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FORMULATION OF DESIGN GUIDELINES FOR
AUTOMATED ROBOTIC ASSEMBLY IN OUTERSPACE

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1. ABSTRACT

In this paper, we illustrate the approach for arriving at design guidelines for assembly by robots in outerspace. The use of robots in a zero gravity environment necessitates that extra factors over and above normal design guidelines be taken into account. Besides, many of the guidelines for assembly by robots on earth do not apply in space. However, considering the axioms for normal design and assembly as one set, guidelines for design and robotic assembly as another, and guidelines for design and assembly in space as the third set, unions and intersections of these sets can generate guidelines for two or more of these conditions taken together - say design and manual assembly in space. Therein lies the potential to develop expert systems in the future, which would use an exhaustive database and similar guidelines to arrive at those required by a superposition of these conditions.

2. INTRODUCTION

In view of the ambitious plans afoot in this country to launch the world's first permanently manned space station, automated robotic assembly in space takes on a whole new significance. Earlier, astronauts have successfully assembled and serviced critical components in space. However, this exposes human beings to the hazardous space environment. In the long-term, it is expected that full automation of the space station, will fulfill all possible objectives without the loss of human lives. At present however, it is intended to restrict, as long as possible, the activities of the astronauts to only those tasks which are impossible without human intelligence and decision-making ability.

Typically, the Permanently Manned Space Station (PMSS) would be involved in collecting

data from remote heavenly bodies, servicing and maintenance of satellites, and experimental production of extremely pure pharmacological products. Progressive automation of these activities will probably eliminate all human involvement.

Current robotic technology is limited to conveying out repetitive tasks (for which the robotic systems have to be programmed beforehand) or having the system undertake a series of actions (for which an operator would have to control it at each step). Though research is underway at Goddard Space Flight Center (GSFC) to build capabilities into the robotic systems so that they could independently decide the course of actions once given a task, very little effort has been made to devise and formulate the special design requirements for components that such robotically operated tasks in space would demand (2).

The area of formulating design guidelines for robotic servicing/assembly in space is one of the key spheres that is expected to emerge as the focus of concentrated study and research efforts in the coming years. This is because of the peculiar demands that the absence of gravity and other factors (like the desire to avoid building complicated, unnecessary capabilities into the robot) would place on the design.

In this paper, we propose to formulate some of these ideas into a set of rules that could be used as guidelines while designing components to be assembled.

By implementing these rules, it is expected that it would be possible to achieve increased efficiency, lower costs and reduced human exposure to space hazards, requiring no EVA (Extra Vehicular Activity).

3. SET OF GENERAL GUIDELINES FOR DESIGN AND ASSEMBLY ON EARTH

Before we discuss the set of guidelines for assembly a) in space and b) by robotic system, we should review normal design and assembly guidelines as they are used in the various engineering industries.

It has been proposed by Suh, Bell et al. (3) that design should be guided by certain axioms which cannot be violated. It is expected that all design and assembly rules should be derivable from one or more of these axioms and thus a large data base would eventually enable the

development of a mechanized design algorithm (4) or even a Design and Manufacturing Advisor (5) that would transform the perceived need into a numerically expressed set of functional requirements, evaluate alternative design concepts, and select final design and production process.

In view of these trends, it is advisable to formulate guidelines for all kinds of applications in designing for assembly. This is so that A.I techniques could be taken advantage of to analyze and synthesize these rules to suit the particular situation.

Some of the general axioms put forward by Suh, Bell et al. (3) are as follows:

- 1) All functional requirements and constraints should be kept at the barest minimum level.
- 2) Functional requirements should be satisfied in their order of importance.
- 3) Information content is to be minimized (Instructions regarding locating, processing etc should be kept to a minimum and tolerances, surface finish, etc. should be as relaxed as possible).
- 4) If some functional requirements in the proposed design can be satisfied independently of each other, they should be integrated in a single part.
- 5) As little material should be used as possible.

Many of the heuristics as well are well known, formalized techniques in manufacturing and assembly like group technology, value engineering etc. involve direct corollaries of these axioms. As far as assembly on earth (with or without robotic systems) are concerned, some more illustrated guidelines follow:

- 6) Symmetry should be maintained as far as possible.
- 7) Parts should be standardized whenever possible.
- 8) Commonality of parts facilitates assembly.
- 9) Mutual interference of parts is to be avoided. Springs must have closed loops, diameter of the spring wire should be greater than the spacing between coils.
- 10) Gravity should be taken advantage of for locating, feeding and damping whenever possible. Figure 1 shows how the front weight of a tractor (provided to ensure stability) is screwed to the front rigid axle without any mechanical fastener, using the force of gravity only.

11) Bottom-up assembly should be used - i.e., the heaviest part should be at the bottom, the next heaviest part on it, and so on.

GUIDELINES FOR ROBOTIC ASSEMBLY IN SPACE OR ON EARTH

It is very important to make sure that no unnecessary features are built into a design because this would stretch the capabilities of the robot, reduce the reliability of the system, increase cost and decrease efficiency. In other words, design should be such that even the simplest of robots using the minimum number and type of motor actions and sensory features can assemble or service the items in space. Other guidelines are as follows:

- 1) Minimize the number of parts.
- 2) Break up the assembly into modules that can be easily assembled or disassembled. This would minimize the effort involved in servicing.
- 3) Use a sequential or layered approach to assembly.

Gripping the items present difficulties on earth as well as in space. However, in space these difficulties must be resolved fully as the consequences of improper gripping can be extremely costly or even fatal. Any component that slips out of grip can become a projected missile and fatally injure the occupants of the spacecraft, or damage the spacecraft and its equipment. Therefore rule 4 is formulated as follows:

- 4) All movements of components must be secure, verifiable and failsafe. Handles or special areas are to be provided for fail safe gripping whenever possible.
- 5) Unidirectional assembly is to be attempted. This would reduce unnecessary motions on the part of the robot.
- 6) Maximize commonality of parts and minimize product variations.
- 7) Eliminate electrical cables.

Experience has shown that electrical cables are extremely difficult to assemble by robots unless they are in the most elementary form. In fact any flexible part creates the same problems. Absence of electrical cables and other flexible parts would alleviate a major problem

area in assembly.

- 8) If the robotic system uses vision equipment, then shiny surfaces should be avoided that blind vision by causing problems with the camera.
- 9) Use gravity whenever possible to locate parts. For example, the heaviest part could be used as a fixture.
- 10) Use gravity-fastening methods.

SET OF GUIDELINES FOR DESIGN AND ASSEMBLY IN SPACE

As mentioned earlier, the absence of gravity is the single most important factor that calls for major changes in the design measurements vis-a-vis assembly on earth.

Gravity acts as a gripping, holding, or locating force on earth. This is something that is normally taken for granted, for in the absence of gravity, a major constraining force is lost. This means that bottom-up assembly is more preferable to any other orientation. Therefore;

- 1) Orientation of components can be in any direction. However, components should be so designed that during assembly (if they are non-symmetric) they should be capable of being assembled from any one particular side.

On earth gripper safety is considered more important than that of the object because of the high cost of grippers. In case of a slip, the object is dropped to save the gripper. However, in space any object that slips out of the robot's grip can become a projected missile and severely damage the spacecraft and equipment or even fatally injure the occupants, hence

- 2) All components should have handles or gripping facilities that prevent their slipping out of grip.

If a component is capable of reconfiguring itself the need to reassemble it is eliminated. The chance of the component slipping out of control, need for unnecessary gripping, extra motion, etc are deviated and therefore, safety and efficiency in space operations are enhanced. This translates itself into the guideline:

- 3) Components should be able to reconfigure themselves whenever feasible. An

example of this would be a solar panel which can fold up, instruments that can realign themselves etc.

- 4) Use of symmetric parts that require no particular orientation.
- 5) Avoid parts with tangling tendencies.
- 6) Gravity fastening can not be used.

In figure 1 the component (front weight of a tractor for providing stability) uses gravity fastening. However, such fastening would not constrain the component in space.

Some other guidelines formulated by Gordon, S.A., (4) are as follows:

- 7) All components have to be constrained fully.
- 8) Servicing operations using two gripping/moving locations should be permissible.
- 9) Fasteners should be constrained from all sides (captive fasteners)
- 10) Hardware used must be the ones that are already in use and standardized.

Guideline number (7) is quite self explanatory. If the components are not constrained fully and securely, they would float away from control due to the absence of gravity. While the components are in the robot's grasp, they must not even be able to shift position as thus would disrupt assembly/servicing operations.

The eighth guideline has been formulated by GSFC in order to make the design of the end effector of the robot arm simpler and more compact as the task of gripping and operating the restraint is now shared by two separate arms. In the case of only one arm, the end effector has to perform both gripping and operating the restraint. Also, in this case the torque is reached back through the robot arm or end effector and this calls for the presence of gripping fixtures at each fastener location. In two arm operation, only one gripping fixture is needed to constrain the component.

Figure 2 (Gordon, S.A., [4]) shows the advantages of using a captive fastener. The only task that the robot has to carry out for assembly / disassembly is to apply torque to the fastener. If the fasteners are not captive, the robot has to perform the additional task of (a) restraining the fastener while operating it and (b) removing it and using a separate fixture to store the fastener.

Thus, a simple design modification considerably reduces the complexity of and the number of operations needed in the task.

The use of standardized hardware eliminates the need for research to develop special hardware and the whole host of design modifications that accommodating such special hardware would entail.

In the above referred research work, a mock-up of a unit of a spacecraft was used to study the effect of the special requirements of the robotic servicing in space on the design and the guidelines discussed (7 to 10) were found to be major influencing factors.

AN ELEMENTARY APPROACH FOR ARRIVING AT GUIDELINES THAT ARE SUBSETS / SUPERSETS OF THESE THREE SETS

Figure 3 explains the position of robotic assembly in space vis-a-vis assembly on earth (by robots or otherwise) using set theory.

Mathematically, S_E denotes the set of design assembly guidelines on earth (using robots or otherwise). S_R denotes the set of design assembly guidelines by robots (on earth or in space). S_S denotes the set of design assembly techniques in space (by robots or by astronauts). Then,

$S_E \cap S_R = S_{RE}$, set of guidelines for design and assembly by robots on earth.

$S_E \cap S_S = S_{ES}$, set of design and assembly guidelines suitable on earth and in space, using robots or otherwise.

$S_R \cap S_S = S_{RS}$, set of design techniques for assembly by robots in space.

$S_R \cap S_S \cap S_E = S_{RSE}$, set of guidelines for design and assembly by robots that can be used in space and on earth.

Thus, in order to arrive at S_{RS} , ie, the set of all guidelines for robotic design and assembly in space, we need only find $S_R \cap S_S$. In this case, it can be done by inspection. The only guidelines of S_R that do not apply are those pertaining to the use of gravity, ie,

- 9) Use gravity whenever possible to locate parts

10) Use gravity-fastening methods, by eliminating these two guidelines we arrive at SRS.

CONCLUSION

Due to the energizing trends of using A-I techniques to design components and assemblies for different kinds of applications, it is important to formulate guidelines that could be used in the data base that such techniques would need. It must be emphasized that these guidelines are far from exhaustive and have been used for illustrative purposes only. It is hoped that at a later time it would be possible to develop expert systems that would be able to arrive at guidelines which can be formed from a combination (union or intersection) of these three sets from an exhaustive data base. Examples of such subsets would be guidelines for design and assembly on earth by robots, guidelines for design and assembly in space by astronauts (This would be important as a back up in case of a failure of the robotic systems), etc. With almost complete computerization, these tools would prove indispensable to several applications.

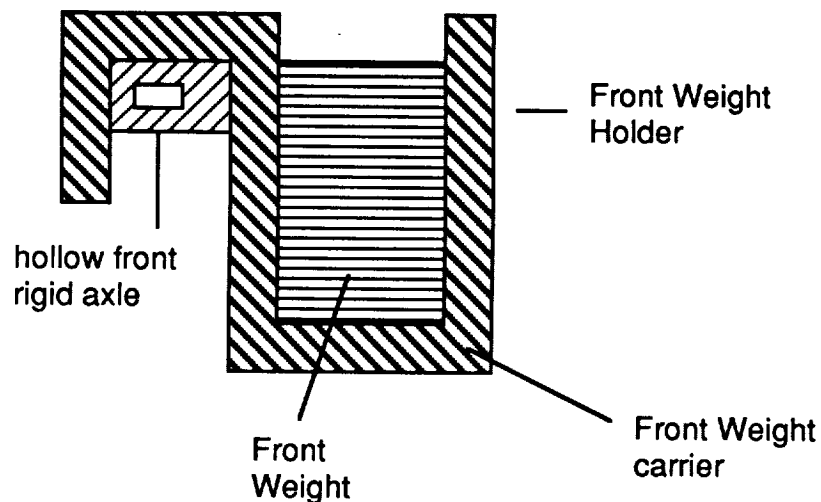


Fig 1. Assembly of Front Rigid Axle of a Tractor

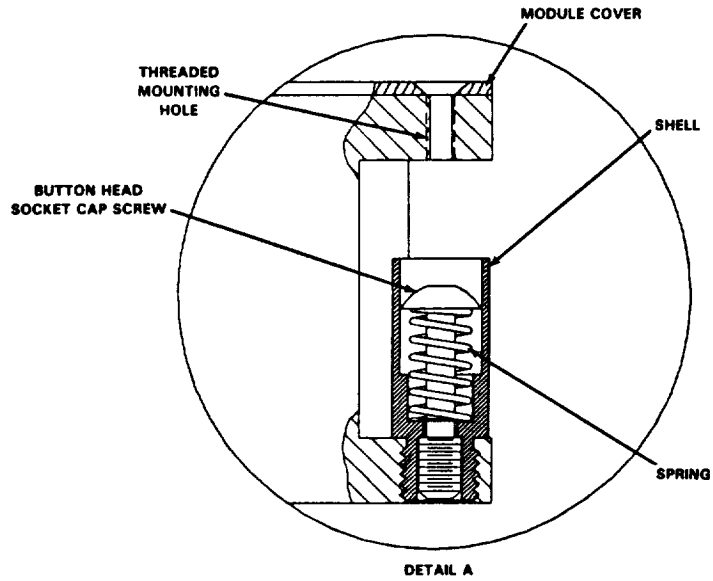


Fig. 2. Use of a Captive Fastener

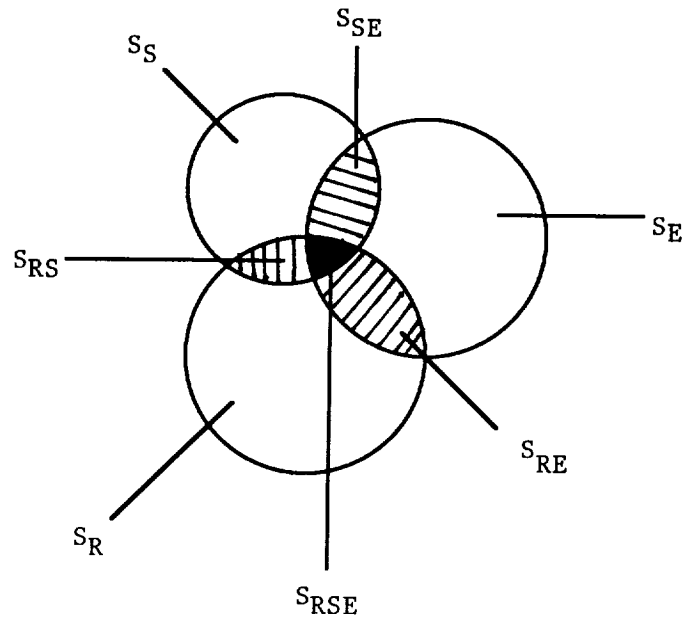


Fig. 3. Robotic Assembly in Space Vis-A-Vis Assembly on Earth.

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