ASTROBEE FACILITY

KIBO ROBOT PROGRAMMING CHALLENGE FINAL ACTIVITY REPORT

NASA AMES RESEARCH CENTER

ABSTRACT

On October 8th, 2020 the Kibo Robot Programming Challenge (RPC) Finals Event took place. Student teams from Australia, Indonesia, Japan, Singapore, Taiwan, Thailand, and UAE were the finalists of the competition and became the first students to ever upload APKs to an Astrobee robot (Bumble) on the ISS. This was the culmination of a joint effort between JAXA's Int-Ball developing team in Tsukuba, Japan and NASA's Astrobee Facility team at NASA Ames Research Center\ in California, USA.

The collaboration between JAXA and NASA started in late 2017. Throughout this time mutual visits by the engineering and management teams were organized. In July 2019 the Kibo RPC concept was formally defined and the competition started. Hundreds of students across the Asia Pacific region participated and during the final event they did so in real time with the participation of NASA's astronaut, Chris Cassidy. Chris interacted with the students, JAXA personnel and with the robot during the activity.

This report aims to summarize the lessons learned from the several crew and non-crew tended activities, the evaluations performed on ground, the coordination of resources both in the ground and at the International Space Station (ISS) as well as operations. It identifies the issues the teams faced and the solutions put in place to mitigate them.

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1 INTRODUCTION

This report aims to summarize objectives, successful and unexpected items during the NASA/JAXA joint collaborative activities towards the 1st JAXA Kibo Robot Programming Challenge (RPC). This competition invited students from several countries in Asia to participate by solving programming challenges that JAXA developed. After a round of elimination, the finalists were selected and they were invited to upload their code to solve a challenge on board the Japanese Experimental Module (JEM) at the International Space Station using the Astrobee robots.

In this challenge, students create Android Packages (APK) that can be loaded on to Astrobee's High Level Processor (HLP), an Android-based computer. It enables an Astrobee robot to visit three different locations inside the JEM to obtain data that would enable the robot to complete a final task. The robot would start at the "Start" position at the center line of the JEM's Bay 2 facing the airlock in Bay 7. Then, the Astrobee should autonomously move towards the first position or "P1" on the aft wall of Bay 3. There, Astrobee would use one of its cameras to decode a QR code and obtain the coordinates of the third position to be visited or "P3". After reading P1, Astrobee would move to P2 and read again another code. This time, the code contains the orientation at which the Astrobee should look at P3. After visiting this position, the student's program commanding Astrobee would instruct it to go to the position decoded in P1 and observe an AR tag at the orientation found in P2. Once the robot does this, it gets the position and orientation it should move to in order to point the Astrobee's laser towards a target. The team with the APK that commands the robot to point the laser the closest to the target's center wins the competition. Figure 1 provides an overview of the competition and the location of the different targets at each position.

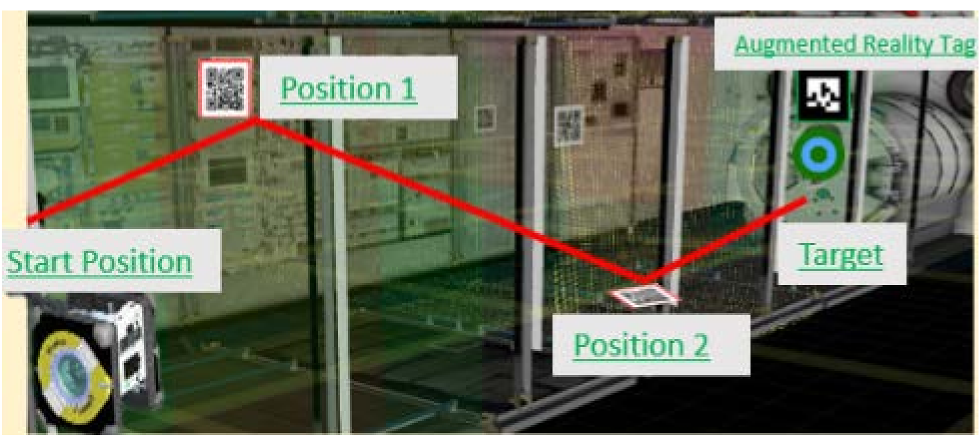

FIGURE 1. CONCEPTUAL OVERVIEW OF THE 1ST KIBO ROBOT PROGRAMMING CHALLENGE (CREDIT: JAXA)

On October 8th, 2020 the Kibo RPC Finals Event took place. Student teams from Australia, Indonesia, Japan, Singapore, Taiwan, Thailand, and UAE were the finalists of the competition and became the first students to ever upload APKs to an Astrobee robot (Bumble) on the ISS. This was the culmination of a joint effort between JAXA's Int-Ball developing team in Tsukuba, Japan and NASA's Astrobee Facility team at NASA Ames Research Center in California, USA.

The collaboration between JAXA and NASA started in late 2017. Throughout this time mutual visits by the engineering and management teams were organized. In July 2019 the Kibo RPC concept was formally defined and the competition started. Hundreds of students across the Asia Pacific region participated and during the final event they did so in real time with the participation of NASA's astronaut, Chris Cassidy. Chris interacted with the students, JAXA personnel and with the robot during the activity.

During this effort several "firsts" were accomplished, namely: the operation of an Astrobee robot without crew present, autonomous image acquisition towards creating/updating a map, non-NASA code run on the robot (both JAXA and students), two heterogeneous free-flying robots from 2 different space agencies working together (Int-Ball & Astrobee) during finals, first payload (student competition) using Astrobee, and having Astrobee controlled from non-NASA location (Tsukuba).

This report starts by describing the overall objectives of the challenge and gives a brief summary of the timeline of activities. The core of the report is centered on the individual goals of each activity, what went according to plan and what did not; how the Astrobee Facilities Team (AFT) tackled those unexpected items and the analysis and results that were obtained. Additionally, the conclusions drawn from these activities as well as the lessons we learned are summarized for all the activities at the end of the report. Finally, what future steps may be taken to improve upcoming activities are provided.

2 MISSION OBJECTIVES

The Kibo Robot Programing Challenge (RPC) mission had multiple objectives summarized as follows:

- Verification of four different positions to be visited during the competition, namely Start Position, P1, P2, and P3:
  In order to complete this objective, JAXA both intended to move Bumble through manual teleoperation using Ground Data System (GDS) graphical user interface (GUI) and verify the readability of its AR tag/Target and QR codes via their HLP's APK.

- Demonstration of Bumble autonomously moving from the Start Position to P3 without keep-in/keep-out zones (KIZ/KOZ):
  In order to complete this objective, JAXA would have Bumble placed at Bay 1 of the JEM facing the airlock and command it to visit each of the verified positions autonomously via its APK. In this case, the Bumble would not consider KIZ/KOZ defined by JAXA.

- Demonstration of Bumble autonomously moving from the Start Position to P3 with JAXA's defined keep-in/keep-out zones:
  In order to complete this objective, JAXA would have Bumble place at Bay 1 of the JEM facing the airlock and command it to visit each of the verified positions autonomously via its APK. In this case, the Bumble would consider KIZ/KOZ defined by JAXA.

3 TIMELINE SUMMARY

JAXA's Kibo-RPC work started towards the end of 2017 however the first on-orbit activity started on May 21st 2020 with the 1st Kibo-RPC Checkout activity. The effort ended with the 1st Kibo-RPC Finals on October 8th, 2020 spanning over 6 months of continuous ground and flight operations.

The timeline of operations performed for this mission is summarized below:

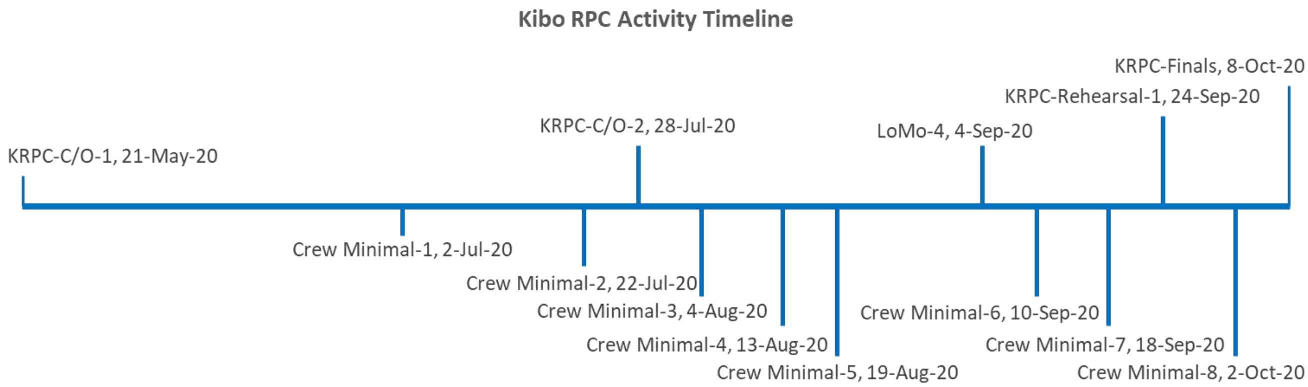

FIGURE 2. KIBORPC TIMELINE SUMMARY

Both crewed and non-crewed (otherwise known as crew minimal) activities started on May 21st, 2020. There was a total of 5 crew-tended activities, 3 crew-tended localization and mapping activities, and 8 crew minimal activities. All of these activities come to 15 activities carried out in 23 weeks, which is equivalent to approximately performing 1.54 on-orbit activities per week. One constant of every activity was that every member of the AFT carried out the tasks remotely from home due to the Covid-19 pandemic. Regardless, the AFT was able to complete successfully the objectives of this joint collaborative project.

It should also be noted that many of these activities were considered part of Astrobee's commissioning process. The formal Astrobee development project ended in 2019. However, due to delays, several of the original commissioning objectives that demonstrate baseline functionality were left to the Astrobee Facility project to complete in 2020.

4 OPERATIONS

The operations towards the Kibo-RPC Finals activity is summarized in the following sections. Each section describes the objectives, successful and unexpected items, actions, evaluations, and results of each activity.

4.1 CHECKOUT ACTIVITY #1:

The JAXA Kibo-RPC Checkout Activity #1 aimed to check the multiple aspects of the operation of Bumble in support of this competition.

Prior to this activity JAXA and Ames completed two rehearsal sessions of the activity. During these rehearsals, JAXA learned how to use features on GDS pertaining to the activity and practiced how to communicate during the actual activity. JAXA also submitted the HLP application to command Astrobee, an Android Package (APK) that would be used during the activity; JAXA also submitted ground and crew procedures which were followed during the rehearsals. After these rehearsals, JAXA and Ames agreed on the roles each member would play during the activity and communication protocols to be followed.

The Astrobee Facilities Team (AFT) submitted a request to be allocated time in order to carry out operations on board the ISS without crew attending the robots. These activities would vastly help the maintenance of on-orbit assets (dock, Astrobee robots, etc.) and the validation of on-orbit operations. As a result, the AFT would be able to carry out dry-runs of the Kibo-RPC activity and iterate over specific points in JAXA's procedure and thereby, increase the confidence of success during the actual competition.

The summary of this activity is fully detailed in the IRG-FFREP0064 Astrobee Kibo-RPC Checkout Activity Report.

4.1.1 OBJECTIVES:

The main objectives of the activity were:

1. Verify readability of printed material: Unless this verification completes, we cannot announce game conditions such as Astrobee positions to finalists. We would like to start developing simulation environment for Final Round from May at latest. So, process checkout should be done.
2. Verify Astrobee's performance on how it follows ground commanding (this can be confirmed in #1 above): If Astrobee acts beyond expectation, such as intruding into Keep Out Zone, we must re-consider ground procedures and settings.
3. Verify API works in real environment as well as simulation (verified during process checkout run): If errors from the difference between real and simulation environment occur beyond allowable, we must find countermeasure and feedback to participants. At least one run must be done in order to see if the error exists.
4. Verify procedures, interfaces of ground personnel: We need to know who talks to who, for both nominal and off-nominal situations.

4.1.2 SUCCESSFUL ITEMS:

This activity accomplished several successes over previous activities with similar goals. The robot's localization was reliable while the robot was docked. Sufficient sparse-map features were registered and integrated into the robot's Extended Kalman Filter (EKF). As a result of this reliable localization, undocking and manual movement to position P3 was also successful. The optical flow demonstrated to be working well, especially since the localization system seemed to rely solely on it during the time the robot was facing the circular window at the airlock and then moved, upon teleoperated GDS command to the actual location where the AR tag/target was located.

Other successful items included a good coordination with JSC imagery group (VCC or building 8), localization based solely on optical flow worked well, JAXA-ARC communication worked but a more immediate means of communication was apparent (e.g. Microsoft's Teams conference system), the roles prepared during the rehearsal sessions were effective, and preparing data profiles was a good idea.

4.1.3 UNEXPECTED ITEMS:

4.1.3.1 CONTROL STATION (GDS) START-RECORDING BUTTON NOT SELECTEABLE

There was an instance where the start-recording button was not selectable for the Kibo-RPC team as expected. This was a known bug in older versions of the GDS software. This has been fixed and the newer software will be distributed to the Kibo-RPC team.

4.1.3.2 DATA RECORDING ERROR

Although having two saving data profiles ready to be used, the krpc_co-MobNav.json profile produced errors after it was set to start recording data. This profile is a combination of JAXA's profile and ARC's usual MobNavSAMPLED.json which has been used previously for LoMo activities. We quickly tested the MobNavSAMPLED.json, but it also produced errors. Ultimately the "krpc_co_imgsampler.json" profile was used successfully and no loss of science resulted.

A possible reason why this may have happened is because Astrobee's Mid-Level Processor (MLP) is the one in charge of running the bulk of the navigation, localization, execution, and data saving processes of the robot. Having a large number of topics being saved while simultaneously running those other processes may have caused an overuse of the MLP's resources. The map being used was bigger than before which increases the use of RAM.

Follow on testing has shown that attempting to record data using a profile with a name longer than 18 characters can result in GDS being unable to handle state messages coming from the Data Bagger subsystem on Astrobee. The result from this is GDS falling into an incorrect state due to not being able to process feedback messages from Astrobee. Ultimately, this results in a duplicate command being issued causing the Bagger subsystem in Astrobee to die. At the moment, no validation is implemented on the Flight Software side to avoid this situation. The short term solution will be to restrict file names to less than 18 characters.

4.1.3.3 BIAS RESETTING BY OPERATOR WHEN NEEDED

A few possible ways to reduce the risk of the robot not being able to localize include: 1) not commanding the robot to move or ask the crew to move it before it has localized and 2) ask the crew to move the robot slowly, particularly if the crew is requested to rotate the robot since it is more prone lose localization when rotated quickly.

4.1.3.4 APK SNAPSHOT FAILED

When the Kibo-RPC team commanded their application (APK) to process a snapshot, the command completed quickly instead of the expected 10 seconds it should have taken. It has not yet been confirmed if imagery was recorded in the expected HLP data directly.

Follow on testing has shown that an improper install command can result in the APK not having the correct directory permissions to record data to the HLP. This can be corrected with improved APK install commands along with improved validation testing.

4.1.3.5 P2 QR CODE NOT RECOGNIZED

When commanded, the robot could not recognize the QR code at the P2 location. The distance to the target was larger than previous successful attempts. It's possible that the lighting, and in particular the source of the lighting, may have impacted the ability to recognize the QR code.

4.1.3.6 RESTRICED ACCESS TO HIVEMIND SERVER FOR POST-ACTIVITY DATA ACCESS

It was realized that Astrobee users require a NASA network VPN account (non-HOSC) to access the data server the AFT has made available from NASA Ames for the purpose of distributing data to users. As a temporary workaround, NASA Large File Transfer tools were used for distribution

4.1.4 ACTION ITEMS:

4.1.4.1 MAP CREATION/UPDATE:

At this activity, Bumble showed a rate of seen raw sparse-mapping features of 25fps (features per second), the worst case scenario was 7 to 10 fps (the highest possible rate is 150fps). During this activity the Astrobee Facilities Team also checked the localization in Honey and found it was not working adequately. Giving the resources and time constraints, further investigation of the issue was not possible during the activity and it has being left for possible future crewless activities and on-the-ground checks.

The map used during the Kibo-RPC Checkout activity was updated from a previous Localization and Mobility (LoMo) activity. During the Kibo-RPC Checkout activity, more images were taken from locations where JAXA is interested in visiting constantly, namely Start Position, P1, P2, and P3. These images were used to further augment the coverage of the existent map towards improving the localization of the robot if it visits these positions.

Based on the imagery data generated during this activity, a new map (merged_20190523_0614_0712_0724_0828_1101_20200513_0521.brisk.hist.map) was created to be used during the next on-orbit activity. This map comprehended images taken from activities starting on 2019-05-23. This map can be found in the server hivemind:/home/incoming/flight/maps/ directory.

After reviewing the recorded rosbags with the augmented map, it was found that the robot should be able to localize itself in 7339 images out of 10315 images with a mean of 84 features. Figure 3 summarizes these results obtained from a sparse map evaluation tool developed by the Astrobee

Flight Software Team. According to this results, the robot should localize in 71% of all the images included in the newly generated map.

FIGURE 3. SPARSE MAP EVALUATION TOOL RESULT

4.1.4.2 ANALYSIS PERFORMED:

Ames was focused on confirming or suggesting new estimated positions “Start, P1, P2, and P3” based on JAXA’s ground procedures and what was recorded with the krpc_co_imgsampler.json data profile (rosbag). The data collected during the activity was contained in 125 rosbags of approximately 90MB and 16 seconds each. These were merged into a single rosbag of approximately 13GB and it has been cleared to share with JAXA.

Ames analyzed the images contained in the topic /mgt/img_sampler/nav_cam/image_record and the robot’s estimated pose using the /gnc/ekf topic.

Since we were interested only in verifying the coordinates of JAXA’s targeted positions, we replayed a collection of bags that contained images and poses from the vicinity of those positions (Start, P1, P2, P3). We retrieved the pose of Bumble by analyzing the images from the recorded bags with internally developed tools as well as Rviz and echo the topic containing the robot’s pose given by the recorded EKF. Additionally, we also used the Plan Editor on GDS as a ground truth to the coordinates given by JAXA’s ground procedure. By comparing these coordinates with those given by the recorded rosbag’s EKF pose output we were able to determine if the desired target positions and the actual positions attained during the activity were in accordance to the centimeter level.

Based on our analysis, we determined that new target positions (Start, P1, P2, and P3) shall be consistent with 2 requirements:

- The robot shall be close enough to the AR/QR tags in order to read them
- The robot shall be not too close to the AR/QR tags in order to keep the robot localized

The first requirement may be interpreted as able to be within Bumble’s nav_cam field of view and the second may be interpreted by having the pose reported by the recorded bag’s EKF not moving over a tolerance of +/- 5 centimeters while looking at the target position.

4.1.4.3 RESULTS:

A summary of the coordinates corresponding to each targeted position comparing those given by JAXA’s ground procedure and this analysis are presented in Table 1. SUMMARY OF COORDINATES FOR EACH TARGET POSITIONTable 1. The values at each coordinate given in green correspond to the values suggested by Ames.

A view of the target positions suggested by Ames as a trajectory plan in GDS' Plan Editor is shown in Figure 4. In this figure it can be seen that the position P3 corresponds to a location from which the robot may be able to localize and simultaneously see the AR tag/target. It also shows how the suggested Start Position is within Bay 1 and Bay 2 of the JEM, giving ample space to the crew member to comfortably follow the activity while keeping the crew member outside of the field of view of the Nav_cam.

	Position						Orientation					
	x		y		z		R		P		Y	
Position	JAXA	ARC	JAXA	ARC	JAXA	ARC	JAXA	ARC	JAXA	ARC	JAXA	ARC
Start	10.95	10.95	-3.4	-4.00	4.85	4.95	0	0	0	0	-90	-90
P1	10.70	10.70	-5.3922	-5.20	4.4826	4.50	0	0	0	0	180	180
P2	10.9789	11.10	-7.7128	-7.60	5.55	5.40	0	0	-90	-90	0	0
P3	10.96	11.35	-9.68	-9.50	5.04	5.40	0	0	0	0	-90	-90

TABLE 1. SUMMARY OF COORDINATES FOR EACH TARGET POSITION

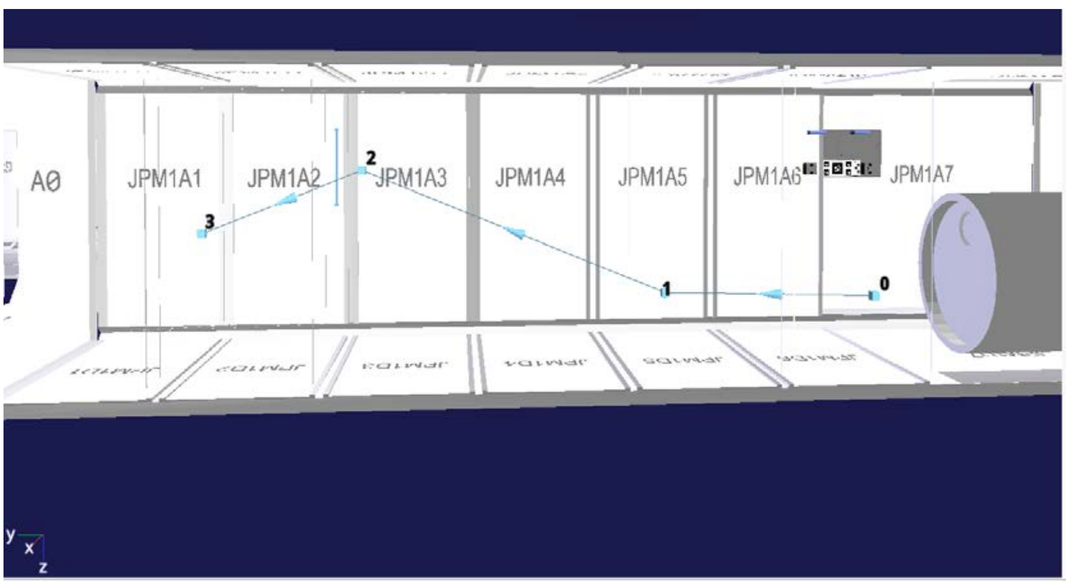

FIGURE 4. DESCRIPTION OF AMES' SUGGESTED NEW ESTIMATED TARGET POSITIONS

4.2 CREW MINIMAL #1:

The Astrobee Crew-minimal activity #1 was run on June 2nd, 2020 (GMT 184) and was successful in achieving all three of its primary objectives: validating Sci-Cam video streaming to the VCC (Bldg-8), validating localization from the Dock, and tested the laser pointer.

Additionally, Astrobee successfully undocked/Re-Dock twice including a small translational motion in the Y axis. The activity was concluded on time and without a "crew rescue". Aside from a last-minute battery swap for the satellite, no Crew intervention was required for the free flights.

There was an unplanned crew request to power cycle the Dock and exchange Bumble's batteries. The crew was able to meet this request using less than 10 minutes of their time.

4.2.1 OBJECTIVES:

The high level objectives of this activity were:

- Establish activity for routine module mapping and validation with minimal dependence on crew time
- Complete Kibo-RPC Checkout objectives leading into Kibo-RPC Rehearsal & Finals activities

The primary objectives of this activity included:

- Validate Sci-cam streaming to VCC (Bldg-8)
- Validate localization from Dock
- Test laser pointer

The secondary objectives:

- Undock and continue with small movements if conditions are good.
- Planned trajectories (e.g. Kibo-RPC trajectories) execute correctly
- Explore areas with poor localization
- Gather new data to augment current map
- Validate Honey camera performance
- Validate JAXA's Kibo-RPC APK performance
- Validate Nav-cam imagery distribution

4.2.2 SUCCESSFUL ITEMS:

All 3 primary objectives were met: tested laser pointer and its data was validated. The robot undock and docked twice and moved 30cm in the Y+ axis. The 4 hr setup time was enough for setup including debugging, the batteries lasted 6hrs in Bumble while at Dock. It took Chris Cassidy, the crew member, 5 minutes to swap batteries, wake both Bees and power cycle the Dock. Coordination with VCC was done as expected. Good impromptu coordination with ISS and Chris to swap batteries, wake both Bees and power cycle the Dock (total from decision to call, to communication, to action performed took 23mins approximately).

4.2.3 UNEXPECTED ITEMS:

4.2.3.1 SOFTWARE RELATED

There were three main items: Bumble's MLP, APK installation on Honey, and robot's state on the Ground Data System (GDS).

The Bumble's MLP needed to be restarted twice. The SSH connection to the MLP stopped functioning, Flight Software (FSW) was not starting but it was still pinging back. Later, the MLP stopped responding, even to ping.

The script for managing APKs (apk_manage.bash) worked nominally on Bumble but not so on Honey. Specifically, the installation of new APKs.

The third issue was related to Bumble's state not getting to GDS. In this case, the Executive was publishing its data nominally, but it was not reaching GDS. Related to this issue was that a plan couldn't be loaded or run and it was needed to restart FSW.

4.2.3.2 BATTERIES DRAINED

The batteries were drained before the operation was completed. In order to avoid this catching the team off guard, it is needed to check the battery level before start operations. This should be reflected in the IRG-FFTEST207a - Astrobee Quick Wakeup and Checkout procedure. A problem that raises as a consequence of this issue is that there was not a GDS health alert observed.

One hypothesis for this issue was a potential repeat of a previous Dock shutdown anomaly. This could be fixed with watch-dog update.

4.2.3.3 COORDINATION WITH OTHER STAKEHOLDERS

The imagery streaming and recording process was started before telling VCC. It became apparent that it is difficult to remember when there are many communications and tasks happening simultaneously. The AFT should tell them every time the process is started and every time it is stopped.

4.2.3.4 RECORDING PROFILES

The recording profile designed for this activity called MobNavDockSAMPLED caused issues during recording, and it was not loading at times. The RAM consumption was reported as nominal. Data recording did work, but slowed down and sometimes killed some nodes. This was the second instance of this problem. After analyzing the issue, it was determined that the internal name of the recording profile had to have a maximum of 32 individual characters. Once this was modified in the recording profile, the problem was solved.

4.2.3.5 ENVIRONMENTAL CHANGES EFFECT ON LOCALIZATION

A new payload called Mochi was installed at the top of the forward wall in Bay 7, making it visible from Bumble's docked position. This translate in the robot's localization system registering fewer mapped landmark features.

Several CTBs were present in the module. Without prior coordination of the activity there is nothing the AFT can do about it. Thus, cleaning of the CTBs inside the module became part of each Astrobee activity. Later on, the setup of the lighting to nominal became also part of each activity.

4.2.4 ACTION ITEMS:

4.2.4.1 SOFTWARE CREATION/UPDATE:

After having issues to assess the localization performance, the need to monitor low level features was identified. Since we did not have any tool to perform this task a simple monitoring script was created with the following features:

- Average count of Mapped Landmarks (ML)
- Average count of Optical Flow (OF) Features
- Average count of integrated ML and OF into EKF
- Customization of average timestamp (default 5 seconds)

This tools enables operators to take quick action to avoid losing localization before the EKF starts to diverge.

4.2.4.2 MAP CREATION/UPDATE:

Based on the imagery data generated during this activity, a new map was created (20200702_1stCrewMinimal.vocabdb.reduced.rebuild.brisk.map). This BRISK map contained 2548 images, 138568 points, and was 228MB. It consumed 602MB/1.91GB of RAM when tested on Bsharp and loaded its processors (1, 2, 3, 4) at up to 70%, 20%, 55%, and 35%. It registered a minimum of 45 sparse map registered features and a maximum of 100, producing them at a rate of 1.6-2.2 Hz. This map can be found in the server hivemind:/home/incoming/flight/maps/ directory.

4.3 CREW MINIMAL #2:

The Astrobee Crew-minimal activity #2 was run on 7/22/2020 (GMT 204) and was successful in achieving all of its primary objectives including: validating the updated map, validating localization and mitigating the effects of the SSLA change-out, re-validating the laser pointer, undocking and doing basic movements.

Additionally, Astrobee successfully undocked/Re-Dock twice including a small translational motion in the X, Y, Z axes as well as rotations around those axes. The laser was confirmed to work on both Bumble and Honey. The activity was concluded on time and it did include a "crew rescue". This rescue happened during our first path trajectory. The Kibo-RPC APK was successfully tested to take Nav-Cam snap-shot pictures.

The SSLA replacement does negatively affect localization, but the map is still usable for localization in the area of the dock. The SSLA imagery gathered will be used to update the map and will help to mitigate the impact of the SSLA replacements. The map update will likely not be ready in time for next week's Kibo-RPC Checkout #2, and crew motion of Astrobee will likely be needed for the Kibo-RPC trajectory.

Batteries on both Bumble and Honey were being charged by the dock, and no dock power cycle was needed.

4.3.1 OBJECTIVES:

The primary objectives of this activity included:

- Validate Sci-cam streaming to VCC (Bldg-8)
- Validate localization from Dock
- Test laser pointer

The secondary objectives:

- Undock and continue with small movements if conditions are good.
- Planned trajectories (e.g. Kibo-RPC trajectories) execute correctly
- Explore areas with poor localization
- Gather new data to augment current map
- Validate Honey camera performance
- Validate JAXA's Kibo-RPC APK performance
- Validate Nav-cam imagery distribution

4.3.2 SUCCESSFUL ITEMS:

Most movements during the activity took 1-2 minutes. Bumble batteries went from 90% to 77% in 33 minutes of continuous operation (translations and rotations on all X, Y, Z axes including undocking/docking actions). JAXA's Kibo-RPC APK snapshot feature was tested successfully. The updated map performed well during activity. Downlink of JAXA files tested successfully: 26 minutes, with downlink difficulties and room for improvement.

4.3.3 UNEXPECTED ITEMS:

4.3.3.1 SOFTWARE RELATED

During the software setup, the APK install processed failed a couple of times, however it ultimately was successful. The most probable causes of this issue were thought to be due to an unexplained corruption of APK given that there was a signature error and sha1sum mismatch. The "INSTALL_PARSE_FAILED_NO_CERTIFICATES" message was received.

Also during the setup, it was found that the map and APK files were not readable by group and therefore were not able to be copied by someone else other than the owner. This was fixed by adding it as a verification check in the Test Readiness Review Confluence document located at https://babelfish.arc.nasa.gov/confluence/pages/viewpage.action?pageId=128549584.

The HLP screen was in a locked state. To solve this a series of changes were implemented in the setup process and its related scripts. The screen turn-off from health check script was removed, a check for eyes focus to debug tree as well as a check for screen on and lock were added to the apk_manage script.

4.3.3.2 ENVIRONMENTAL CHANGES

JEM module lights were off at beginning of activity (left over from prior day's EVA activity). Crew was asked to put all JEM lights back to nominal "General" configuration.

4.3.3.3 OPERATIONS RELATED

One failed dock attempt, multiple re-attempts failing from bad position, however, the maneuver was ultimately successful.

Bumble was lost twice. The 1st time the procedure had the wrong direction for motion, making the operator move the robot to a location with poor localization, however, the operator was able to move Bumble back to the dock. The 2nd time, the robot did not register sparse mapping features and optical flow features were not being integrated. This time, the crew had to rescue the robot and dock it thereby ending the activity. An improvement to help the robot localize solely on optical flow features was being developed and tested at the same time of this activity.

4.3.3.4 COMMUNICATIONS

There was a loss of connection to DDS2 which caused a restart in the connection to TReK. Although the issue was identified, coordination with MMOC admins was still looking for a solution.

4.3.4 ACTION ITEMS:

4.3.4.1 MAP CREATION/UPDATE:

There was no new map created or any update made to the previous map.

4.4 CHECKOUT ACTIVITY #2:

On July 28th, 2020, JAXA and ARC ran the 2nd Kibo-RPC Checkout activity. TEAMS and JEMCOMPAYLOAD loop comms checks were successful and throughout the activity they were effective. Bumble undocked and then moved to P3 under GDS teleoperated command successfully. At P3, localization was registering up to 20 sparse map features and it mostly relied on optical flow features. Reading the AR tag and laser pointer on/off switch was successful both with and w/o the flashlight. Teleoperation of Bumble to P2 was unsuccessful and crew moved it manually to that location. At P2, Bumble was able to read P2's QR code correctly with and w/o the flashlight. As per JAXA instruction, P1 was not visited and Bumble was moved to the Start position to run demo1.

The demo1 was run twice. The 1st time the robot was placed on Bay 2 and after being localized it reported a tolerance error suggesting it could not achieve the first position commanded via the APK. On the 2nd time, the robot was placed between Bay 2 and 3 and after being localized and demo1 ran, Bumble rotated slower than usual towards P1, it then pitched at the same rate towards P1 and it moved up towards it. Once it reach a position where P1's QR code was in the nav_cam field of view, Bumble reported it was lost.

After these runs, it was decided to request the crew to assist with a LoMo mapping pass from the airlock facing the entry node and back.

4.4.1 OBJECTIVES:

The primary objectives of this activity were:

- Verify readability of printed material: Unless this verification completes, we cannot announce game conditions such as Astrobee positions to finalists. We would like to start developing simulation environment for Final Round from May at latest. So, process checkout should be done.
- Verify Astrobee's performance on how it follows ground commanding (this can be confirmed in #1 above): If Astrobee acts beyond expectation, such as intruding into Keep Out Zone, we must re-consider ground procedures and settings.
- Verify API works in real environment as well as simulation (verified during process checkout run): If errors from the difference between real and simulation environment occur beyond allowable, we must find countermeasure and feedback to participants. At least one run must be done in order to see if the error exists.
- Verify procedures, interfaces of ground personnel: We need to know who talks to who, for both nominal and off-nominal situations.

The secondary objectives of this activity were:

- Measure lap times of mission (this can be confirmed with #3): We need to know how long the final round takes by measuring time of one run and time to bring Astrobee back to start position from goal.
- Verify if crew can set Astrobee at start position: We need to know if Astrobee loses self-location when crew manually brings it back to start position from goal.

4.4.2 SUCCESSFUL ITEMS:

JAXA's APK snapshot feature command was successful. The three different methods to send to ground the images were successful: directly from the APK, via email and through NASA's Large File Transfer system. The download and sending of snapshots from the APK to ground took approximately 15 minutes.

Teleoperation of Bumble from undocked position to JAXA's Kibo-RPC P3 position was successful as well as turning Bumble's laser pointer on and off from JAXA's APK commands. Reading the AR tag at P3 was also successful. With the assistance of the crew to position Bumble, reading JAXA's Kib-RPC's P2 QR code with the flashlight on or off was successful.

The communication between JAXA and ARC over TEAMS was improved from the last activity and was easier to coordinate among the teams.

4.4.3 UNEXPECTED ITEMS:

4.4.3.1 COMMUNICATIONS

The connection to the dds2 server failed again and the VPN was disconnected. Two actions can be taken to solve this issue: 1) when an agent (robot) state does not show in GDS, the FSW should be restarted and 2) when the Guest Science (GS) manager state is not correct, the Python program called gs_manager should be restarted.

In addition, after the script apk_manage.sh was started, pinging the HLP failed.

4.4.3.2 OPERATIONS

Bumble lost localization and therefore started tumbling in the transition from JAXA's Kibo-RPC position P3 to P2. A similar behavior was apparent when JAXA's APK demo_run command was issued to reach its defined Start position. When Bumble was commanded to move towards the defined P1 position, it did so but it relied solely on optical flow features and after the accumulated error grew without recognition of sparse mapping features, the robot got lost and started spinning.

The same map used during the Crew Minimal # 2 activity was used during this activity with no modifications. The localization system performed better than in the previous activity, however it also failed at similar point in trajectory As it did then. This may have been caused by the changes in certain parameters related to the localization, e.g. number of minimum sparse mapping features allowed to be registered by the Extended Kalman Filter (EKF).

4.4.4 ACTION ITEMS:

4.4.4.1 MAP CREATION/UPDATE:

Based on the imagery data generated during this activity, a new map was created (20200728_2ndKRPC_vocabdb.reduced.rebuild.hist.brisk.map). This BRISK map contained 2547 images, 138737 points, and was 229MB. It consumed up to 673MB/1.91GB of RAM when tested on Bsharp and loaded its processors (1, 2, 3, 4) at up to 60%, 70%, 55%, and 85%. It registered a minimum of 26 sparse map registered features and a maximum of 222, producing them at a rate of 1.25-2.068 Hz. This map can be found in the server hivemind:/home/incoming/flight/maps/ directory.

4.5 CREW MINIMAL #3:

On August 4th, 2020 the 3rd Crew Minimal activity took place. During this activity the setup previous to the activity went smoothly. Based on the low number of registered sparse map features, localization was poor. Visual inspection showed that there were CTB's in the opposite wall of the dock. These CTB's coupled with suspected lighting setting changes, appear to have impacted the localization.

After crew members removed those CTBs, the localization improved sufficiently to test the undock/dock operations as well as the first planned trajectory: "centerLineSingleLength.fplan". Bumble was able to reach the "Station 13" waypoint while always looking towards the airlock. When commanded to go to the dock approach position, it lost localization and tumbled for a few minutes until it reached the dock area (Bay 7). Once there, it was commanded to dock as it was able to register a high number of features and re-acquired localization. These docking commands failed due to tolerance violation and being too far from the dock. The crew member rescued Bumble when it was in the vicinity of the dock.

The minimum success criteria for activity #3 as described in our procedure was not met.

4.5.1 OBJECTIVES:

The primary objectives of this activity included:

- Validate Sci-cam streaming to VCC (Bldg-8)
- Validate localization from Dock
- Test laser pointer

The secondary objectives:

- Undock and continue with small movements if conditions are good.
- Planned trajectories (e.g. Kibo-RPC trajectories) execute correctly
- Explore areas with poor localization
- Gather new data to augment current map
- Validate Honey camera performance
- Validate Kibo-RPC App/APK performance
- Validate Nav-cam imagery distribution

4.5.2 SUCCESSFUL ITEMS:

The trajectory designed to autonomously map the JEM called “centerLineSingleLength.fplan” was completed up to the Station 13 only 4 stations before reaching the JAXA’s Kibo-RPC Start position in Bay 2. In addition, the modification to face airlock at all times while following this trajectory worked as designed. This modification had in mind maintain a clear view of a region with numerous, well-known areas that have a sufficiently large number of sparse map features (over 30) in the current map.

4.5.3 UNEXPECTED ITEMS:

4.5.3.1 COMMUNICATIONS

There was another random disconnection from dds2 server. *more info Jonathan?

Testing on Sci-cam showed that the highest possible rates achievable were only 1.1MB/s, this seems to be due to congestion on the 2.4 GHz wireless network at the JEM.

4.5.3.2 ENVIRONMENTAL CHANGES

There were several CTBs place at different locations of the JEM, e.g. F7 rack and at bay 1 and 2. In addition, the light setting was not in a nominal state. As a result, part of the operation's time was consumed by crew reorganizing the CTBs and the localization system would not perform nominally if they would have remained there.

4.5.3.3 LOCALIZATION RELATED

Bumble was not able to localize at the dock given the substantial changes in the environment. Different maps were tested as well as restarting various times the FSW.

4.5.4 ACTION ITEMS:

4.5.4.1 SOFTWARE CREATION/UPDATE:

Script running in the Astrobee's Low-Level Processor (LLP) was created to show the raw and integrated mapped landmark (sparse mapping) and optical flow features.

4.5.4.2 MAP CREATION/UPDATE:

Based on the imagery data generated during this activity, a new map was created (20200804_3rdCrewMinimal_vocabdb.reduced.rebuild.hist.brisk.map). This BRISK map contained 2598 images, 145039 points, and was 234MB. It consumed up to 701MB/1.91GB of RAM when tested on Bsharp and loaded its processors (1, 2, 3, 4) at up to 48%, 47%, 23%, 38%. It registered a minimum of 40 sparse map registered features and a maximum over 200, producing them at a rate of 1.6-1.8 Hz. This map can be found in the server hivemind:/home/incoming/flight/maps/ directory.

4.5.4.3 ANALYSIS PERFORMED:

Storage locations were studied and a list prioritizing where CTBs should not be placed by the crew in case there were new CTBs left in the JEM was created. There were three tiers of priority: high, medium, and low based on the expected impact CTBs in those locations would have during operations and specifically, in the performance of the localization system. High priority indicates locations where it is extremely important not to have CTBs. Likewise, low priority indicates locations where if there was a CTB, it would not severely impact operations or the localization system.

4.5.4.4 RESULTS:

List of locations not to have CTB's:

High:

JPM1F7 (Airlock area, P3 AR tag will be here), JPM1D5 (P2 QR code will be put here), JPM1A3 (Aft, P1 QR code will be put here), JPM1F6

Medium:

JPM1F7 (Starboard side), JPM1F7 (Port side) (P3), JPM1D3

Low:

JPM1O2, JPM1D1, JPM1D2

4.6 CREW MINIMAL #4:

On August 13th, 2020 the 4th Crew Minimal activity took place. During this activity the setup previous to the activity went smoothly. One attempt was made on the "Center-line" trajectory. Half way through, localization was lost. Attempts to re-acquire localization were partially successful. Astrobee was re-docked by crew.

An attempt was made to run a Kibo-RPC representative trajectory. Astrobee made it half way through before losing localization. Overall, Astrobee was able to travel further and for longer than all previous activities. However, localization performance improvements were not enough to meet the success criteria for this activity. More analysis on mapping and localization performance will be done.

A workaround for getting the Sci-Cam video streaming working under low-bandwidth conditions was found. We can move forward with a SSIPC end-to-end test. However, the workaround does limit video quality (specifically, high motion video). A longer term solution will be worked together with the ISS DMC and JSL teams.

4.6.1 OBJECTIVES:

The primary objectives of this activity included:

- Validate Sci-cam streaming to VCC (Bldg-8)
- Validate localization from Dock
- Test laser pointer

The secondary objectives comprehended:

- Undock and continue with small movements if conditions are good.
- Planned trajectories (e.g. Kibo-RPC trajectories) execute correctly
- Explore areas with poor localization
- Gather new data to augment current map
- Validate Honey camera performance
- Validate Kibo-RPC App/APK performance
- Validate Nav-cam imagery distribution

4.6.2 SUCCESSFUL ITEMS:

The setup was smooth and error-free, it was ready 1 hr before flight time. It was possible to dynamically replan and modify the original designed trajectory. Switching between the primary and secondary operators was done seamlessly, and the operators were able to recover Bumble a couple times from being lost.

A configuration was found for Sci-cam to provide a stable stream for the ground transcoder to update and send to VCC: 30fps, 640x480, 800 Kbps, MTU 1400. However, this stream was not stable enough during movements. The Iperf from the HLP to DDS2 was approximately 900 Kbps. A second configuration that works for the ground transcoder was determined to be: 30fps, 640x480, 2400 Kbps, MTU 800. This configuration is to be tested during movements on the 5th Crew Minimal activity.

The script running on Bumble's LLP was really helpful as it allowed to see terminal of raw and integrated ML/OF features as the robot was traversing the JEM.

4.6.3 UNEXPECTED ITEMS:

4.6.3.1 SOFTWARE RELATED

GDS reported a fault: "No heartbeat from mapper". This was resolved by restarting the FSW on Bumble.

At the end of the activity, a Bumble and Dock power cycle was requested to ensure Bumble was in a battery-charging condition. The crew was then requested to power cycle the Dock, power cycle Bumble (with Wake-button), and re-seat Bumble on the Dock. A FSW shutdown did enable charging right before the power cycle, thus this process is an added item to check before requesting crew action in the future. A possible rationale for this behavior may have been an interaction between the eps_driver_tool and FSW.

4.6.3.2 OPERATIONS RELATED

There were some issues with the setup of the JEM Camera. Initially it was zoomed in and had a green hue. A camera reset from ground fixed the zoom, but not the green hue. The color was not nominal and one hypothesis was that it was operating in IR mode as it was reported Astrobee's HazCam flashing was distinguishable.

Before one Loss of Signal (LOS) event, Astrobee was lost. After the event was finished, Bumble was docked. Crew member docked us without checking with the AFT first.

4.6.3.3 LOCALIZATION PERFORMANCE

During this activity a previously designed trajectory was used to follow a similar path to that of JAXA's intended during the Kibo-RPC final event. The localization degraded very quickly while reaching the end of the trajectory in Bay 3 facing the airlock. When manually moving the robot towards Bay 5 on top of JAXA's P2 position at the centerline, a movement downwards of 15cm resulted in worse localization performance even though the robot was still facing the airlock. This suggested additional image acquisition from different view towards the airlock was necessary. Similarly, twice the localization was lost when trying to go to dock approach point suggesting additional images were necessary in that area.

4.6.4 ACTION ITEMS:

4.6.4.1 SOFTWARE CREATION/UPDATE:

Updates to setup profiles were made, specifically to startup_machine_vision_NavDock.fplan, startup_machine_vision_Nav.fplan, startup_streaming_NavDock.fplan, and startup_streaming_Nav.fplan.

An open-loop mechanism was developed in coordination with the FSW group to help controlling the Astrobees during a localization loss event. This tool would allow to spin up the propulsion modules but not station keep mode. It would allow to have simple motion primitives, have a spin rate dampening.

4.6.4.2 MAP CREATION/UPDATE:

Based on the imagery data generated during this activity, a new map was created (20200804_3rdCrewMinimal_vocabdb.reduced.rebuild.hist.brisk.map). This BRISK map contained 2646 images, 150499 points, and was 239MB. It consumed up to 707MB/1.91GB of RAM when tested on Bsharp and loaded its processors (1, 2, 3, 4) at up to 24.7%, 40%, 55%, 36%. It registered a minimum of 31 sparse map registered features and a maximum over 458, producing them at a rate of 1.6-2.5 Hz. This map can be found in the server hivemind:/home/incoming/flight/maps/ directory.

4.7 CREW MINIMAL #5:

On August 19th, 2020, the 5th Crew Minimal activity took place at the JEM on board the ISS. This activity had a planned trajectory aiming to undock the robot, move to a center line position inside the JEM and while looking towards the airlock, move "backwards" in the direction of the entry node stopping every 30 cm. At each stop or waypoint of the trajectory, the robot was planned to sweep a total of 40 degrees from right to left and from up to down. This is part of our updated approach to re-base-lining the map in lead up to the Kibo-RPC activities.

On the first attempt, the robot got momentarily lost at the first waypoint. The robot was recovered manually and place in a center line position facing the airlock at the same height of the planned trajectory. The planned trajectory was then resumed and successfully visited waypoints and produced rotations until approximately Bay 4. Given the proximity to an extended LOS (~15 mins) the robot was brought manually to a close position to the dock, and then docked autonomously.

After the LOS, a second attempt was ran but it again the robot got lost at the 1st way point. It was not possible to recover this time and crew manually docked the robot.

The SCI-CAM tests showed an improvement in the stream quality when the packet MTU was reduced. It maintained a good video stream quality (640x480, 30fps) throughout. Additional troubleshooting will be done to improve the quality and bandwidth throughput further.

4.7.1 OBJECTIVES:

The primary objectives of this activity included:

- Validate Sci-cam streaming to VCC (Bldg-8)
- Validate localization from Dock
- Test laser pointer

The secondary objectives comprehended:

- Undock and continue with small movements if conditions are good.
- Planned trajectories (e.g. Kibo-RPC trajectories) execute correctly
- Explore areas with poor localization
- Gather new data to augment current map
- Validate Honey camera performance
- Validate Kibo-RPC APK performance
- Validate Nav-cam imagery distribution

4.7.2 SUCCESSFUL ITEMS:

On the first sortie attempt, Bumble got lost in Bay 7 but then recovered and continued operations (following the planned trajectory). It got as far as Bay 4/5 before returning, and successfully re-docked before an extended LOS.

The new trajectory provided controlled data acquisition and improvements on the map are expected. Successfully transitioned command line operators through the activity

The tests run on the SCI-cam distribution showed that the working stream configuration 640x480, 30fps, 800 Kbps, MTU 700 and a reduction of the MTU did help the stream quality. The amount of MTU reduction needed was half than before: from 1400 to 700. Datagram fragmentation is believed to cause issues with the streaming.

4.7.3 UNEXPECTED ITEMS:

4.7.3.1 OPERATIONS RELATED

The battery charging status did not switch to charging when Bumble was re-docked while it had the FSW running.

During the uplink and setup phase, Bumble required two MLP restarts since the rsync process hanged.

4.7.3.2 LOCALIZATION PERFORMANCE

Bumble's localization at the height of the first waypoint of the trajectory was poor and got lost during the two attempts to run it. During the second attempt, Bumble got lost in Bay 7 and in the last attempt it got lost as soon as it undocked. During the undock procedure, it appeared as the speed at which Bumble moved was sufficiently fast to affect feature tracking.

4.7.4 ACTION ITEMS:

4.7.4.1 SOFTWARE CREATION/UPDATE:

Modifications were made to the setup profile machine_vision_nav.fplan to make sure cameras (Nav-cam and Sci-cam) can be set appropriately.

4.7.4.2 MAP CREATION/UPDATE:

Based on the imagery data generated during this activity, a new map was created (20200819_5thCrewMinimal_vocabdb.reduced.rebuild.brisk.hist.map). This map has additional images from the trajectory's first waypoint.

This BRISK map contained 2741 images, 157871 points, and was 248MB. It consumed up to 707MB/1.91GB of RAM when tested on Bsharp and loaded its processors (1, 2, 3, 4) at up to 74%, 71%, 85%, 60%. It registered a minimum of 0 sparse map registered features and a maximum over 140, producing them at a rate of 1.2-1.4 Hz. This map can be found in the server hivemind:/home/incoming/flight/maps/ directory.

4.8 LOCALIZATION AND MOBILITY ACTIVITY #4:

On September 4th, 2020, the Astrobee LoMo activity took place on the JEM on ISS. The full procedure, including all mapping motions were completed successfully. The motions were completed early. Time was left for gathering extra mapping imagery using additional motions focused on improving localization for the upcoming Kibo-RPC activity.

Some optimization of the Sci-Cam video stream settings was done. A bandwidth issue continues to prevent an ideal solution. However, a working solution was tested successfully.

4.8.1 OBJECTIVES:

The primary objectives of this activity included:

- Obtain comprehensive imagery data from JEM to improve current Astrobee's on-board maps

The secondary objectives comprehended:

- Characterizing video streams from Sci-Cam

4.8.2 SUCCESSFUL ITEMS:

The movements made by the crew member while carrying Bumble were done nominally. Additionally movements not written in the flight procedure were able to be done after a quick assessment and coordination with crew.

The tests on the Sci-cam to find a good balance between available bandwidth and quality found two useful configurations: 640x480, 30fps, 800Kbps, 700 MTU and 720x576, 30fps, 800Kbps, 700 MTU. Actual video coming from ISS is smoother but the efforts of the transcoder to uprate the feed causes pixelation. However, we have to transrate since it is a requirement for VCC decoder. Higher resolution and higher bitrate also works but video suffers from much more pixelation (suspected increased data lose with increased bitrate).

4.8.3 UNEXPECTED ITEMS:

During the uplink/setup phase, prior to the activity, a segmentation fault happened again in Bumble. The issue was caused by a configuration Debian that did not have DDS files.

4.8.4 ACTION ITEMS:

4.8.4.1 SOFTWARE CREATION/UPDATE:

Given the issue with the configuration Debian, a check in the ground procedure was implemented.

4.8.4.2 MAP CREATION/UPDATE:

A completely new map was created based on the imagery data generated during this activity (20200904_Lomo_vocabdb.rebuild.brisk.registered.merged.surf.map). This map is the new baseline for future updates and it incorporates images only from this LoMo activity.

This BRISK map contained 2105 images, 174759 points, and was 223MB. It consumed up to 652MB /1.91GB of RAM when tested on Bsharp and loaded its processors (1, 2, 3, 4) at up to 58%, 62%, 36%, 89%. It registered a minimum of 16 sparse map registered features and a maximum over 73, producing them at a rate of 0.945-1.324 Hz. This map can be found in the server hivemind:/home/incoming/flight/maps/ directory.

4.9 CREW MINIMAL #6:

On September 10th, 2020 the Astrobee 6th Crew Minimal Activity took place. This activity was aimed at demonstrating localization with the data obtained during a previous LoMo activity, perform the complete JAXA trajectory (which starts at Bay 2 and visits each target point), and gather imagery around COSMIC in order to update the map after it was installed between the previous LoMo activity and this activity.

Localization at the dock worked and a first attempt at moving from the airlock to the JEM's entry node was done under a programmed trajectory. Unfortunately, this attempt was unsuccessful. The robot drifted and was later positioned by crew at the start position.

At this start position in Bay 2, an attempt to run a programmed trajectory approximating JAXA's trajectory was attempted but the robot was unsuccessful in executing the expected commands. A second visit by crew was done and the robot was docked.

A final attempt under manual control, had the robot undocking and moving along the center line towards the entry node and the Kibo-RPC start position. Once at the start position, it turned 180 degrees towards the airlock in preparation for starting JAXA's APK. However, an unexpected movement towards the forward wall occurred and the robot was stuck until battery levels reached our operational limits and the activity was stopped. Crew docked the vehicle and the activity ended.

By JAXA's latest go/no-go criteria (an APK controlled trajectory from P1 through P3), this activity did not meet the success criteria.

4.9.1 OBJECTIVES:

The primary objectives of this activity included:

- Validate Sci-cam streaming to VCC (Bldg-8)
- Validate localization from Dock
- Test laser pointer

The secondary objectives comprehended:

- Undock and continue with small movements if conditions are good.
- Planned trajectories (e.g. Kibo-RPC trajectories) execute correctly
- Explore areas with poor localization
- Gather new data to augment current map
- Validate Honey camera performance
- Validate Kibo-RPC App/APK performance
- Validate Nav-cam imagery distribution

4.9.2 SUCCESSFUL ITEMS:

Bumble was commanded up to Bay 2 using relative motions through the centerline of the JEM. It registered a good number features from the dock to Bay 2 while looking towards the entry node during this displacement. The robot was able to rotate 180 degrees from the entry node to the airlock, around Bay 2.

4.9.3 UNEXPECTED ITEMS:

4.9.3.1 SOFTWARE RELATED

There was a recurrence of segmentation fault on Bumble when trying to copy the map to the /res/maps folder. Faults on Bumble with multiple nodes dying happened a couple of times. Had to restart FSW and reboot the LLP to fix the issue.

Although Honey's HLP responded to ping, it had a problem with the adb commands actions which returned "error: device offline". This problem was not immediately debugged as other issues took precedence.

There were some issues regarding the new GDS GUI version 994; it was not working for a couple of team members even though it was for Roberto. Andres' GUI was not listing cameras in the drop-down menu at the teleop images tab. This issue was cleared with a GDS restart.

The designed fplan trajectories showed issues related to holonomic mode. The issue was found to be that the option "Face forward" had to be unchecked from each individual segment of the trajectory.

4.9.3.2 LOCALIZATION PERFORMACE

When the crew dropped off Bumble at start position, JAXAmanual plan command from JAXA's APK was run. The robot rolled and was almost getting lost requiring the assistance from crew (Chris Cassidy) to put Bumble straight again. Localization towards the airlock and around the dock area (Bay 6-7) was not stable. As a result, Bumble got stuck around Bay 2, forward wall. After investigating the issue it was found that the propulsion modules' fan were pulling the robot towards the wall. It was agreed to avoid getting as close as 50-60cm to any wall.

4.9.4 ACTION ITEMS:

4.9.4.1 MAP CREATION/UPDATE:

Based on the imagery data generated during this activity, a new map was created (20200910_6thCrewMinimal_vocabdb.registered.sub.brisk.map). This BRISK map contained 1864 images, 149793 points, and was 209MB. It consumed up to 674MB /1.91GB of RAM when tested on Bsharp and loaded its processors (1, 2, 3, 4) at up to 65%, 51%, 43%, 43%. It registered a minimum of 33 sparse map registered features and a maximum of 326, producing them at a rate of 1.6-2.5 Hz. This map can be found in the server hivemind:/home/incoming/flight/maps/ directory.

4.10 CREW MINIMAL #7:

On September 18th, 2020 the Astrobee 7th Crew Minimal Activity took place. During this activity 2 JAXA's APKs were successfully demonstrated. The first APK run consisted of starting at the start position and then visit each of the P1, P2, and P3 target positions. The second APK run consisted in moving the robot in the vicinity of P3 towards the airlock. A third APK run was going to be attempted but prior to start it, the robot drifted towards the forward wall and it was eventually rescued.

The next steps had Bumble repeating the first maneuver (undocking, manually moving to Bay 2 and initiate JAXA's APK.). During this attempt it was confirmed that there is an issue in the transition between reading the QR code at P1 and continue the movement to P2. We proceeded to manually move towards P2 while visiting intermediate steps. At the last and second intermediate step, Bumble was close to the Aft wall and the number of features seen was low. It is believed this caused the robot to drift towards the Aft wall and lose localization. The robot was eventually rescued.

During the final part of the activity the robot was undocked and docked three times in order to verify an issue with the Propulsion Module Controller (PMC). After some initial verification, the robot was moved to a centerline location facing the entry node and it drifted causing it to get lost. This was the final time the robot was rescued.

The outlook going into next week's Kibo-RPC activity is good. The current navigation map was validated and we have an increased confidence in the localization performance in the areas used by Kibo-RPC.

4.10.1 OBJECTIVES:

The primary objectives of this activity included:

- Validate Sci-cam streaming to VCC (Bldg-8)
- Validate localization from Dock
- Test laser pointer

The secondary objectives comprehended:

- Undock and continue with small movements if conditions are good.
- Planned trajectories (e.g. Kibo-RPC trajectories) execute correctly
- Explore areas with poor localization
- Gather new data to augment current map
- Validate Honey camera performance
- Validate Kibo-RPC App/APK performance
- Validate Nav-cam imagery distribution

4.10.2 SUCCESSFUL ITEMS:

Bumble was able to undock, manual traverse from dock to Bay 2 and autonomously return to the dock. The JAXA's demo_with_KOZ and backup_2_old APKs were ran successfully.

A large improvement (over 100) on how many sparse map features were registered was accomplished with the new map at the dock and higher number of features seen and registered throughout the trajectories (+70).

Two 180 degree rotations from left and right starting facing the entry node from Bay 2 ending facing the airlock.

The recovery tools to stop rotation and recover localization were useful to maintain control over Bumble during a localization loss event.

4.10.3 UNEXPECTED ITEMS:

Bumble experience again a segmentation fault while trying to copy map from /data/maps to /res/maps folder. Honey's installation of the APK was nominal, but the testing portion of the script seemed to hang.

There was a communication issue with Bumble after coming back from LOS at GMT 11:53. It's LLP responded to ping from Honey, but its MLP did not. After performing a power cycled Honey's MLP on accident lost communication to both. This issue was resolved by having the crew member power cycle Bumble and Honey.

In Bumble, nodes were not responding to heartbeats and running slow, however they came back. Later, more nodes died, including executive and bagger (when trying to record data). After FSW was restarted the nodes were more stable.

JAXA's demo_with_KOZ command from its APK did recognize there was no AR code and did say it would continue but it did not continue moving to P2. This was due to an implementation issue in the APK that was later resolved.

While manually positioning Bumble at P2 robot was localizing but moved unexpectedly towards the FWD wall and got lost before being able to run JAXA's backup_1 APK command.

Operating limits didn't switch to iss_lomo or nominal after undocking, which sets it to difficult mode. This seems to have been by design and has been fixed.

4.10.4 ACTION ITEMS:

4.10.4.1 MAP CREATION/UPDATE:

Based on the imagery data generated during this activity, a new map was created (20200910_6thCrewMinimal_vocabdb.registered.no1stCM.sub.brisk.map). This map had the same image collection as LoMo with the addition of images from Crew Minimal 2-6.

This BRISK map contained 2143 images, 170136 points, and was 236MB. It consumed up to 744MB/1.91GB of RAM when tested on Bsharp and loaded its processors (1, 2, 3, 4) at up to 55%, 51%,70%, 73%. It registered a minimum of 36 sparse map registered features and a maximum of 367, producing them at a rate of 1.3-2.1 Hz. This map can be found in the server hivemind:/home/incoming/flight/maps/ directory.

4.11 KIBO-RPC REHEARSAL #1:

On September 24th, 2020 the 1st Rehearsal towards the upcoming Kibo RPC event took place. During this activity 3 APK runs aiming to go from Bay 2 to Bay 7 were performed. The first two runs were done with JAXA's APK command 14:demo_with_KOZ, unfortunately an issue in the transition between P1 and P2 occurred in both instances. On the 2nd instance, the robot was commanded via the APK to visit P2 and P3 successfully.

The third run was based on the students from Indonesia's APK command called Run Plan 1. It successfully initiated from the start position and visited P1, P2, and P3. At P3 it remained for 60 seconds as programmed by the team. The APK then commanded the robot to move to the final position however, this position had a z-coordinate very close to the deck.

The overall activity demonstrated full movement from start position to P3 by APK commanding, and manually commanding the robot via an APK.

The criteria for bypassing the rehersal #2 activity was to achieve a long trajectory. A trajectory from the start position to P3 was achieved. However, the final commanding sequence from 'aim target', 'laser', 'finish', was not confirmed. Another concern is that final coordinate/position of P3 with final QR codes, which provide the information on P3 coordinate was not demonstrated. JAXA strongly requests to conduct Rehearsal #2.

4.11.1 OBJECTIVES:

The primary objectives of this activity included:

- Verify readability of printed material: Unless this verification completes, we cannot announce game conditions such as Astrobee positions to finalists. We would like to start developing simulation environment for Final Round from May at latest. So, process checkout should be done
- Verify Astrobee's performance on how it follows ground commanding (this can be confirmed in #1 above): If Astrobee acts beyond expectation, such as intruding into Keep Out Zone, we must re-consider ground procedures and settings.
- Verify API works in real environment as well as simulation (verified during process checkout run): If errors from the difference between real and simulation environment occur beyond allowable, we must find countermeasure and feedback to participants. At least one run must be done in order to see if the error exists.
- Verify procedures, interfaces of ground personnel: We need to know who talks to who, for both nominal and off-nominal situations.

The secondary objectives comprehended:

- Measure lap times of mission (this can be confirmed with #3): We need to know how long the final round takes by measuring time of one run and time to bring Astrobee back to start position from goal.
- Verify if crew can set Astrobee at start position: We need to know if Astrobee loses self-location when crew manually brings it back to start position from goal.

4.11.2 SUCCESSFUL ITEMS:

There were two complete runs of an APK (Start Position, P1 through P3) while maintaining localization for majority of activity. A record max number of sparse map features was also observed. First time students' APK was used: Indonesia. Indonesia APK was able to move continuously from P1 to P2 to P3 without interruptions and was able to activate and point the laser command and Finish command at P3.

4.11.3 UNEXPECTED ITEMS:

When station keeping at Start Position, Astrobee ended up with a tilted pose (map related issue?)

Got "position tolerance violated" error multiple times

- May need to reacquire position more often between teleoperations. APK plans handle this error on their own, they don't reacquire position but keep trying.
- Might need to increase tolerances
- Change to nominal mode may have decreased the flapping but it may have increased position tolerance errors.

GS manager (or potentially the APK) stopped working twice, needing the restart of the GS manager and the APK before running again

- GS manager worked fine but APK either got stuck or didn't stop when commanded. We had to force-stop the APK and restart the GS manager to refresh the state.

Checkout demo1 stopped in P1, not moving to P2

- Programming error: null pointer exception
- Cause of the issue: Point currentPoint = api.getTrustedRobotKinematics(2).getPosition();
- Timeout worked fine but the error was calling 'getPosition' since the previous function may return 'null'
- This error was not present in Indonesia APK, they correctly checked Kinematics instead of Point.

P2 coordinate in both APKs might be too low

Coordinate of P3 seemed good for AR tag reading but resulting point from transformation (from AR tag) using P3 (QR code) produced a position that was not good for laser aiming and localization.

Coordinate of P3 seemed good, but the AR tag coordinates move the robot too low

Indonesia APK has a very long loop when trying to go to last aiming point (50 tries). Didn't respond to stop command, had to force-stop it.

Indonesia APK may have not completed their plan (no laser, finish) because it got stuck in a loop when moving to the last point. Code was set to try 50 times. we didn't wait that long.

To avoid issues with getTrustedKinematics users may use timeout and fallback to getKinematics or fixed point if needed.

4.11.4 ACTION ITEMS:

4.11.4.1 MAP CREATION/UPDATE:

Based on the imagery data generated during this activity, a new map was created (20200918_7thCM_vocabdb.modP1P3.reduced.registered.brisk.merged.surf.map). This map removed some of the images included from Crew Minimal 7 in order to reduce a drift in the map of approximately 20 cm at JAXA's P1 and P3 positions while maintaining a high number of registered sparse map features.

This BRISK map contained 2021 images, 161066 points, and was 223MB. It consumed up to 707MB/1.91GB of RAM when tested on Bsharp and loaded its processors (1, 2, 3, 4) at up to 70%, 77%, 65%, 65%. It registered a minimum of 0 sparse map registered features and a maximum of 88, producing them at a rate of 1.3-2.1 Hz. This map can be found in the server hivemind:/home/incoming/flight/maps/ directory.

4.11.4.2 ANALYSIS AND RESULTS:

After observing strange localization/control behavior a data exploration was done, leading to the discovery of inconsistencies in the pose of the features included in the latest map. We narrowed down the problem to a set of pictures added from recent activities. Due to time constraints we were unable to reconstruct the whole map and instead opted for removing certain images from the map. This of course, meant a reduction on detected features but an increased accuracy of the localization.

Figure 5 shows the trade-off between lost features due to removed images from the map. We used an old map with less features but good enough localization as a metric (blue). The latest map (green) has a greater count of features but mostly inaccurate, so the resulting map (red) included a number of features in between, effectively increasing on feature count and accuracy.

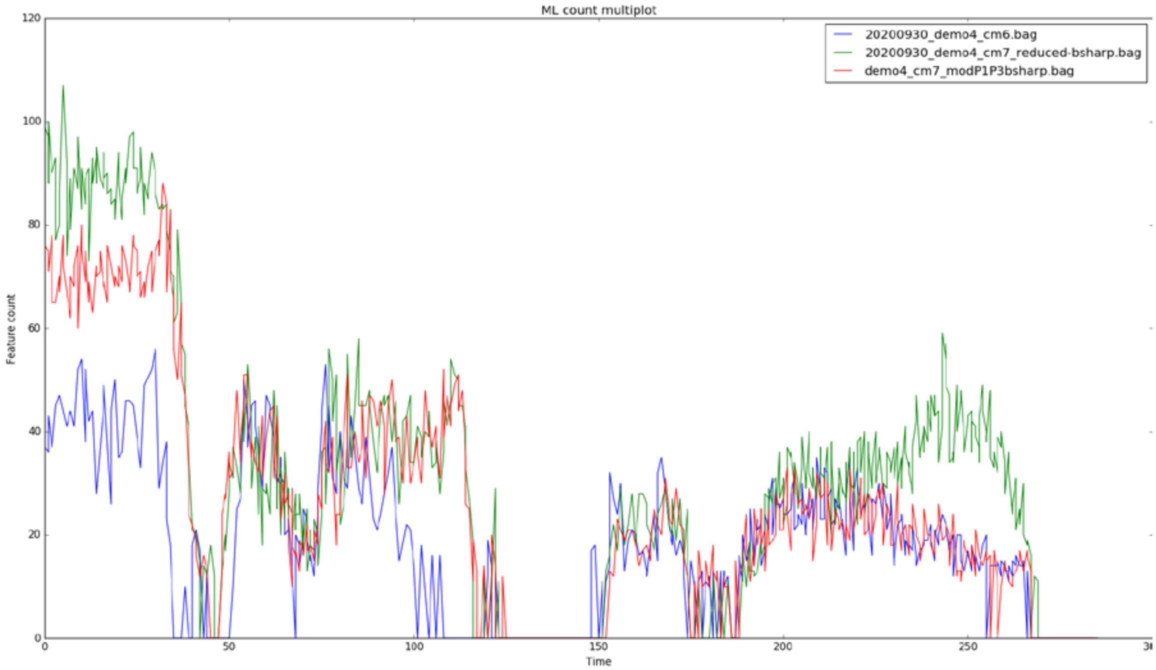

FIGURE 5. NUMBER OF SPARSE MAP FEATURES REGISTERED COMPARISON

The new map was also tested for localization accuracy. Figure 6 shows the localized position of Astrobee on a test run (note P1-P3 on the plot). The map used on the ISS (green) produces a wrong position in P1 and P3. The new fixed map shows a better localization (red) closer to our metric (blue). Therefore confirming that this change created a map with similar coverage than the latest used on the ISS but increased accuracy.

On the other hand, P2 is a difficult position for localization as noted for the lack of poses on the plot. Astrobee uses OF only when flying on that vicinity.

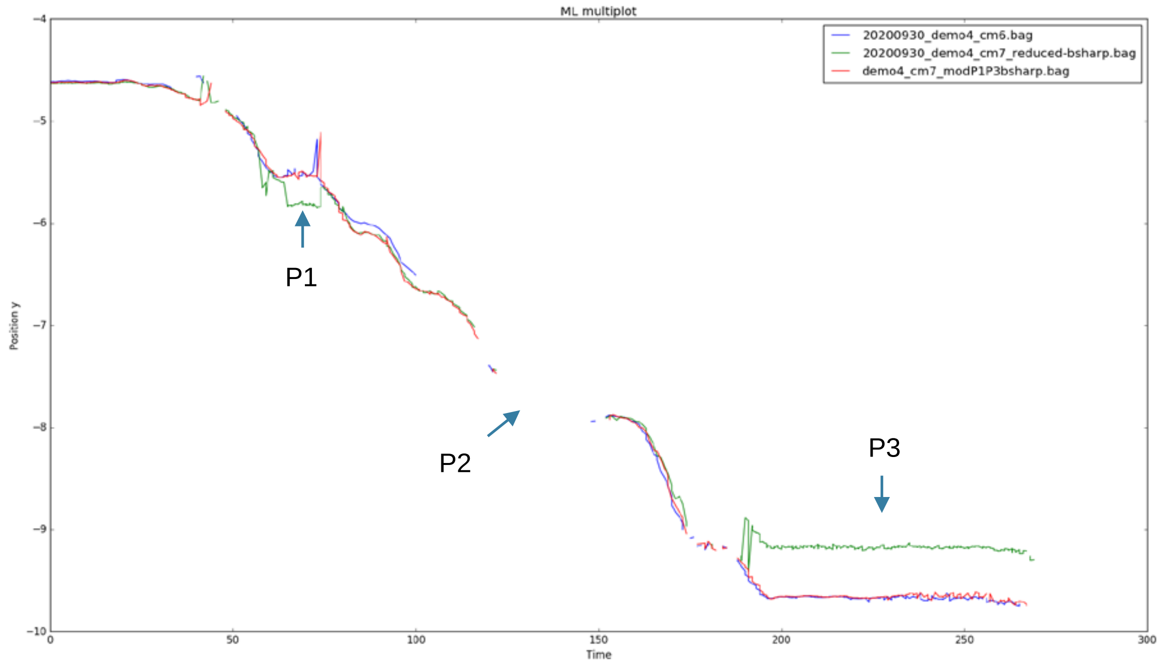

FIGURE 6. MAP LANDMARK POSITIONS ON Y-AXIS MAP COMPARISON

4.12 CREW MINIMAL #8:

On October 2nd, 2020 the 8th Crew Minimal Activity took place. During the activity four major tests of JAXA's and Thailand's student APKs were run. The first attempt run JAXA's APK command "13: demo_without_KOZ". It correctly identify and decoded the QR at P1, move towards P2, the robot identified the QR code there but it did not decode it. The robot continued to move until it reached the deck and remained there until manually moved.

The 2nd attempt at running JAXA's APK performed the same as the 1st however it was stopped after it passed P2 in an effort to avoid having to recover it from getting lost.

The 3rd attempt tested Thailand's APK command "Run Plan 1". It correctly visited P1 and correctly identified and decoded the QR there. It move towards P2 but it was not able to identify nor decode the QR code there. It then continued to P3 where it had its AR tag within the Nav_cam's view. The robot then moved towards the left until it reached the aft wall.

A 4th attempt had the robot placed at the centerline on Bay 6 facing the airlock, however right before starting JAXA's AK command "19: demo_backup_2" the robot moved towards the aft wall.

Outlook going into next week's final activity is promising. The objective of completing a run that matched the new QR codes with the P3 coordinates was not accomplished. The objective of completing a P3 targeting maneuver was not accomplished. This has made it difficult to definitively judge student APK performances. However, APK demonstration onboard in real world in next week's final activity can be taken into consideration and will be an important component to student's participation. Definitive ranking may be done with simulation results and student APKs will be run as originally scheduled.

4.12.1 OBJECTIVES:

The primary objectives of this activity included:

- Validate Kibo-RPC APK trajectories
    - Specifically, connecting new P1 and P2 QR codes with updated P3 coordinates
- Validating targeting behavior after reaching P3

4.12.2 SUCCESSFUL ITEMS:

Bumble was able to move from the Dock to the starting position three times and recovered localization after being lost once. Finally, multiple switching between operators was accomplished.

Four attempts of APKs were completed successfully: twice JAXA's checkout, Thailand, and demo_backup_2 although this last attempt was not started as Bumble drifted to the left. From these runs QR at P1 was successfully read by both JAXA's and Thailand's APKs, QR at P2 was successfully seen by JAXA's APK but it did not decode it.

4.12.3 UNEXPECTED ITEMS:

HLP communication dropouts

Stuck in tele-op mode after recovering localization (after run 3)

- recovered by reacquirePosition command

Data fault from low flash memory

- More data was recorded than expected

During run 2, high air flow was noticed (in bay 6) an attempt was made to re-localize but failed.

APK errors?

Too many errors in GDS history. Command line had to be used.

During APK motion, Robot seems to move fast. Does it use 'difficulty' setting? RE: I (Ruben) believe that JAXA uses same configuration as previously set. Nominal was used in the first checkout run and then it was set to iss_lomo. Impeller gain was changed to 2 (nominal) during the last activity.

4.12.4 ACTION ITEMS:

4.12.4.1 MAP CREATION/UPDATE:

No new map created nor updated.

4.13 KIBO-RPC FINALS EVENT:

On October 8th, 2020 the Kibo Robot Programming Challenge Finals Event took place. Student teams from Australia, Indonesia, Japan, Singapore, Taiwan, Thailand, and UAE were the finalists of the competition and uploaded their APKs to Bumble on the ISS.

Every student team had at least one chance to run their APK with different approaches and corresponding levels of success. At least three student teams made it all the way to the last target position at the airlock and pointed the laser to the bull's eye.

Overall, the activity was extremely successful by enabling students to run their APKs and some even multiple times within the time allocated for the activity. Hundreds of students across the Asia Pacific region participated in real time. The crew member, Chris Cassidy, got to interact with the students by answering questions during the activity.

4.13.1 OBJECTIVES:

The primary objective of this activity was to run Kibo-RPC APKs submitted by students.

4.13.2 SUCCESSFUL ITEMS:

Each student team got at least one full run and the distribution of Nav-cam images was done as expected. The activity was a complete success.

4.13.3 UNEXPECTED ITEMS:

Bumble batteries were not charging when first powered on the day before. This was a new instance of the same issue previously seen. It was solved by asking crew to power cycling the dock.

During one of the students' runs, there was an issue where the APK would request the position of Bumble but it created a connection exception with the LLP. The problem was due to a name resolution problem for the name "llp". Bumble asked the gateway to resolve the name with no luck, therefore, the /gnc/ekf is not subscribed. The temporary solution was to remove any default gateway in the IP routes.

There was an issue with APK commanding being canceled by system_monitor. When lost for a while, Bumble launches a fault which triggers a stopAllMotion command. In turn, the APK commanding got canceled and they didn't try again to move. The cause was that the trajectory chosen by some APKs was bad from a localization perspective as Optical Flow was still good. The students' APK made Bumble stay too long in a bad pose and they didn't add checks for this kind of external interruptions.

The AFT temporary solution was to change LOCALIZATION_PIPELINE_UNSTABLE fault response from "stopAllMotion" to "noOp". In this way, Bumble would continue it movement.

There was a network connectivity issue with the WiFi to both Bumble's MLP and HLP processors. Both of them were able to connect to the 2.4GHz access point, however, they missed the 5GHz. Further, it was observed that the MLP and HLP were fighting for the best connection. MLP connected to the furthest 2.4GHz access point and the HLP connects to closest access point 2.4GHz.

After the recess caused by the long LOS, there was a series of restarts and reboots. It is unclear if they have to do with the bagger, performance issues.

4.13.4 ACTION ITEMS:

4.13.4.1 MAP CREATION/UPDATE:

No new map created nor updated.

5 CONCLUSIONS

The collaborative work JAXA and NASA to carry out the 1st Kibo Robotic Programming Challenge was completed and successful. After 2 years of planning which spanned over 6 months of continuous on-orbit activities, seven teams from the Asia Pacific region were able to run their code (in the form of an Android Package, APK) on board of Bumble, one of the three Astrobees on board the International Space Staion.

Constant and effective communication among the multiple stakeholders was paramount to the success of this collaboration. This became evident during the development of ground and crew procedures as well as other operational products.

Environmental factors were more important than initially expected for the reliability of Astrobee's localization and mapping systems. Control over CTB and cargo bags , coordination with crew, and light settings proved essential to improve their quality and facilitate both crew-minimal and crew-tended operations.

6 LESSONS LEARNED

6.1 SOFTWARE IMPROVEMENTS TO BE MADE

6.1.1 GENERAL ROBUSTNESS

The localization system should be less sensitive to environmental changes and the software operations should present fewer restarts and fewer bugs.

6.1.2 PERFORMANCE CHARACTERIZATION

The simulator validation of behavior of the Astrobee robots e.g. overshoot expectations and the localization and map “safe areas” should be characterized and as much as possible, visualized.

6.1.3 STUDENT-USER APPLICATION “SANDBOXING”

There should be an on-line, real-time validation of student APK commanding during runtime. In this way, the JAXA and the AFT will be able to determine if there are issues with the students’ software or the robot. One approach to doing this could include a Kibo-RPC specific intermediate API in between the Astrobee API and the student’s software. Requiring student software to utilize the Kibo-RPC API would allow the Kibo-RPC team to validate actions and impose constraints that would minimize unexpected behaviors.

6.2 GDS USER TRAINING FOR OFF-NOMINAL COMMANDING

The Astrobee Facility Team has to make sure that Astrobee Guest Scientists are familiar with the use of the GDS tool to command and control the Astrobee robots and its subsystems. There were some instances in the activity where additional GDS commanding may have recovered the localization system.

Although it was very useful to train JAXA operators to use GDS, under off-nominal situations and with minimal communication channels it became evident that further more in-depth training for such situations was necessary.

6.3 IMPROVED APK VALIDATION TESTING

Some additional functionality and install/uninstall testing of the user APK may have identified the snapshot issue. Ames should extensively validate the APK configurations and settings of the robot before the on-orbit activity, in addition to the ground validation currently performed.

6.4 ADDITONAL BACK-ROOM COMMUNICATION BETWEEN AFT AND THE USER

We also learned that a better and faster mode of communication between the Astrobee Facility Team and the Guest Scientist Team during the on-orbit activity needs to be implemented. This may include a chat and/or a teleconference number

6.5 OPS LESSONS LEARNED KIBO-RPC CHECKOUT #1

The three main lessons learned from the May 21, 2020 JAXA Robotic Programming Competition Checkout (Kibo-RPC Checkout) are 1) the procedure review process, 2) clarifying the responsible entities for submitting timeline activities, and 3) understanding who is responsible for crew time.

6.6 MAIN CAMERA BECAME NAV-CAM INSTEAD OF SCI-CAM

Although it was initially determined to use the Sci-cam as the main camera during the competition to be used by students APK's to identify targets, Nav-cam took that role. Sci-Cam however, is still utilized for real-time observers. The reason for this was Nav-cam’s wider field of view.

In addition, there was the challenge to obtain snapshots from the Sci-cam and simultaneously stream them while considering that Android only allows one access to a camera at a time. An initial suggestion was to add the capability of creating snapshots while streaming (all within the same Sci-cam app), but since JAXA did not need colors for the AR/QR recognition, the Navcam/Dockcam were chosen instead. This solution ended up delivering more flexibility and range.

6.7 RELIANCE ON NAV/DOCK-CAM

GDS operators came to rely on both Nav and Dock-Cam vs telemetry driven animation and Sci-Cam when operating Bumble. Despite the tunnel vision this may have caused, additional information from GViz and the script running at the LLP showing the raw and registered sparse mapping and optical flow features increase the operator’s awareness.

6.8 IMPROVED APK VALIDATION TESTING

In order to have a cohesive and comprehensive evaluation of the APKs uploaded to Astrobees in the JEM, a series of tests described in Confluence were incorporated into overall Confluence-based preparation process.

6.9 BACK-ROOM COMMUNICATION

The communication sustained through Microsoft Teams between Astrobee Facilities Team and JAXA facilitated workflow during operations.

6.10 OPS FLIGHT PRODUCTS

Working together, JAXA and NASA Ames improved the crew procedures, PPO, and crew supplemental documents. It is important to better understand and define roles and responsibilities with respect to PPO and requesting ISS resources. Additionally, it is necessary to introduce better and clearer communication between JAXA, Ames, and MSFC PODF teams when submitting procedures.

6.11 GROUND PROCEDURE REVIEW PROCESS WAS IMPROVED

The use of Confluence, the online wiki collaboration tool Ames uses, was a big help. It helped better synchronize ground and crew procedures with step-sync-points.

6.12 NAV-CAM DISTRIBUTION

The distribution of Nav-cam images towards judging points was accomplished within 30 minutes of being taken thanks to scripts Ames created. Added APK verification test for checking Nav-cam image recording was key to confirm the process was successful.

6.13 SCI-CAM DISTRIBUTION

Streaming Sci-cam was successfully sent to Building 8's decoder for being observed by SSIPC. There were however, network issues that prevented the use of HD streaming. Thus, a lower resolution was used for activities since it provided a stable enough video feed. Importantly, an internal process to handle Sci-cam's setup and commanding was simplified and semi-automatized.

6.14 AR/QR TAG READABILITY DISTANCE FROM ON-SITE TESTS

Several experiments were run under different distances and lighting conditions in the Granite lab to reproduce those found in the JEM. It was learned which optimal flash-light settings to use during the activities to read and decode the QR and AR codes.

6.15 APK DATA RECORDED HELPED EVALUATE TEAM′S RESULTS

APK logging and data recording practices were improved and translated in better understanding of issues that arose during activities and thereby helping fix them promptly.

6.16 ISS′ JEM 3D MODEL MISMATCH

NASA Ames did not have a ground truth model of the JEM until JAXA kindly shared it with the team. Before then, the maps used had a mismatch of approximately 20 cm from the model used by JAXA. This introduced errors in localization, after receiving JAXA's 3D model however, NASA Ames was able to fix the issue and improve the robots localization.

6.17 COMPETITION′S SIMULATED SYSTEM NOT CLEAR TO AMES TEAM

Prior to the final's event, it was not clear to NASA Ames how the simulation used by the students work. In future events, better communication between Kibo-RPC and NASA Ames will facilitate the validation of the students APK. In this way, full conditions for APK simulations can be communicated in a reproducible way by both parties.

6.18 ENVIRONMENTAL CHANGES EFFECT

Early on, it was determined that environmental changes in the JEM may affect negatively the localization system. Examples of constant changes in the environment included: CTBs moved around frequently, lighting replacement, lighting control and setup by crew members before activities, and loose cables where the robot may get tangled.

6.19 PEER COMMUNICATION IMPROVEMENTS

NASA Ames should have been better from the start at explaining Astrobee's localization and mapping systems to JAXA.

6.20 MAP CREATION/UPDATE/VALIDATION PROCESSES IMPROVEMENT

The map creation, update, and validation process is a delicate, lengthy process that is done "manually". This can be improved by automatizing certain components. This is a work in process.

6.21 TRAJECTORY′S LOCALIZATION QUALITY VISUALIZATION

Visualization of how well localized a trajectory is in a given map is desirable.

6.22 CONFLUENCE-BASED TEST READINESS REVIEW (TRR) PROCESS

The Confluence-based Test Readiness Review (TRR) process was improved to account for the many configuration details associated with an Astrobee Operation.

7 FORWARD STEPS

The Astrobee team is constantly improving the robot's capabilities and systems' reliability.

Although a substantial enhancement was achieved to the reliability of the robot's localization and mapping, work already is being done to further account for unexpected changes in the ISS environment that may negatively affect the robot's localization system. This is being achieved by an improved localization algorithm.

The map creation/update process is being streamlined to minimize human error and the time it takes to finish. A series of software tools are being developed to automate the mapping process, to visualize areas that have been mapped vs those which have not, and determined if a particular trajectory will be localized with the current map.

Coordination during the students' APK evaluation phase between JAXA and NASA should be improved. By having confirmed a given APK produces the same results in both the simulator provided to students to develop their code as well as that used by the Astrobee Facility Team to evaluate them, issues regarding APK performance may be easily identified and corrected prior to the competition.

8 REFERENCES

This report is a compilation of several documents and notes taken throughout the time of these activities. These includes:

Ground Procedures:

https://babelfish.arc.nasa.gov/confluence/display/FFFSW/IRG-FFTEST214+-+On-orbit+No+Crew+Localization+and+Mobility

https://babelfish.arc.nasa.gov/confluence/display/FFOPS/Kibo+RPC+Finals+-+Ops+Procedure

https://babelfish.arc.nasa.gov/confluence/pages/viewpage.action?pageId=130712005

On-orbit Activity Logs and Debriefs:

https://babelfish.arc.nasa.gov/confluence/display/FFFSW/On-Orbit+Activities

https://babelfish.arc.nasa.gov/confluence/display/FFOPS/Kibo-RPC+Activity+Debriefs

Test Readiness Reviews:

https://babelfish.arc.nasa.gov/confluence/display/FFFSW/Test+Readiness+Reviews

Evaluation Logs:

https://babelfish.arc.nasa.gov/confluence/display/FFOPS/Kibo-RPC+Android+Application+Verification

https://babelfish.arc.nasa.gov/confluence/display/FFFSW/IRG-FFTEST301++-+Astrobee+Sparse+Map+Evaluation+Log

9 ASTROBEE FACILITIES TEAM

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10REVISION HISTORY

Date	Version	Notes	Released by
11/24/2020	Version 1.1	Added graphs, images, and analysis. Revised overall	Andres Mora

		content and expanded conclusions and future work.	
10/23/2020	Version 1	N/A	Astrobee Facility Team, internal review