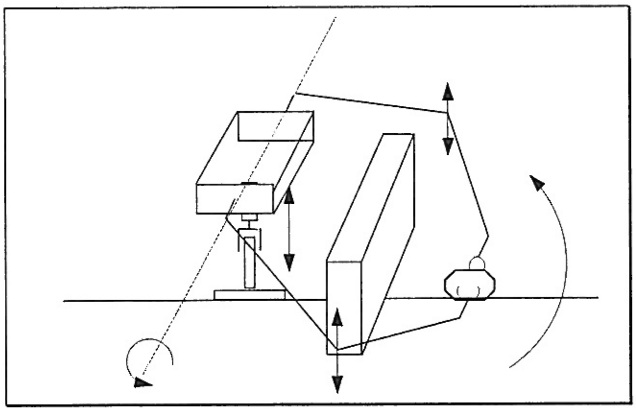


Fig. 13 Retrieval of the hidden object, using transverse docking rotation, linkage, and the 3 link arm movement

Alternatively, the robot can use rotation around the transverse docking axis to distance itself from the obstacle, possibly combined with the telescopic joint motion of the docking arm.

5. Conclusions on obstacle avoidance

The robot avails itself of various options to overcome an obstacle. These depend mainly on the way in which one wishes to reach an object : either using one or both arms. The possibility of reaching it with both arms is essential in terms of robot operating features. Moreover when studying the sequence pertaining to transit above an obstacle, it has been shown that the robot has to use independently rotation of the two half-bodies around the transverse docking axis.

The limitations involved in the possibility of overcoming an obstacle using this procedure are the dimensions of the obstacle itself. If this is much larger than the dimensions of the robot itself, the obstacle will not be able to be exceeded rectifying and reaming operations but also industrial robotic operations such as welding, object transportation and part replacement.

Other operations also include clearance, unlocking and disengagement. Each operation has a different degree of complexity. Simpler operations include cutting and drilling, whose movements and positioning can be used for more complex operations.

Unlike basic cutting and drilling operations and unlike the simpler operations, where more complex operations are in question, the robot must resorts to the substitution of tools. For this reason the robot body is equipped with a tool kit which can be easily accessed by its 2 arms in order to load new tools.

In order to ensure the performance of such maintenance duties , the robot will be equipped with the 13 degrees of freedom shown in the figure below.

The aim of the maintenance operation related to the “replacement of parts" is to allow for the replacement of defective parts, within a framework of modular substitution.

The term " maintenance operations " refers to a wide range of procedures including not only classic mechanical drilling cutting, milling, spot facing,

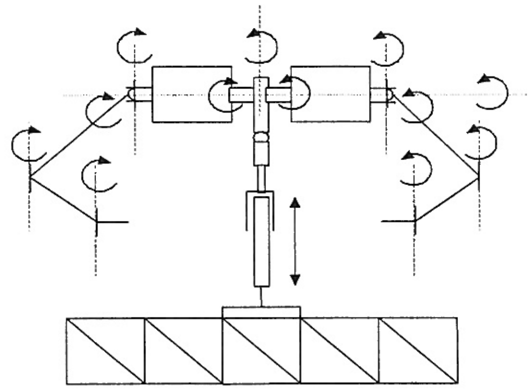
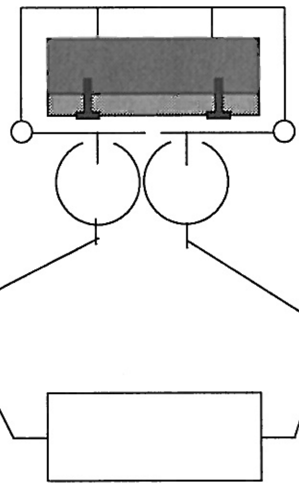


Figura 14 Mechanical Model of Robot

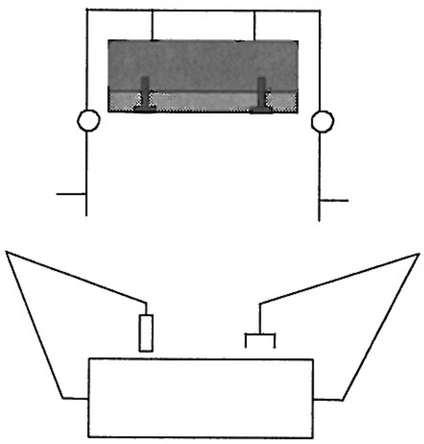
6. Part Replacement

Let us analyse the "Part Replacement" operation when the damaged component is shielded by protection panels. The robot positions its body frontally to the latter in order to make opening easier.

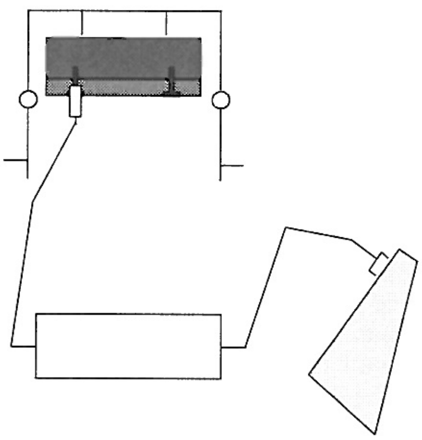


Once this initial positioning has been carried out, the robot loads the specific end effector for the panel opening on its 2 arms, activates the motors of the 2 arms in order to access the handles/locks and then opens the panels using the specific end effector that have just been loaded.

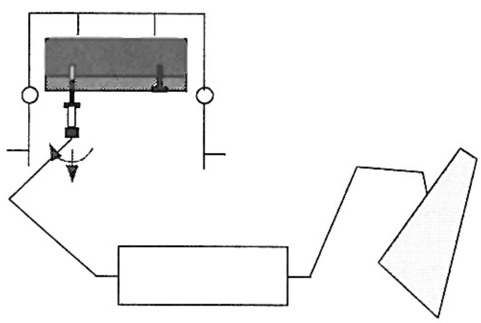
After opening the panels, the tool changing phase is envisaged; in fact, the robot recalls its 2 arms towards the tool kit where depositing of the opening tools and loading of a specific disengagement tool on the active arm and loading of the specific anchorage tool to the reticular beam takes place.



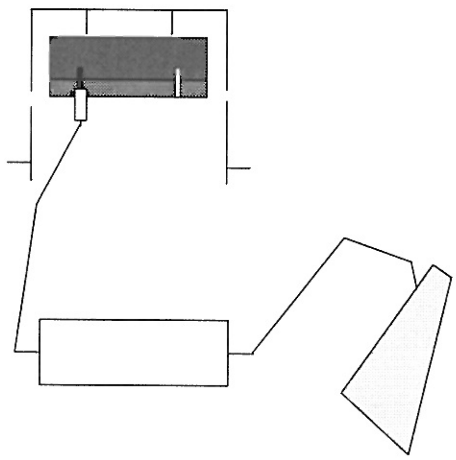
The passive arm is anchored to the reticular beam in order to guarantee increased robot stability during subsequent operation phases.



The motors of the active arm equipped with the disengagement tool are activated in order to permit access to the damaged component to be replaced as well as to centre the disengagement tool with the attachment mechanisms of the component. The disengagement end effector is set in motion in order to free the damaged component from its own support.



Once the damaged component has been disengaged, another tool change is envisaged to equip both arms with specific tools to grasp and transport the damaged component. Using these end effectors, the two arms deposit the damaged piece, grasp the spare-part "module" and then take it within reach of the fixed support where it is gently deposited. A temporary blocking mechanism is thus released in order to prevent disengagement of the spare part from its own support. Another tool change is performed in order to equip respectively the active arm and the passive arm with a specific assembly tool and a specific anchorage tool for attachment to the reticular beam. The robot now performs assembly, i.e. final attachment of the component to its own support by means of the end effector of the active arm. This is followed by an additional tool change phase in order to equip both arms with specific tools designed for closure of the protecting panels.



The part replacement operation is concluded with closure of the protection panels and the return of the robot to the rest position.

6. Conclusions on parts replacement

The part replacement analysis method is generically valid and can thus be used to study all other maintenance operations.

However, this first analysis should be backed up by a subsequent dynamic analysis developed by resorting to the multibody method in order to lay the bases for control system development.

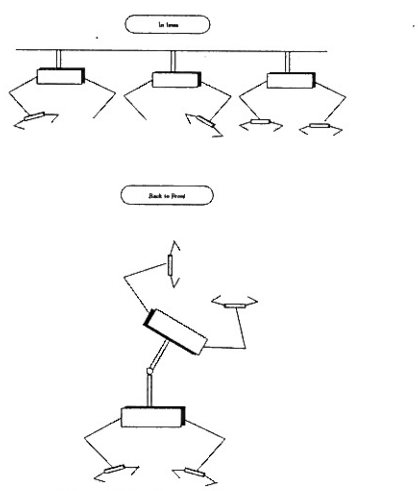


Fig. 15 Fractal robot

7. Future developments

The methodology adopted to describe the possible motions and functions of robot FRIEND represent a step towards a design engineering, able perform with non traditional robots tasks which are difficult, but require light structures and high reliability.

The software has been developed both for robotic control and telerobotic control. The simulation of the motion on the space structure is performed with two and three dimensional drawings and with models.

Tests on earth show that the efficiency is high, and the possible applications may be pointed out during the spatialisation phase.

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