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A HUMAN FACTORS EVALUATION OF THE ROBOTIC INTERFACE FOR SPACE STATION *FREEDOM* ORBITAL REPLACEABLE UNITS

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ABSTRACT

An orbital replaceable unit (ORU) is often defined as any orbital unit aboard Space Station with a wearout life of less than 30 years. The capability of successful changeout of these units by remote manipulation is critical to the ORU to telerobot interface design. A human factors evaluation of the selected interface showed certain inadequacies of the alignment target concept that was part of the interface package. Alternative target concepts which addressed these inadequacies were developed and are presented in this paper. Recommendations from this work will be incorporated into NASA requirements documents which ORU suppliers and manufactures must then build to.

ACRONYM LIST

IDR	Interface Design Review
JSC	Johnson Space Center
ORU	Orbital Replaceable Unit
ROIL	Remote Operator Interaction Laboratory
RSIS	Robotic Systems Integration Standards
SSF	Space Station *Freedom*

INTRODUCTION

The changeout of orbital replaceable units (ORU) will be a vital day to day activity for the crew aboard Space Station *Freedom* (SSF). Performing the changeout of these units by both the extravehicular astronaut as well by the various robotic devices aboard SSF will be critical to the success of *Freedom's* operation. Therefore it is critical that the interface to these ORUs assure successful manipulation. In response to this, an Interface Design Review (IDR) process has been formed in order to assess SSF robotic interfaces and to establish appropriate interface design standards which will be published in the Robotic Systems Integration Standards (RSIS). These will become the standards which ORU suppliers and manufacturers must build to.

As a result of the IDR process, the robot to ORU interface package selected for ORUs of 1200 pounds or less was the Spar Aerospace Limited design. Once the selection was made, a design validation process began with the intent of evaluating the suitability of the selected interface design. This entailed making recommendations intended to refine and improve the Spar package. Several NASA as well as private laboratories were chosen to participate in the design validation process, among them the Remote Operator Interaction Laboratory (ROIL) at NASA's Johnson Space Center (JSC) in Houston. The ROIL was chosen specifically for its expertise in dealing with human factors issues relevant to the interface design.

In evaluating the Spar package, personnel at the ROIL determined that the Spar ORU alignment target had the greatest impact from a human factors perspective. Consequently, it was this part of the interface which ROIL personnel chose to focus on in an attempt to refine it. This paper discusses the approach taken by the ROIL during its evaluation and refinement of the Spar alignment target.

THE SPAR ALIGNMENT TARGET

Shown graphically in Figure 1, the Spar alignment target was 2 inches by 2 inches square. The front and base plates of the target were separated by a depth of .5 inch. This .5 inch separation between the .25 inch diameter white circle on the face plate and the .284 inch diameter black circle on the base plate provided the cues necessary to align the pitch and yaw rotational axes. This was done by making sure a black ring from the base circle was always visible around the white circle on the face plate. An overlay displayed on the end effector camera view, when aligned properly with the target, provided the cues necessary to adjust the additional rotational roll axis as well as the translational X, Y, and Z axes. Once aligned properly, the target—mounted 2.5 inches above the center of the grapple fixture on the ORU—was designed to assure that the misalignment tolerances of the grapple fixture were met before a grapple attempt was made.

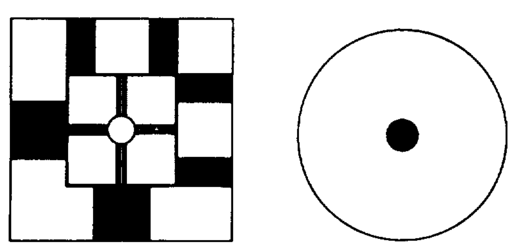
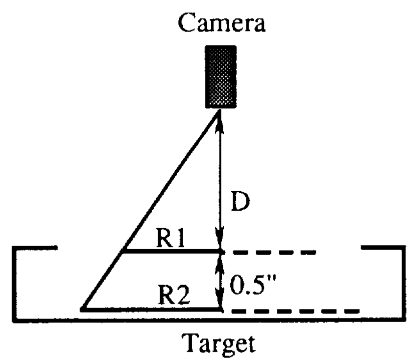


Figure 1. Face plate and base plate concepts incorporated into the original Spar target.

Certain aspects of the Spar alignment target design were very well conceived. The compactness of the target allowed for it to be mounted appropriately near each grapple point. Further, because it was an enclosed unit, it would pose little to no risk of snagging an extravehicular astronaut. The simplicity of the target was also a good feature. Corrective alignments were thus logical and easy to interpret. Initial evaluations by the ROIL, however, pointed out several shortcomings inherent to the target's design.

First among these limitations was a matter of geometry. According to the operational scenario provided by Spar, at grapple the camera to target distance was defined to be 4 inches. Figure 2 shows that according to the dimensions specified by Spar, the minimum distance at which the black circle on the base plate would be visible around the white circle on the face plate was 3.67 inches. As a result, at the 4 inch grapple distance, the cues provided by the base circle were so slight that final alignment corrections were often difficult to determine.



Formula 1

$$\frac{R1}{D} = \frac{R2}{D + 0.5"}$$

Spar Dimensions

R1 = 0.125"
R2 = 0.142"
D = 3.67"

Figure 2. The relevant target and camera dimensions (not to scale) are represented in Formula 1. Given the specified Spar dimensions, the minimum distance necessary to view the base circle around the face plate circle was 3.67 inches.

Accuracy evaluations were performed by mounting the target to a rotating base 4 inches in front of and centered with the camera. An operator would then call out when they felt that a zero degree rotational alignment (i.e. perfect alignment) had been achieved. Due to the geometry of the Spar target's relevant features, accuracy was typically within 2° to 3° to either side of zero degree rotational alignment.

When examined under controlled lighting conditions, certain other drawbacks to the Spar alignment target design became apparent. When a collimated light source—in this case a solar simulator—was directed at the target from an angle displaced 15° to 25° from the camera centerline, certain angular displacements of the target caused the face plate to obscure the black base plate circle by shadows from either the outside frame of the face plate or by the white circle on the face plate. The corrective action needed in these cases would not be clear and could result in the issuance of an incorrect command.

Similarly, at certain incident angles, light would reflect off the highly specular paint specified by Spar to the point that features of the target were completely washed out due to the blooming effect that would appear on the video monitor. If the iris on the camera's lens were closed to the point that the blooming effect was relieved, the contrast would be so slight that the target's features were still indistinguishable on the monitor view.

PROPOSED TARGET MODIFICATIONS

It was clear that the desirable features of the Spar target concept needed to be preserved in any new concept to be proposed. Just as clear, however, was the need to address the limitations of the original Spar target's design. With this in mind, ROIL personnel began an iterative process intended to devise target concepts which preserved the desirable features of the Spar design, but which also improved upon its limitations. It should be noted that none of these proposed target modifications addressed the reflectivity of the paint due to the long turnaround time in having a target concept painted to specification. Paint reflectivity will be addressed as an issue separate from features of the target design.

Rather than address each limitation of the Spar design separately, alternative designs were developed in order to address the various issues as a system rather than as independent problems. This way, solutions which addressed one potential flaw in the Spar target design would be less likely to complicate another. This was done specifically with respect to the shadow and geometric problems encountered in the Spar design.

Figure 3 depicts an alternative target design, designated concept A, which both reduced the likelihood of any potential confusion caused by shadows as well as assuring that all alignment cues are clearly discernable at any camera to target distance. The opening in the face plate was widened to both allow more light into the target as well as reduce the likelihood of a shadow from the edge of the face plate obscuring the center of the base plate. Likewise, the width of the crosshairs were reduced from the original Spar dimension of .12 inch to .02 inch. The narrower crosshair created much less of a shadow on the target base, eliminating the possibility of obscuring relevant features on the base plate. Further, the alternating black and white colors on the crosshairs, in combination with the features of the base plate, made them always distinguishable from the background. This made corrective movements easier to determine. Consequently, the same accuracy evaluations as performed with the original Spar target resulted in accuracy typically within .33° to either side of zero degree rotational alignment with no apparent shadowing problems.

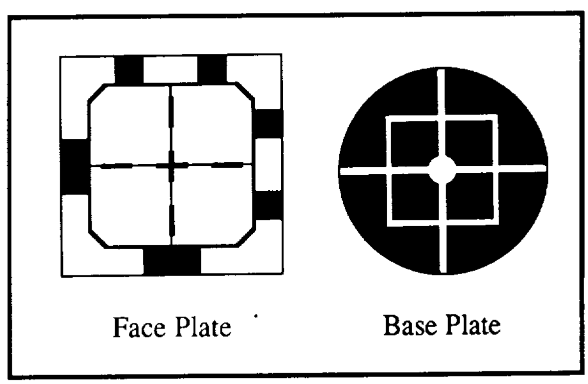


Figure 3. Face plate and base plate depictions proposed in alternative target concept A.

Certain concerns were raised regarding target concept A, however. Chief among them was a lack of robustness with respect to the crosshairs. Any contact with the crosshairs by a robotic end effector or by an extravehicular astronaut could potentially bend or even break them. Therefore, further designs were developed with the intent of addressing that concern in particular.

It was felt that the same level of accuracy could be maintained if the crosshairs were widened. Preserving many of the features of target concept A with widened crosshairs could result in a more robust target that was easy to interpret and which could provide the cues necessary to achieve the accuracy of the first alternative design. At the same time, it was felt that additional cues could be built into the target which would provide cues redundant to the primary alignment cue, in this case the center of the crosshair.

Figure 4 depicts target concept B. The crosshairs have been widened to .063 inch, making them very robust. At the same time, the level of accuracy exhibited by concept A was preserved in this concept. Once again, accuracy evaluations resulted in alignment typically within .33° to either side of zero degree rotational alignment and again, no apparent shadowing problems appeared. The new feature incorporated into this target was a redundancy of the alignment cues used prior to grapple. To achieve proper alignment of the end effector at the 4 inch camera to target distance, the center cross on the face plate crosshairs had to be centered within the white circle on the base plate. The redundant cues were provided by the black hashmarks further out on the crosshairs. When proper alignment was achieved at the 4 inch distance, the inside edge of the black hashmarks appeared to touch the outside edge of the base plate black circle. Pitch and yaw cues which the target must provide are then also offered by these redundant cues as well.

The redundant cues offered by this concept do two things. First, they provide an extra measure of certainty that proper alignment has been achieved prior to attempting grapple. If both sets of alignment cues tell the operator that the end effector is positioned properly, the operator will be that much more sure at the time of grapple. The second, and perhaps more important feature offered by the redundant cues is that they can used as primary alignment cues in the event that the original cues, i.e. the center of the target, cannot be used for alignment. This scenario could occur if certain harsh shadows extended over the target, or if the target were partially damaged in some way. The redundant cues might allow a successful grapple to be made which might otherwise not be attempted due to the extraneous circumstances.

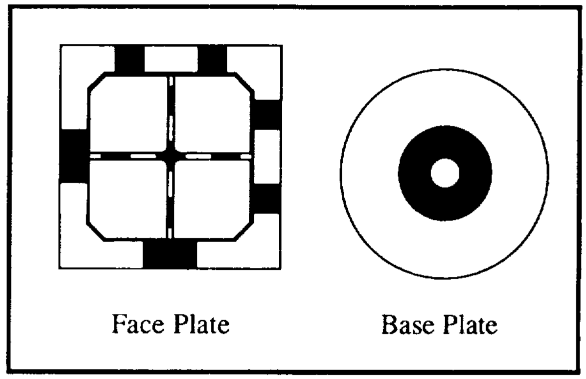


Figure 4. Face plate and base plate depictions proposed in alternative target concept B.

FUTURE WORK

The alternative designs presented here are only two of several iterations on the target concept conceived by ROIL personnel. While these represent the most promising of the iterations attempted so far, other concepts may offer even greater promise. Consequently, work on improving the design has not terminated and further iterations on the concept will proceed.

It is important to note that a clear line of communication has already been established between ROIL and Spar personnel. Thus, this work is becoming a collaborative effort consisting of feedback offered by the ROIL being strongly considered by personnel at Spar.

Further work is being planned by the ROIL to address the issues raised in this paper. Alternative paints will be evaluated at the ROIL with the intent of determining which have acceptably low reflectivity characteristics. The primary effort to be taken on by the ROIL, however, will be to perform an operational evaluation of these and other target concepts. Test subjects will consist of personnel at JSC with experience in operations, including the crew. Data will be gathered with respect to accuracy achieved during each alignment run as well as subjective data regarding how well each subject felt they could interpret the targets evaluated. Results of these evaluations will be incorporated into the RSIS documents.

CONCLUSION

It seems clear that these proposed modifications are improvements upon the original Spar design. The line of communication opened between ROIL and Spar personnel as well as the incorporation of this work into RSIS documentation means that this work will have clear implications to future space hardware design. The end product of this work will hopefully result in an alignment target that is very easily interpretable and which will work under a wide variety of situations.

ACKNOWLEDGEMENTS

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