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A Practical Demonstration of Advanced Teleoperation Techniques Applied to the Assembly of Payloads

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ABSTRACT

The drive to planetary exploration, including re-visiting our own moon will inevitably require a level of interaction with these environments that is beyond previous robotic probes. To fully explore these hostile environments will require increasing levels of dexterity. This trend is already evident with the robotic sampling devices of Beagle2[1], EXOMARS[2] & Mars Science Laboratory 2009[3]. Payload assembly for planetary missions present their own unique challenges when the search for organic matter requires stringent aseptic environments, posing problems for human assembly.

Advanced teleoperation for complex and delicate assembly and maintenance tasks has been pioneered at the JET nuclear fusion project[4] for the past 15 years and this paper will present the results of a practical demonstration of its applicability to the highly dexterous remote assembly activities required for space relevant hardware. As a contribution to the ESA activities in the evaluation of Robotised AIV[5] the authors considered the potential for exploitation of the developments made in teleoperation at JET. In particular the investigation sought to identify whether the high level of dexterity required for assembling delicate and complex space relevant components can be supplied using the state-of-the-art terrestrial teleoperation methods. A challenge was issued to the authors to demonstrate the assembly of the following items:-

- Spacecraft honeycomb panel with studs and inserts attached
- Solar Array Drive Motor (SADM) from Astrium Eurostar 2000 spacecraft with additional harness included
- Swab
- MLI blanket (in a 'tent' configuration)
- Blanket buttons (plastic retainers)
- Stainless steel standoffs
- Ty-base and ty-wrap

An advanced Master-Slave manipulator was deployed and the activities were successfully completed by a single operator in one three hour session with no a-priori rehearsal and with no modification of the spacecraft items. The tasks included fully remote assembly of the above items with no external assistance and completion by post-terminal sterilisation also by teleoperation. The entire activity was photographed and recorded using video.

1 INTRODUCTION AND SCOPE

The drive to planetary exploration, including re-visiting our own moon will inevitably require a level of interaction with these environments that is beyond previous robotic probes. To fully explore these hostile environments will require increasing levels of dexterity. This trend is already evident with the robotic sampling devices of Beagle2[1], EXOMARS[2] & Mars Science Laboratory 2009[3]. Payload assembly for planetary missions present their own unique challenges when the search for organic matter requires stringent aseptic environments, posing problems for human assembly.

Robots have been in active use in maintaining fusion machines for the last 15 years and have built up many thousands of operational hours. Deployed in environments hostile to humans they can be configured to carry a wide range of load bearing end-effectors for assembly of large payloads or alternatively with telemanipulators for dexterous 'Man-in-the-Loop' tasks. It is in this 'dexterous' mode where the combination of human intelligence and sophisticated robotic control allows for tasks of considerable complexity to be completed remotely.

On the JET project, the largest fusion device of its kind presently operating, Man-in-the-Loop remote working has been used to re-configure the in-vessel components and systems several times during the machines operational life. These operational 'shutdowns' can last for a year or more of near constant shift working with teams of operations engineers and technicians carrying out complex remote tasks previously developed in virtual and real world mock-ups. It is from this intense and arduous working environment that our present remote handling technologies and working methodologies have been developed.

When developing solutions to remote handling problems, engineers are often faced with the dilemma of adding features to the component to improve its 'handle-ability' or adding complexity to the tooling where changes to components are not possible or unacceptable. This balance is particularly relevant to space hardware where the component validation process is long and costly. An alternative to creating overly complex tooling with associated reliability and usage issues is to use remote handling technologies that can mimic human dexterity and sensitivity while still able to handle 'simplified' tooling for a wide range of tasks. This is the approach developed from long experience at JET.

2 THE AIV DEMONSTRATION TASK

The relevance of this remote handling technology and associated methodologies to space hardware was tested during an assembly task devised by the AIV engineers at Astrium Ltd.

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3 SETUP

On receipt of the AIV mock-up parts from Astrium, Oxford Technologies remote operations personnel were invited to assess the task requirement and to make recommendations as to its feasibility and tooling. It was decided that the work was entirely feasible using Dexter™ under Man-in-the-loop (MIL) mode and that to demonstrate the effectiveness and dexterity of the Manipulator, no bespoke tooling need be used. The only tools used were a standard Allen Key and gripper compatible pliers.
The mock-up was placed on a flat bench in front of Dexter™ as shown in Figure 1.

Figure 1 – Dexter Manipulator with AIV Mock-up (dis-assembled)

The AIV mock-up components were placed within reach of the Manipulator with the base positioned centrally between the Manipulator shoulders. With the exception of the Sterile Swab packet which was attached to a vertical bracket, no components were fixed to the bench. The fixing screws, plastic retention clips and the motor pillars were positioned at the start of the operations onto a small wooden plinth next to the manipulator.

The Manipulator is fitted with 2 Zoom Cameras, one above between the Manipulator shoulders and the other below and behind the Manipulator. In addition, small cameras are mounted on each Manipulator arm providing views of the Grippers. The remote operator fixed the position of the cameras to obtain best working views of the mock-up.
The operation was performed using Dexter™ entirely under MIL mode - no robotic functions were used at any stage of the operation. In the following sections the assembly operations are described as they happened under full MIL mode and with no manual intervention at any stage inside the operations area.

Motor Assembly onto Base

The 4 loose Aluminium pillars upon which the Motor would rest were positioned in turn onto the AIV base. The Motor was then gripped and located onto the (loose) pillars. The remote operator visually checked and where necessary re-positioned the pillars.

The first fixing bolt and washer assembly was collected (gripped) from the plinth and located into a Motor retention hole and through a pillar. Due to the Motor cable assembly, which was wrapped around the Motor and retained via 'Tie-Rap', the bolt had to be presented at an angle to be inserted into the Motor hole.

This procedure was repeated until a further 2 bolts were fitted through the Motor and Pillars but not located into the Base. During this and following procedures, the remote operator rotated the Base on the bench, as he required improving access.

The remote operator then used the Grippers to gently re-position each Pillar until the bolts located into the Base fixings. During this procedure one of the loose Pillars fell over. The remote operator then gripped the Motor and lifted it clear of the remaining Pillars with the 3 fitted bolts hanging from the Motor. He then used the second Gripper to re-position all 4 Pillars onto the Base and carefully lowered the Motor assembly onto the loose Pillars. After some minor re-positioning of the loose Pillars (under the Motor) and witnessing the screws locate into the Base fixings, the remote operator Gripped the Allen key and fastened the first bolt (not tight). He repeated this procedure of checking the position of each remaining Pillar prior to fastening its adjacent bolt. The remote operator then collected the remaining bolt from the plinth and fitted as described. All 4 bolts were now tightened.

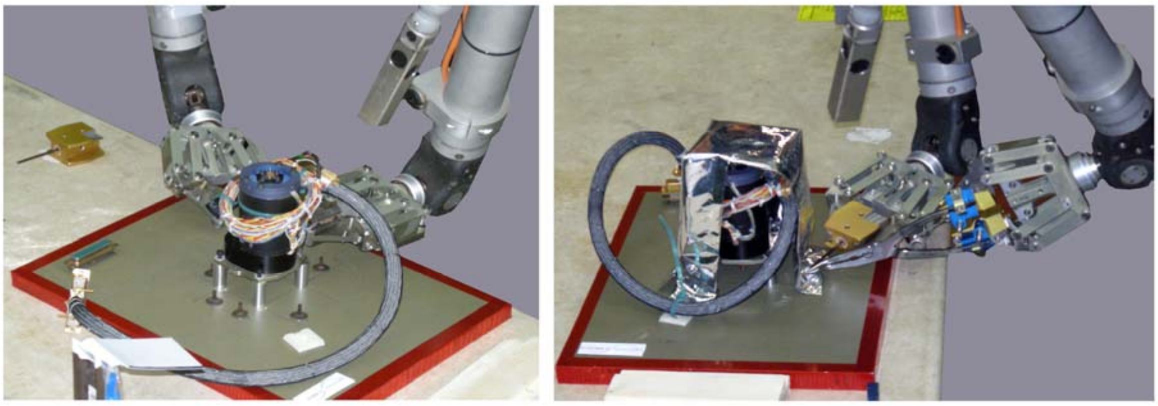

Figure 2 – Motor Assembly and Fitting Plastic Retainers

Attaching D-Type Connector and Retaining Cable Assembly to Base with Tie-Wrap

The remote operator gripped the Cable Assembly adjacent to the Connector Plug and mated it with the female connector mounted to the Base. He then re-positioned the Cable adjacent the pre-fitted Tie-Wrap plastic base (glued to Base).

The remote operator collected the loose Tie-Wrap with a Gripper and located the pointed end into the Tie-Wrap base, feeding it through the base until around 70mm protruded. Using the second Gripper he looped the loose end of the Tie-Wrap around the Cable and into the Tie-Wrap head. Using both Grippers he zipped the Tie-Wrap around the Cable.

Fitting Insulating Foil Cover to Base

The remote operator carefully gripped the Foil Cover and located it over the Motor and Cable Assembly onto the Base. He then gripped the Pliers and located the Foil flaps over plastic pegs pre-mounted to the Base using the Pliers and free gripper.
The remote operator collected the first Plastic Retainer with the Pliers and located the Plastic Retainer over a peg and Foil. To assist pressing the Plastic Retainer down over the peg he collected the Allan Key with the second gripper and pushed the Plastic Retainer down the peg retaining the Foil to the Base. This operation was repeated until all 7 Plastic Retainers were fitted.

Using Sterile Swab to Sample Foil

As mentioned, the Sterile Swab pack was attached (double sided tape) to a vertical bracket mounted to the bench. A ‘tongue’ was fitted to the pack to facilitate gripping.
The remote operator gripped the ‘tongue’ and pulled forward opening the sealed pack. Using the Pliers he removed the cap of the sterile tube, gripped the Swab and placed it fully inside the tube then withdrew the Swab and began wiping the surface of the foil on all 5 outer surfaces. The Swap was then returned to the tube.

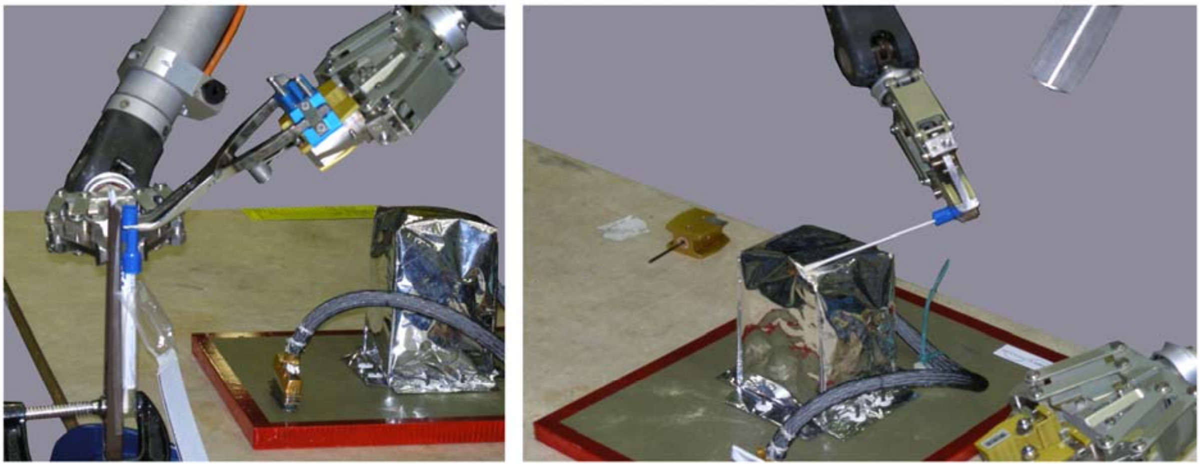

Figure 3 – Removing Cap from Sterile Tube and Swabbing Foil

Suggestions for improving the Remote Assembly process

The assembly operation described above was completed at the very first attempt and with no special tooling. The remote operator, although trained and experienced at Teleoperation had no time to practise on the mock-up prior to the first assembly. Operational trials are normally conducted in advance of live tasks to provide the opportunity to develop techniques suited to the tasks and make recommendations together on improvements to design of tools & fixtures. Trials are also used to develop best camera positions, lighting requirements and to identify and record any robotic functionality that can improve productivity and safety.
When handling components remotely we would generally avoid direct contact with the Manipulator Grippers which are hardened steel and prefer to use either an intermediary gripper attachment to the fingers or remote tooling specifically designed for the characteristics of the components being handled to avoid damaging those components and facilitating improved handling. The grippers, Allen Key and Pliers used for this trial are our standard items for manipulating hardened components and so were not entirely suitable for gripping plastic components, braided cables or foil insulators.
When handling and positioning small components such as the Aluminium Pillars we would develop simple fixtures that can be located on some feature of the mating part and locate the Pillars in the correct position. Such a fixture may also be used to retain the Pillars while the Motor and Bolts are fitted. In many cases the same fixtures may be used to transport the components to the ‘workface’ improving identification and handling.

Handling the Motor could be improved using a simple tool with gripper compatible handle. Adding spirit levels to such tools help orientate the operators when assembly is not in a horizontal plane. In such working condition components may need to be screwed or clamped by the fixture or tooling for transportation. Such fixing’s should use common head form to reduce the range of tools (Allen Keys etc) required. The cable assembly wrapped and fastened around the Motor was a hindrance when locating the 4 fixing Bolts. Our preference would have been to have assembled the Motor onto the Base via the Pillars and securely retained it with the Bolts prior to wrapping the cable around the Motor and securing with Tie-Wraps.
Where we have the ability to influence component design for remote assembly, small changes can significantly aid handling of these components. Where possible, small fixings should be captive so removing the possibilities of dropping items, reducing the requirement for tooling and improving assembly times. The direction of assembly of components and sub-assemblies should be along the same axis to facilitate remote assembly from one direction where possible. Larger components and sub-assemblies would where possible provide gripper compatible features for handling or features for attaching tooling.
Where components or sub-assemblies require accurate mating, location dowels should be remote handling compatible. Where camera access and views may be limited, alignment markers (engraved on components) are beneficial to aid the remote operator in locating items.

4 CONCLUSION

This was an interesting and challenging remote assembly that provided an excellent demonstration of the dexterity of the Dexter Manipulator and skill of the remote operator. The challenge was greater due to the lack of practice time, and the components not being designed for remote assembly. It is not unusual for us to assemble / dis-assemble components not designed for remote handling but our productivity is usually significantly worse than if the components had been designed to be compatible from the outset. In this situation we ameliorate the incompatibility problems by the introduction of fixtures and more complex tooling.
It was therefore very rewarding to have succeeded with this assembly using standard Grippers, Pliers & Allen Key. There was an element of fascination in watching the remote operator gently coaxing these delicate items into place, zipping up Tie-Wraps and carefully swabbing the foil. The total assembly time of 2 hours for an un-practised task containing a number of dexterous challenges was impressive. The team are confident that this particular assembly can be achieved in around an hour with practice and considerably less than an hour if more fixtures and tooling are introduced.
To this date we have not been faced with a remote handling task we have been unable to complete. That remains the case!

5 FUTURE APPLICATION TO PLANETARY PROTECTION

This ad-hoc demonstration of remote assembly of unmodified spacecraft payload components only scratches the surface of the potential for such techniques in the planetary exploration programmes. It is entirely within the capability of current remote handling technologists to develop manipulators suitable for high dexterity manipulation in a high quality aseptic environment. With such devices and suitability trained operators it will be possible to build exploration payloads with a level of cleanliness unattained to date and thence suitable for category IV & V missions (COSPAR).

6 REFERENCES

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