Evaluation of On-line 3D Motion Measurement by On-orbit Monitoring Image

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Abstract

When the crew on ISS operate the critical robotics tasks such as the payload handing or berthing with less clearance to the environment, they utilize not only the digital telemetry of the robotics status but also the overview image for the situational awareness. The objective of the research is the assistance and refinement of the situational awareness by overlaying the additional information to the overview images for the crew operation. To obtain the clearance information from the overview image, the feature tracking method has been introduced. The clearance between the payload handled by robot arm and the environment can be measured in realtime so that the crew can be easily monitored through the overlaid image. The paper describes the detail of the method and techniques used to measure the relative position and the details of the quantitative evaluation by using the actual data obtained from the on-orbit operation. It is concluded that the proposed method by overlaying the clearance to the overview images could improve situational awareness.

1 Introduction

When the crew on Kibo/ISS operates the critical robotics tasks such as the payload handing or berthing with less clearance to the environment, they utilize not only the digital telemetry of the robotics status but also the overview image for the situational awareness. As the moving images contain many different aspects of the information, they may be effective source for the situational awareness. In fact, the several moving images have been directly utilized by crew at the actual ISS assembly and maintenance operation.

Currently the crew spend many hours for the training on the ground before the flight to understand the contents and meaning of the moving images for situational awareness. The crew robotics operation will be greatly improved if the moving images provide the additional information such as the distance to the environment to enhance the situational awareness as shown in Figure 1.

The research focuses on enhancing the situational awareness by adding the motion measurement information using on-orbit monitoring images. The single camera image is only required as the most of the current robotics operation on ISS including Kibo robot arm are performed under the known structural environment.

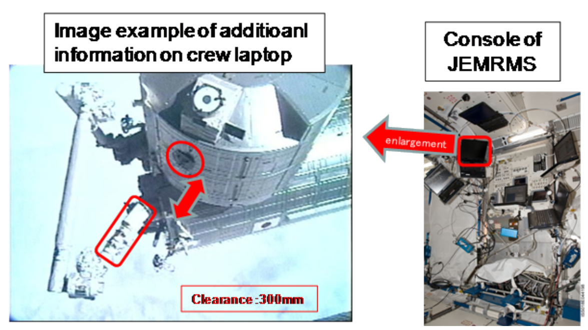


Figure 1 Situational Awareness Enhancement

2 JEMRMS Operation Overview

The construction of International Space Station (ISS) has been completed and the operation of the ISS will continue until 2020. The JEM (Japanese Experiment Module called Kibo) Remote Manipulator System (JEMRMS) was successfully launched on June 2008.

Since then, the JEMRMS functional checkout has been initiated, and the JEMRMS has successfully performed to assemble the total of five standard payloads on 2009.

The JEMRMS is selected as the example of the situational awareness enhancement of the crew robotics operation. Although the several robotic arms exist on the ISS, the similar crew operation has been performed at the robotic arm on orbit.

The JEMRMS is a space teleoperation manipulator to facilitate conducting experiments in an exposed environment and to maintain Kibo facilities. The JEMRMS is a 10m-long, 780kg manipulator with six degrees of freedom (DOF). It consists of two main arm booms, six identical joint mechanical/electronics units, an end effector at the tip and cameras with pan/tilt units on the elbow and wrist joints. The end effector is used to grapple the special fixture mounted on each payload. The wrist camera is used to measure the relative distance of the payloads from the target mounted on the berthing ports at Kibo Exposed Facility.

The JEMRMS console is located inside the Kibo Pressurized Module. By using the console, the JEMRMS is operated by on-orbit crew members. The console mainly consists of a management data processor (MDP), an RMS laptop terminal (RLT), translation and rotation hand controllers (THC/RHC), a camera control panel (CCP), two TV monitors, and an arm control unit (ACU), as shown in Figure 2.

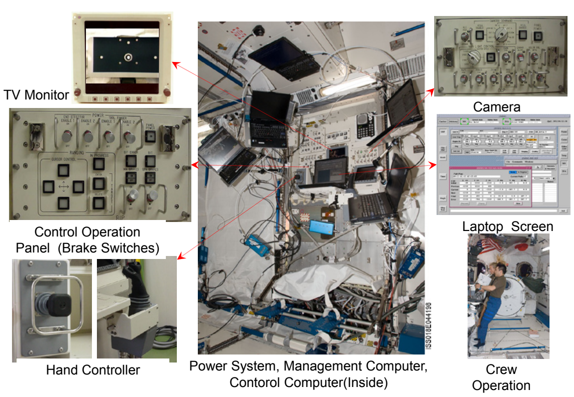


Figure 2 JEMRMS Console

3 Feature Tracking Method

The objective of the research is the assistance and refinement of the situational awareness by overlaying the additional information to the overview images for the crew operation. To create the additional information, the image recognition process by tracking the feature of the model is added into the current process of the image generation as shown in Figure 3.

As the most of the current robotics operation on ISS including JEMRMS are operated under the known structural environment, the single camera image is only required. Although the designed model or the as-build model is slightly different from the real world, the shape based on the design parameters are suitable for the matching of the actual image. As the payloads handled and berthed by JEMRMS wear multi layer insulations (MLI) which are usually difficult to model, the non-MLI parts are selected for the feature to track.

The following assumptions have been made to measure the motion of the payload during the robot arm handling.

- Coarse posture of robot arm and camera position and orientation with camera parameters
- Shape of the Kibo Exposed Facility platform and the payload carried by robot arm

The feature tracking technique is utilized to measure the relative position and orientation. The EEU (Experiment Equipment Unit) has the unique circled feature on both EFU on Exposed platform and PIU on the payload. shown in Figure 4. The circled feature is selected as one of the tracking features.

The feature tracking technique consists of the following steps. Figure 5 illustrates the features at each step also.

(1) Predict the image representation from the known configuration of 3D space. In this example, the circle in the green line is the feature to be tracked.
(2) Search the edge along with radius direction at each point on the circumference and detect it from the captured image. The blue arrows and red points are the direction and edge respectively.
(3) Create the relation between the circle position of 3D space and the edge location on image as shown in Equation {1}.
(4) Estimate the circle position in 3D space to minimize the distance between the red point and the points on the circumference shown in Equation {2},{3}. The circle in the red line is the tracked feature from the captured image.

4 Results of Feature Tracking

The video data are selected from the overview images of the actual payload operation on orbit recorded on the ground. When the payload is berthed to the Kibo Exposed Facility platform by JEMRMS, the overview images from the elbow camera on JEMRMS indicates the earth cloud as the background of the payload. The earth cloud are varied and changed over the time of the operation.

The feature tracking technique predict the features at the camera frame and match positions and orientation the between the prediction and images. By the nature, feature tracking creates the strong advancement when the background is varied and changed. Figure 6 shows the example of the intermediate results by motion measurement. The green dots are detected as the features while red lines are estimated from the model. The left top and right top are the shape model utilized in the image process. The algorithm is tracking the circled feature even under the varied background such as the earth cloud for all cases. When the image contains the additional circle, the algorithm detect the new circled features and start tracking until the features are disappeared from video. There are good matches between the image and the model estimated from the image. The feature tracking technique is relatively low cost in calculation even in reltime (10Hz) due to the necessity of the local image area calculation, although the feature is needed to select in advance.

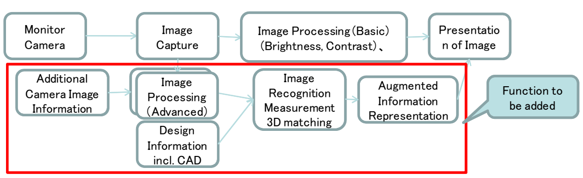


Figure 3 Process of Image Recognition

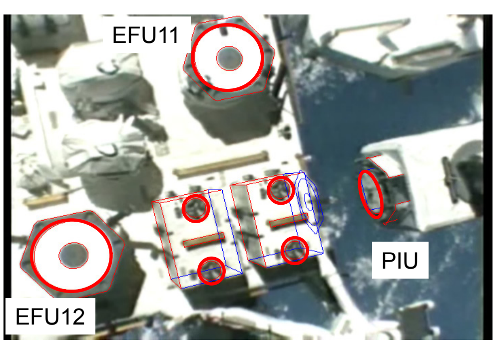


Figure 4 Process of Image

Figure 7 shows the comparison between the image measurement and robot telemetry. They agree each other at 3 dimensional positions and orientations for the most of the time. The three events are identified as the disagreed event. The event A shows rapid changes of the image measurements on Y-axis and Roll. The reason is evaluated as the shadow reflection on the platform by watching at the actual images as shown in Figure 8. The event B shows the spiky noise at the all axis. The reason is evaluated as the tracking errors by the rapid pan motion of the camera as shown in Figure 9. The event C is bias errors within 6cm and 2 deg at the maximum direction. This can be improved with better calibration of the camera and the shape.

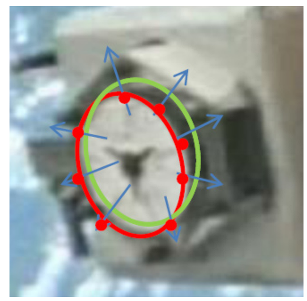


Figure 5 Feature Search

Figure 6 Intermediate Results

$$\begin{pmatrix} \frac{\partial^2 S}{\partial x\partial x} & \frac{\partial^2 S}{\partial x\partial y} & \frac{\partial^2 S}{\partial x\partial y} & \frac{\partial^2 S}{\partial x\partial \theta} & \frac{\partial^2 S}{\partial x\partial \phi} & \frac{\partial^2 S}{\partial x\partial \rho} & \frac{\partial^2 S}{\partial x\partial f} \\ \frac{\partial^2 S}{\partial y\partial x} & \frac{\partial^2 S}{\partial y\partial y} & \frac{\partial^2 S}{\partial y\partial y} & \frac{\partial^2 S}{\partial y\partial \theta} & \frac{\partial^2 S}{\partial y\partial \phi} & \frac{\partial^2 S}{\partial y\partial \rho} & \frac{\partial^2 S}{\partial y\partial f} \\ \frac{\partial^2 S}{\partial z\partial x} & \frac{\partial^2 S}{\partial z\partial y} & \frac{\partial^2 S}{\partial z\partial y} & \frac{\partial^2 S}{\partial z\partial \theta} & \frac{\partial^2 S}{\partial z\partial \phi} & \frac{\partial^2 S}{\partial z\partial \rho} & \frac{\partial^2 S}{\partial z\partial f} \\ \frac{\partial^2 S}{\partial \theta\partial x} & \frac{\partial^2 S}{\partial \theta\partial y} & \frac{\partial^2 S}{\partial \theta\partial y} & \frac{\partial^2 S}{\partial \theta\partial \theta} & \frac{\partial^2 S}{\partial \theta\partial \phi} & \frac{\partial^2 S}{\partial \theta\partial \rho} & \frac{\partial^2 S}{\partial \theta\partial f} \\ \frac{\partial^2 S}{\partial \phi\partial x} & \frac{\partial^2 S}{\partial \phi\partial y} & \frac{\partial^2 S}{\partial \phi\partial y} & \frac{\partial^2 S}{\partial \phi\partial \theta} & \frac{\partial^2 S}{\partial \phi\partial \phi} & \frac{\partial^2 S}{\partial \phi\partial \rho} & \frac{\partial^2 S}{\partial \phi\partial f} \\ \frac{\partial^2 S}{\partial \rho\partial x} & \frac{\partial^2 S}{\partial \rho\partial y} & \frac{\partial^2 S}{\partial \rho\partial y} & \frac{\partial^2 S}{\partial \rho\partial \theta} & \frac{\partial^2 S}{\partial \rho\partial \phi} & \frac{\partial^2 S}{\partial \rho\partial \rho} & \frac{\partial^2 S}{\partial \rho\partial f} \\ \frac{\partial^2 S}{\partial f\partial x} & \frac{\partial^2 S}{\partial f\partial y} & \frac{\partial^2 S}{\partial f\partial y} & \frac{\partial^2 S}{\partial f\partial \theta} & \frac{\partial^2 S}{\partial f\partial \phi} & \frac{\partial^2 S}{\partial f\partial \rho} & \frac{\partial^2 S}{\partial f\partial f} \end{pmatrix} \begin{pmatrix} \partial x \\ \partial y \\ \partial z \\ \partial \theta \\ \partial \phi \\ \partial \rho \\ \partial f \end{pmatrix} = \begin{pmatrix} \frac{\partial S}{\partial x} \\ \frac{\partial S}{\partial y} \\ \frac{\partial S}{\partial z} \\ \frac{\partial S}{\partial \theta} \\ \frac{\partial S}{\partial \phi} \\ \frac{\partial S}{\partial \rho} \\ \frac{\partial S}{\partial f} \end{pmatrix} \quad \{1\}$$

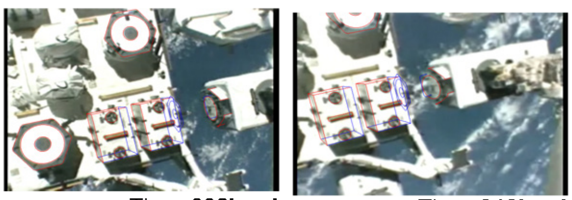
$$S(\partial x, \partial y, \partial z, \partial \theta, \partial \phi, \partial \rho, \partial f) = \sum_i wi \bullet Di^2 \quad \{2\}$$

$$Di(\partial x, \partial y, \partial z, \partial \theta, \partial \phi, \partial \rho, \partial f) \quad \{3\}$$

The figure 10 shows the another views used to measure the relative position. The wire frame lines on the images are estimated from the image measurements. There are good matches between the image and the model estimated from the image. These results indicate the potential to inform the ready-to-latch by the side view images.

Time: 50[sec] Time: 70[sec]

Figure 8 Shadow Reflection on Platform



Time: 330[sec] Time: 346[sec]

Figure 9 Rapid Pan Motion of Camera

5 Conclusions

The assistance and refinement of the situational awareness for the crew robotics operation has been discussed. The proposed method by overlaying the clearance to the overview images could improve situational awareness. To obtain the clearance information from the overview image, the feature tracking method has been introduced. The clearance between the payload handled by robot arm and the environment can be measured in realtime so that the crew can be easily monitored through the overlaid image. The paper describes the detail of the method and techniques used to measure the relative position and the details of the quantitative evaluation by using the actual data obtained from the on-orbit operation.

References

[1] H.Ueno, Situational Awareness Enhancement for Crew Robotics Operation by Image Recognition, i-SAIRAS 2012, Turin, Italy, 4-6 September 2012.

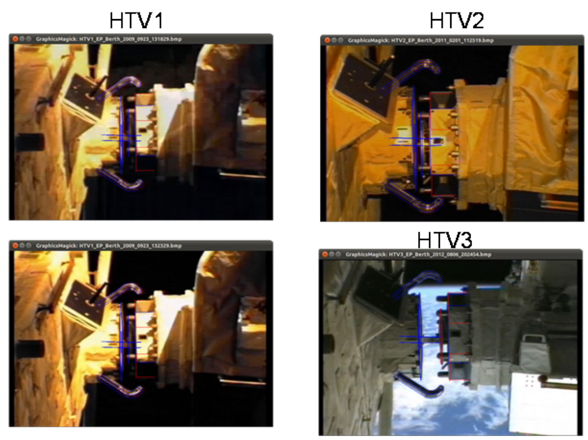


Figure 10 Image Measurement of Potential Ready-to-latch by Side View

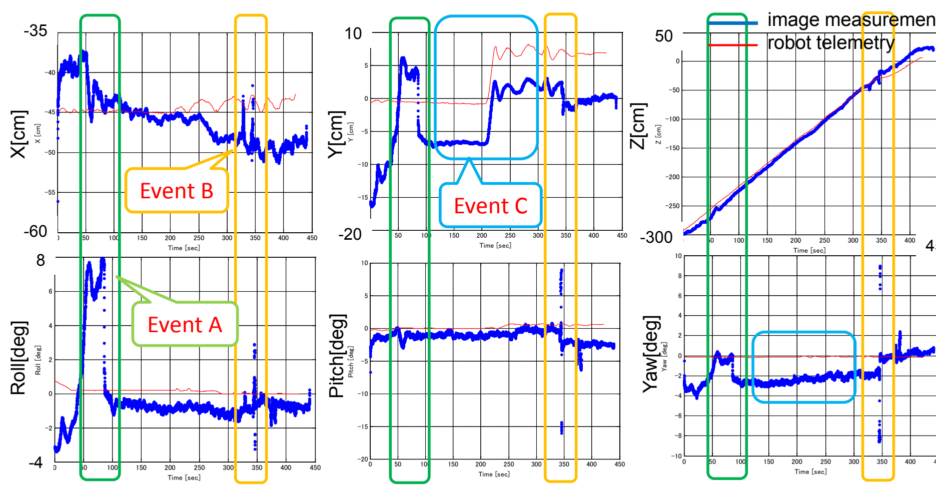


Figure 7 Image Measurement and Disagreed Event