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RFID Advances in the ISS REALM: RFID-Enabled Autonomous Logistics Management

RAIN ENGAGE Conference
Dec 2020

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National Aeronautics and Space Administration

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…and others

REALM Experiments

- RFID-Enabled Autonomous Logistics Management (REALM) experiments are jointly funded by NASA's Advanced Exploration Systems (AES) and ISS Programs

- Why: Autonomous Logistics Management (ALM) was identified in 2015 as a high priority technology need for long duration Human Exploration missions
  - Identify location of all items
  - Allows for more efficient packing, which becomes possible when efficient crew retrieval is assured

- Objectives:
  - Use ISS to learn how to implement Autonomous Logistics Management
    - Investigate different strategies/tools and assess for different missions
      - Fixed reader/antennas, RFID-equipped free-flyer, smart stowage structures
  - Determine combinations of RFID strategies and how they might vary according to mission needs
  - Apply knowledge to define a REALM system for Gateway

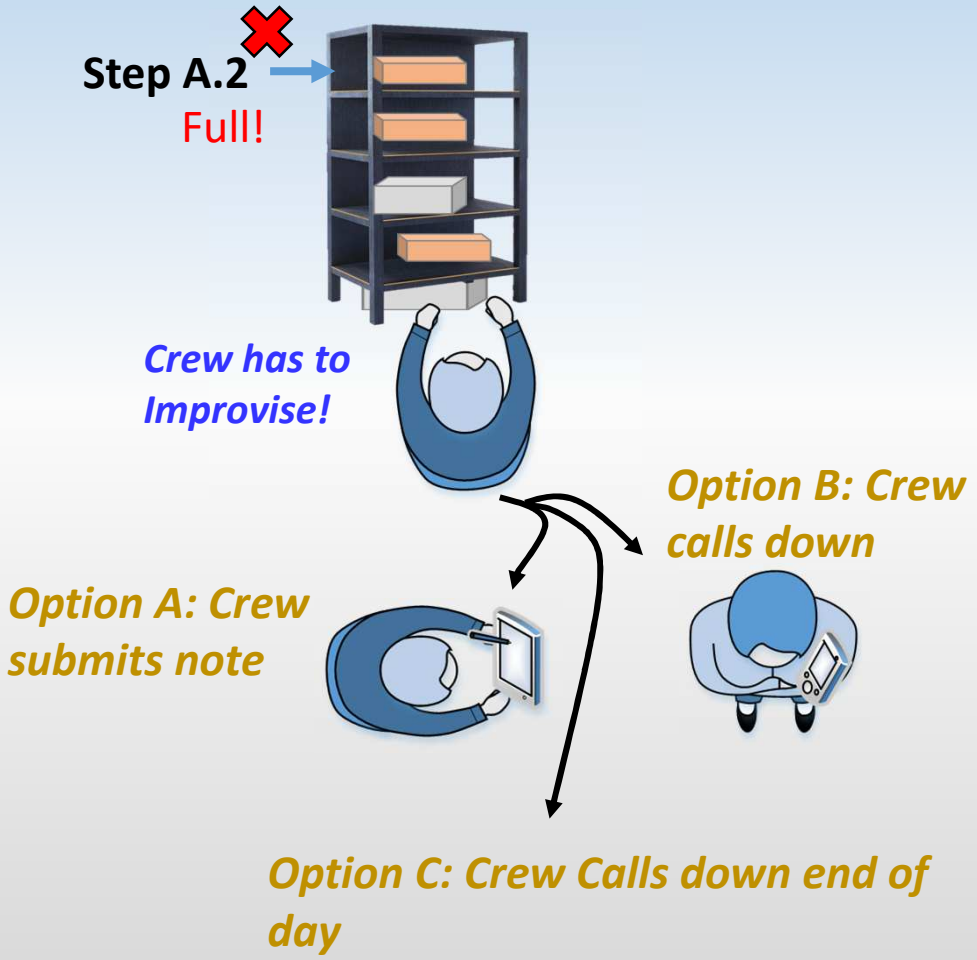
ISS Stowage Background

ISS Inventory and Stowage

- ISS has approx. 118 cu m (2250 CTBe) of usable stowage space
  - CTBe: Cargo Transfer Bag equivalent
- On board stowage is tracked and utilized via the Inventory Management System (IMS)
  - Database with Java interface
  - Tracks over 130,000 items
  - 64,000 items are active
  - ~3,000 items are considered lost

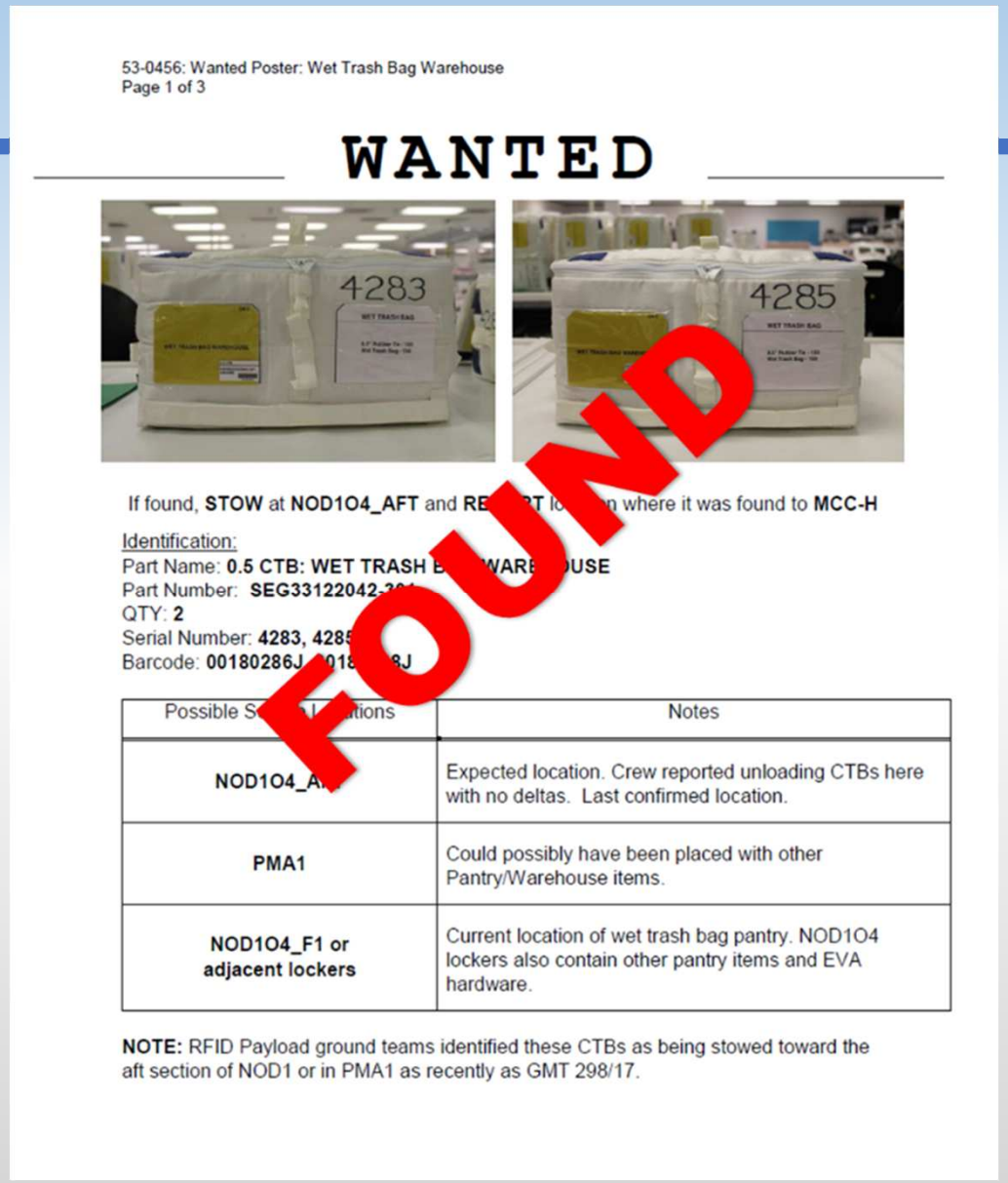
ISS Inventory and Stowage: Ground-Assisted

- Updating the IMS data is a largely manual process with assistance from a handheld barcode reader
  - ISS crew has the capability to update IMS
    - Requires additional time to input updates
  - IMS updates primarily performed by Flight Controllers
  - Data in IMS is only as accurate as the information provided by the crew.
    - Crew is responsible for communicating changes to stowage plans to the ground.



Wanted Posters

- Provide information regarding
  - Picture of lost item
  - Identifying data, e.g., part number, serial number, barcode, etc.
  - Last known location
  - Potential alternate locations
  - Stowage location if found
  - Rationale regarding use
- Average time allotted for a “Wanted Poster” is ~30 minutes



53-0456: Wanted Poster: Wet Trash Bag Warehouse
Page 1 of 3

WANTED

FOUND

If found, **STOW** at **NOD1O4_AFT** and **RE RT** lo n where it was found to **MCC-H**

Identification:
Part Name: **0.5 CTB: WET TRASH B WARE USE**
Part Number: **SEG33122042-**
QTY: **2**
Serial Number: **4283, 428**
Barcode: **00180286J 018 8J**

Possible S l tions	Notes
NOD1O4_A	Expected location. Crew reported unloading CTBs here with no deltas. Last confirmed location.
PMA1	Could possibly have been placed with other Pantry/Warehouse items.
NOD1O4_F1 or adjacent lockers	Current location of wet trash bag pantry. NOD1O4 lockers also contain other pantry items and EVA hardware.

NOTE: RFID Payload ground teams identified these CTBs as being stowed toward the aft section of NOD1 or in PMA1 as recently as GMT 298/17.

Return-on-Investment Targets for RFID

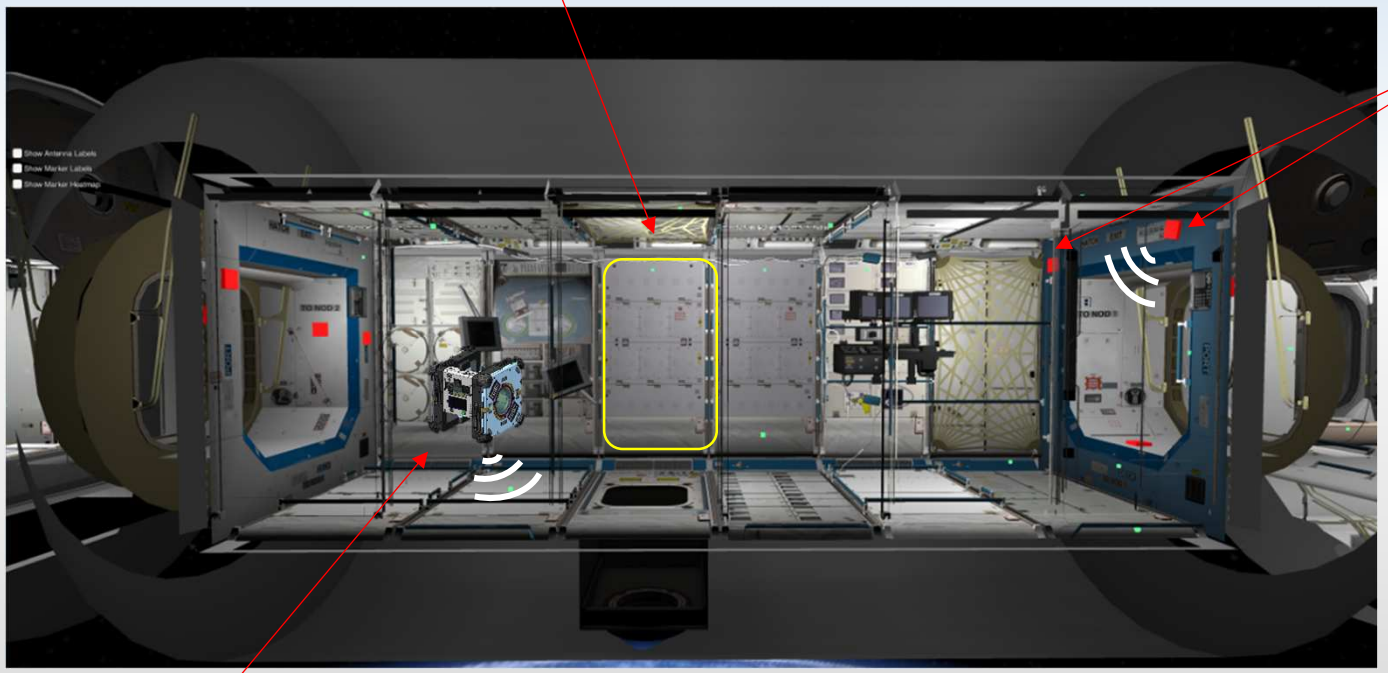
- Localization: where is it?
  - Capability tracked for instrumented and non-instrumented modules
    - Non-instrumented adjacent modules are likely for future Exploration as well as ISS
- Transfer audits
  - Confirm correct items are transferred
    - Avoids unintentional jettison of critical items
    - Assures essential provisions are transferred to departure missions; e.g., for lunar surface
- Inventory audits
  - Track critical consumables
  - Verify spares and contingency consumables remain at outpost in support of next mission

REALM RFID Technology Building Blocks

REALM-3

- Smart stowage system (reader integrated into drawers/racks)

Key attribute: RF penetration into dense collections



REALM-1

- Fixed reader/antenna System

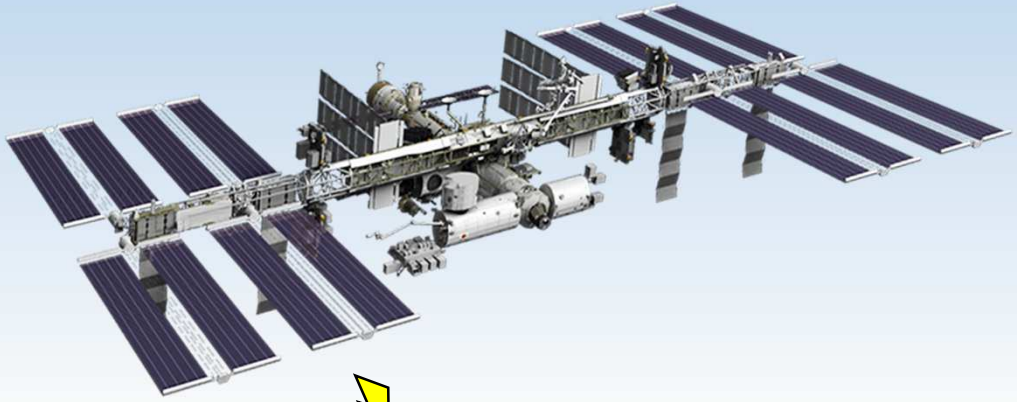
Key attribute: pervasive, 24/7 coverage

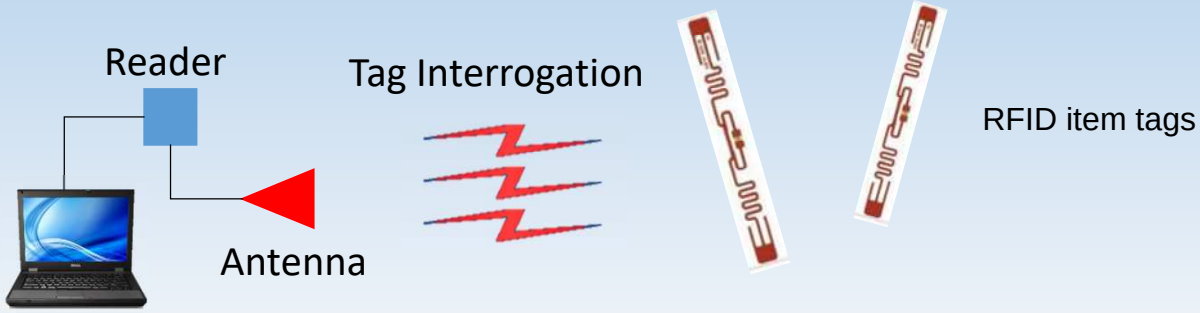
REALM-2

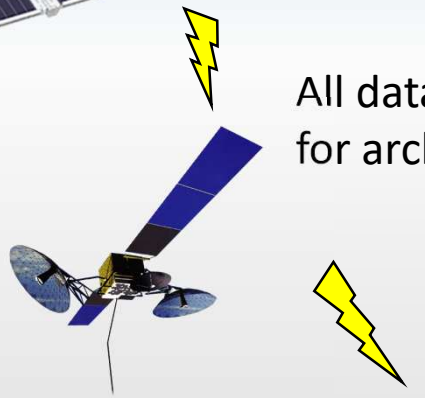
- Robotic free-flyer equipped with RFID reader

Key attribute: mobile, coverage extension, homing

Insight: Fixed Reader System + CEP







All data downlinked to ground for archiving

- Tags utilize RF power from interrogator – no batteries
- Links to readers can be interrupted
- Tags typically fit profile of existing ISS labels

<u>Complex Event Processing</u>
Machine learning algorithms analyze data for inferences such as location

RFID Logistics (aka REALM)

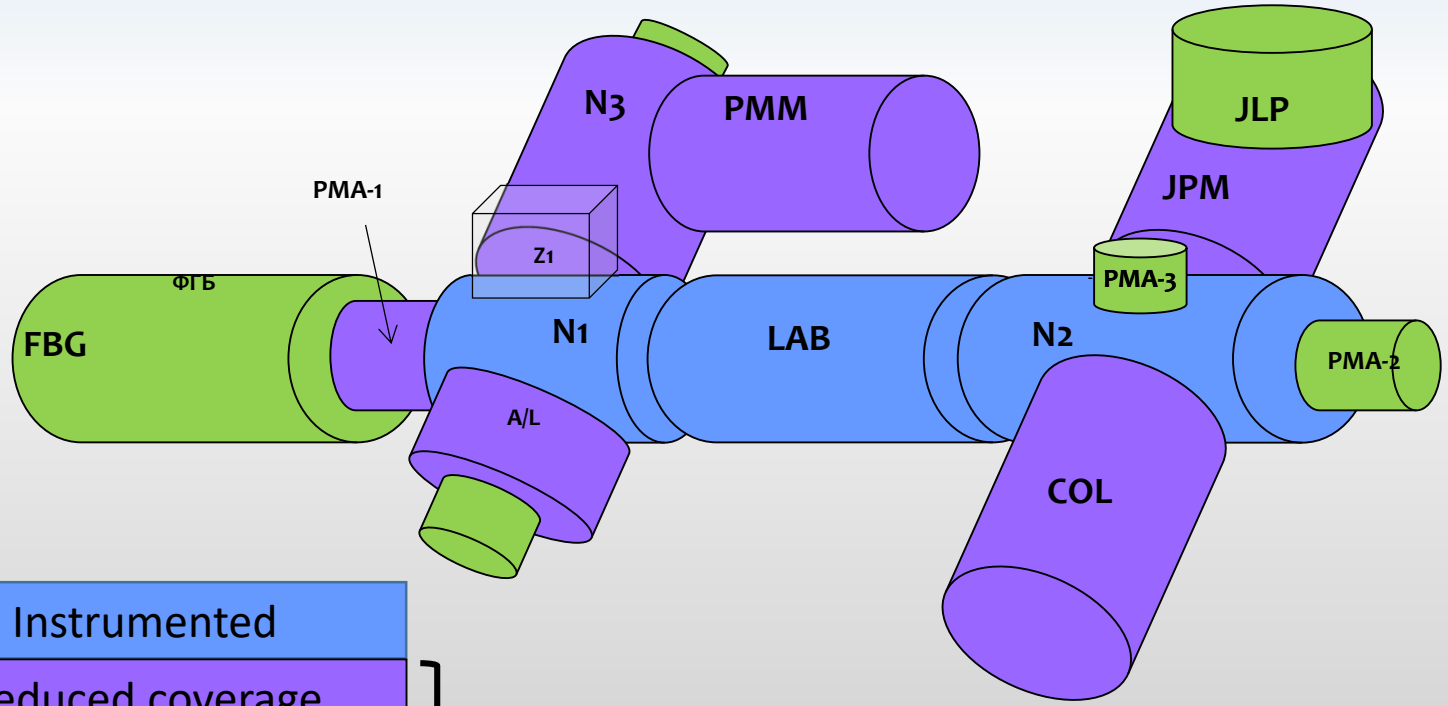
RFID-**E**nabled **A**utonomous **L**ogistics **M**anagement

– RFID readers track cargo transfer within the USOS

– 8 antennas and 2 readers in each instrumented module

– Data downlinked to ground and manually compared to IMS, reporting any differences to stowage officers.

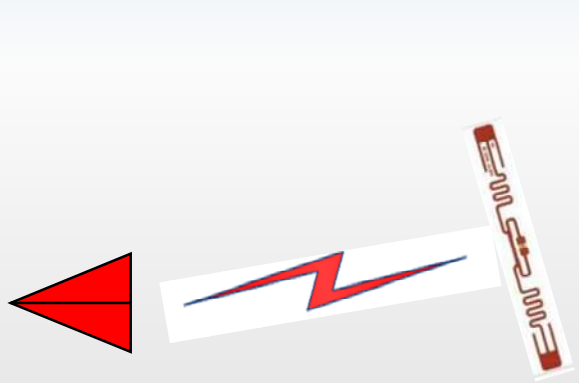
– Initial installation and setup occurred on 2/14/2017



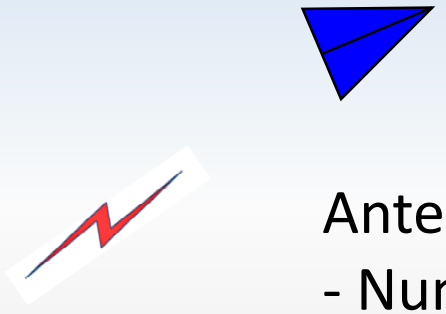
REALM-1 Localization Progress

Location by Nearest Reader Antenna

- Target tag is assigned an estimated position = to the reader antenna that reads that tag the most over a fixed interval



Antenna 1 (x_1, y_1, z_1)
- Number reads N_1



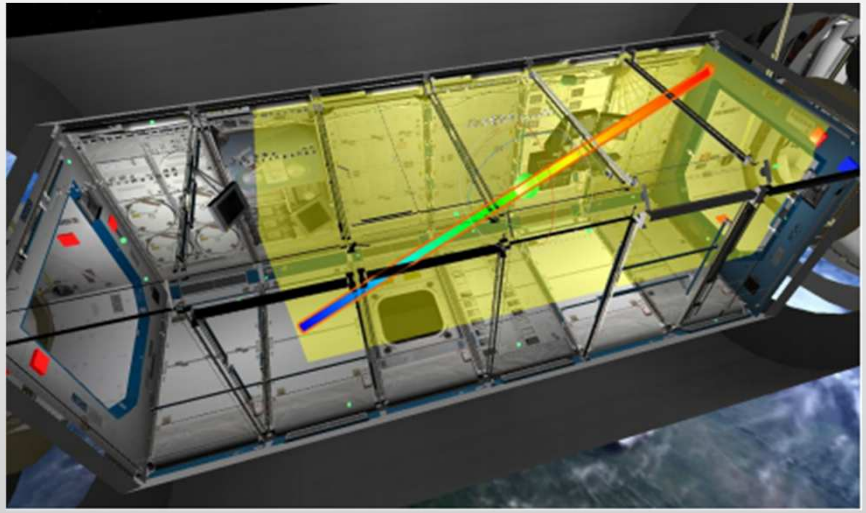
Antenna 2 (x_2, y_2, z_2)
- Number reads N_2

Signal-Strength Weighted Triangulation (RSSI-Weighted)

- Estimated location is interpolated through volume based on signal strength (RSSI) received by different antennas

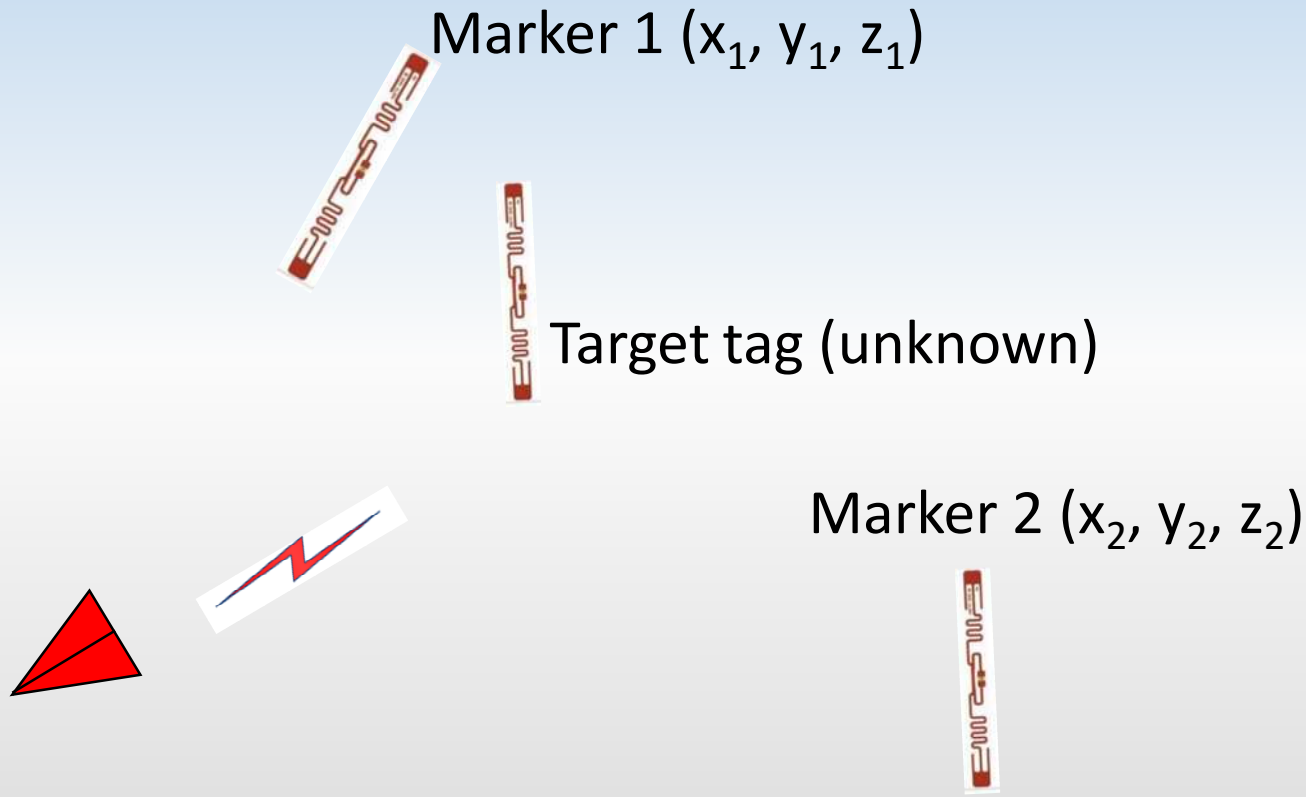
Antenna 1 (x_1, y_1, z_1)
- RSSI 1

Antenna 2 (x_2, y_2, z_2)
- RSSI 2



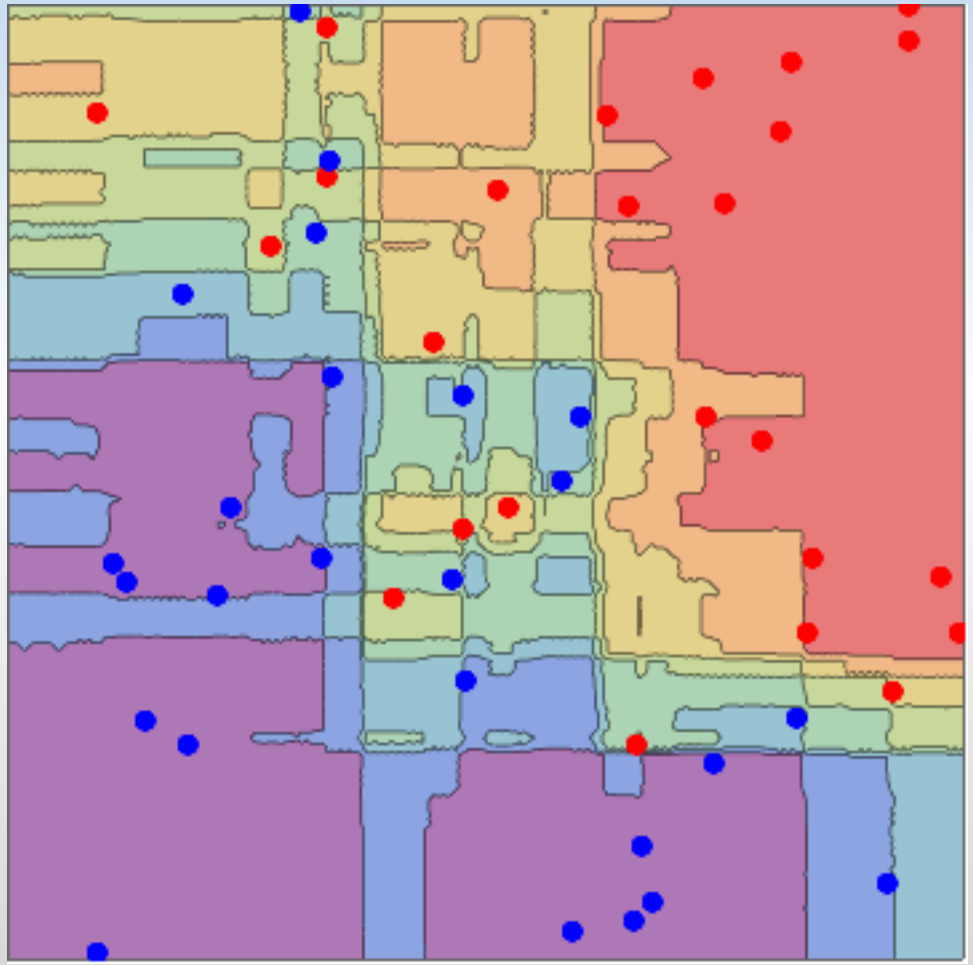
kNN (kth Nearest Neighbors)

- Mathematical interpolation between nearest marker tag positions with weighting by difference in signal response (RSSI) of target tag and nearest marker tags
- Marker tags are affixed to ISS structure and have known locations



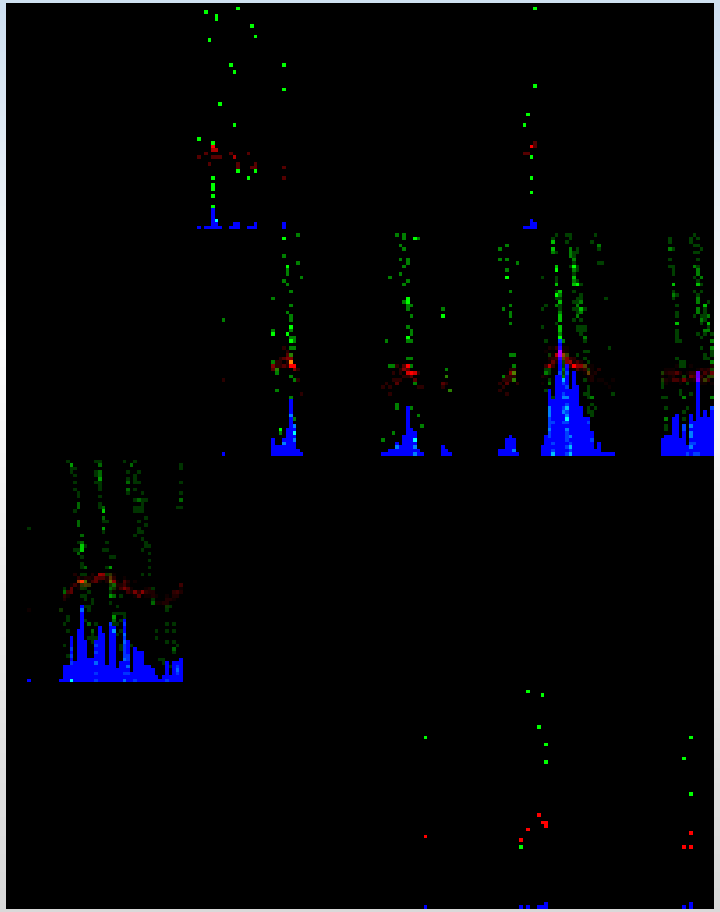
Machine Learning: Random Forest

- Machine Learning Classifier
- Aggregate an hour of reads into 800+ features
- Utilize IMS rack information as a source of truth to train a set of 200 Decision Trees
- Generates a set of Rack Probabilities



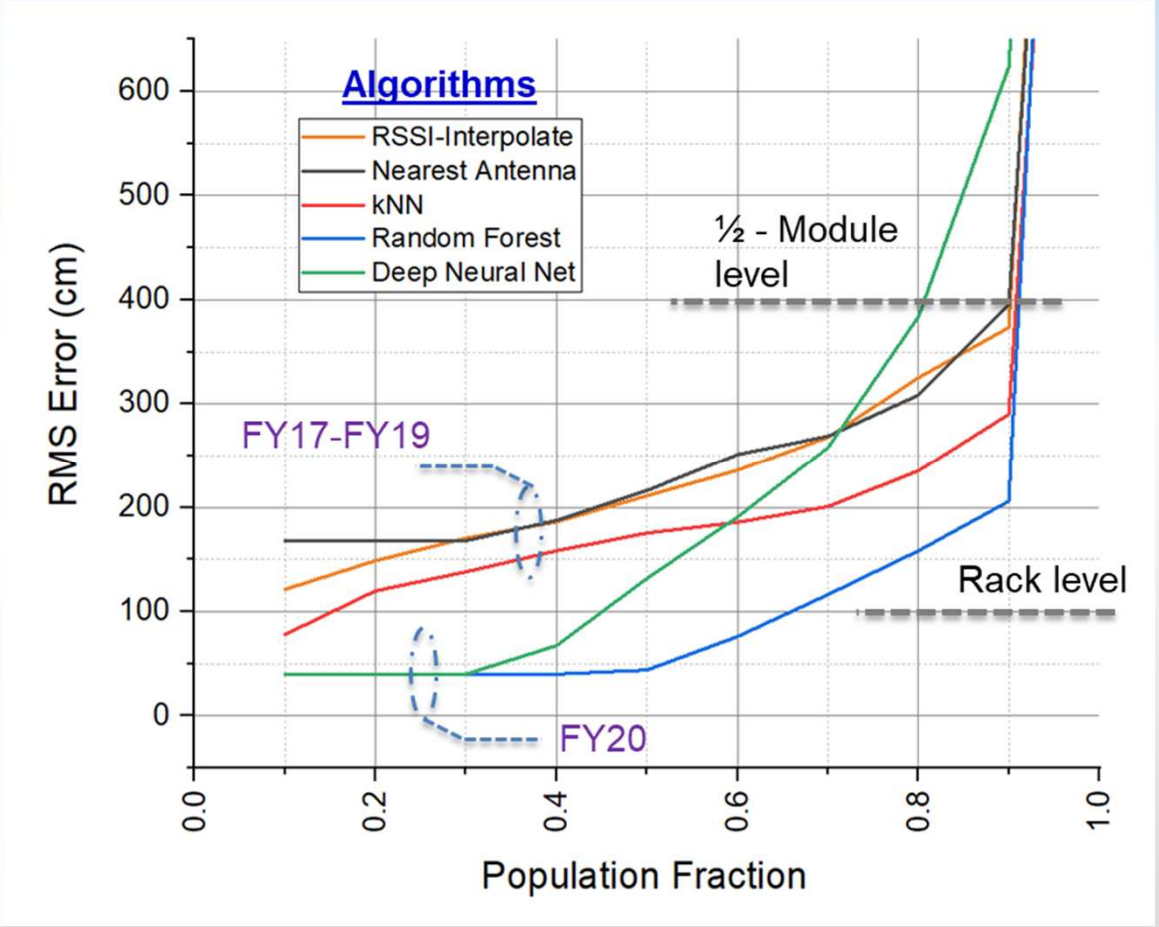
Machine Learning: Deep Neural Network

- Generates images to represent frequency response for all antennas
- Utilize State of the Art Image Classification Convolutional Neural Network
- Utilized semi-hard negative mining and a triple loss function to generates Similarity Embeddings
- Generates a set of Rack Probabilities

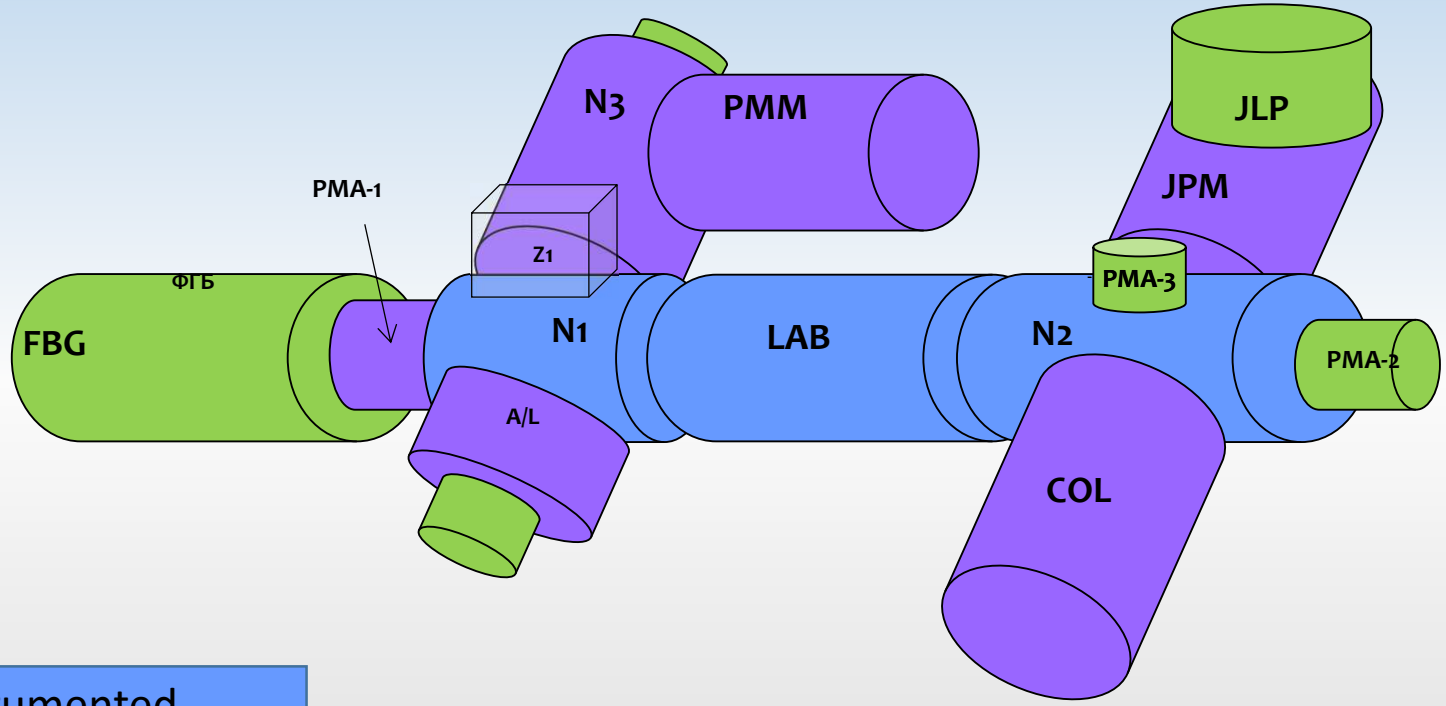


Localization Results: Instrumented Modules

- Error based on Euclidean distance from stowage cell
- Machine learning solutions estimate according to racks
  - Correct racks are assigned an error equal to 1/2 rack width (50 cm)
- Instrumented: NOD1, US LAB, NOD2



REALM Modules: Instrumented/Not-Instrumented



Instrumented

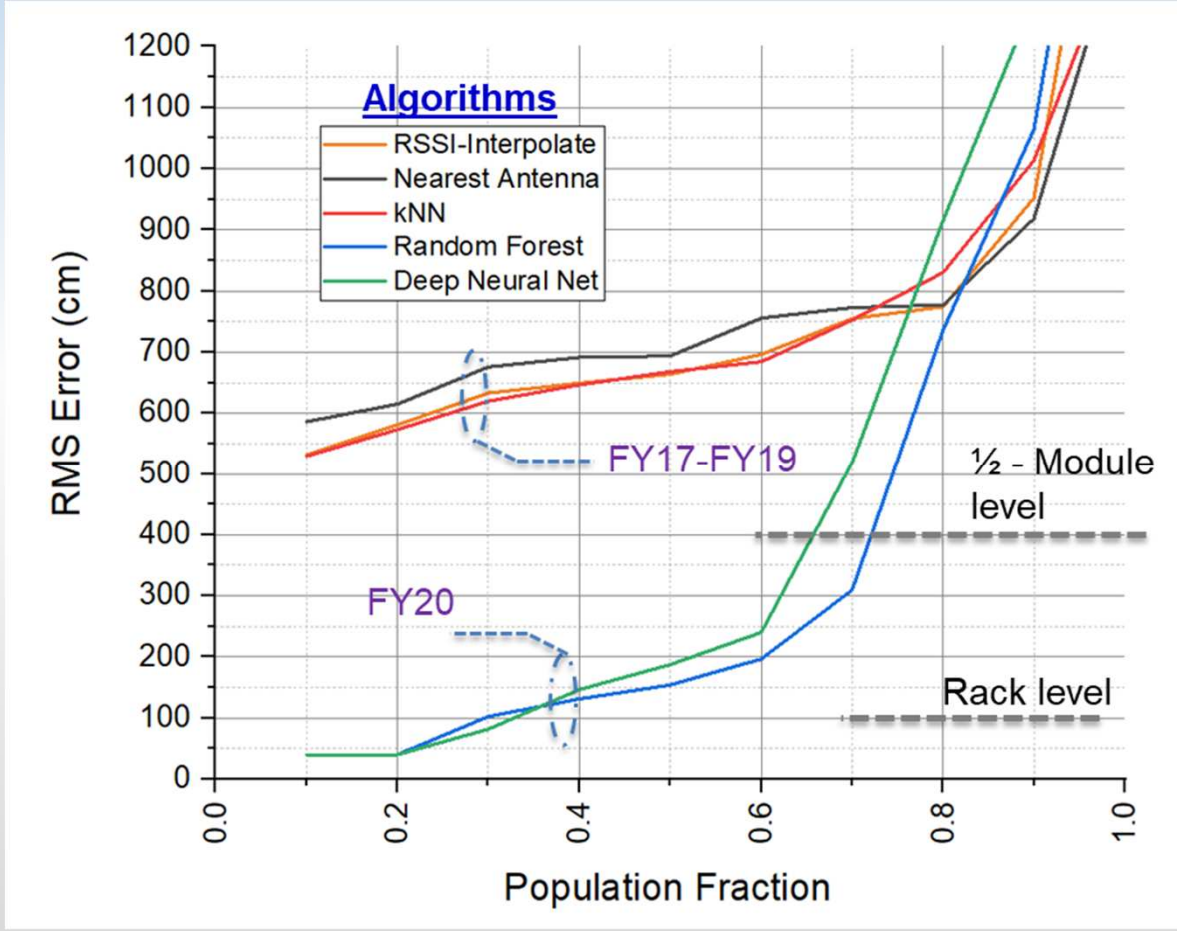
Reduced coverage

No coverage

Non-instrumented

Localization Results: Non-Instrumented Modules

- Error based on Euclidean distance from stowage cell
- Non-Instrumented: NOD3, PMM, JPM, COL

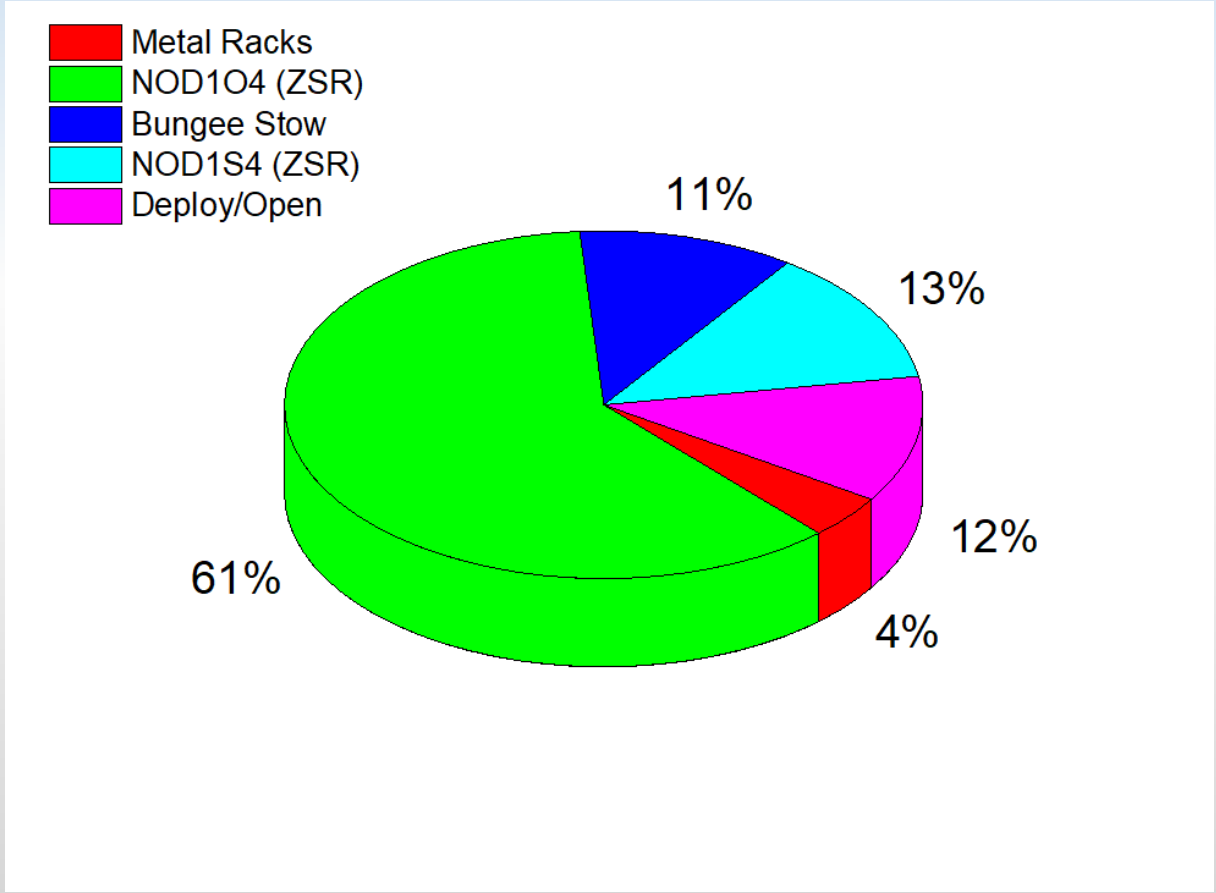


REALM Audit Capability

NOD1 Audit Results

- Inventory accuracy: 72%
- Tagged items in NOD1: 492
- ZSR: “Zero-gravity Stowage Rack”
  - soft stowage with metal foil wrapped food bags
- Bungee Stow – CTBs held in place with bungee cords

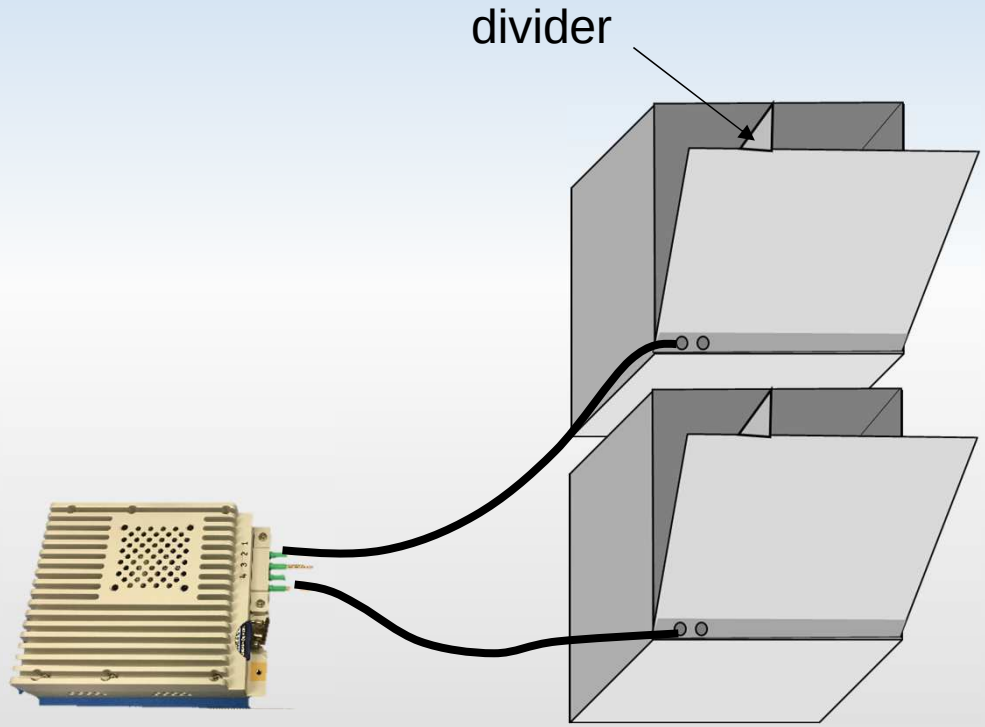
Missing Items by Stowage Location in Node 1



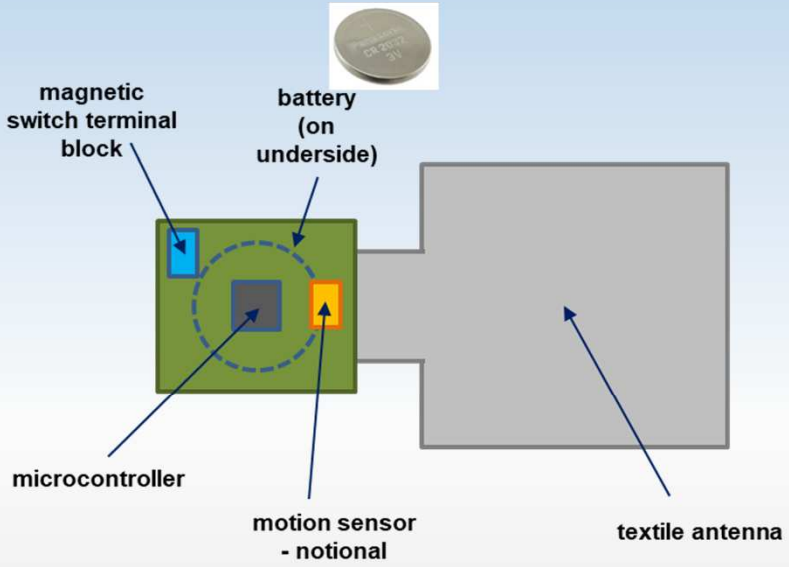
REALM-3 Technology: Smart Stow

- Addresses challenges with dense populations of tagged items, especially those with metal content
- Signal from reader is routed to antennas inside textile ZSR inserts
- Reads are activated:
  - By schedule
  - On demand from ground control
- Typically exhibit >90% read accuracy
- Launch: September, 2021

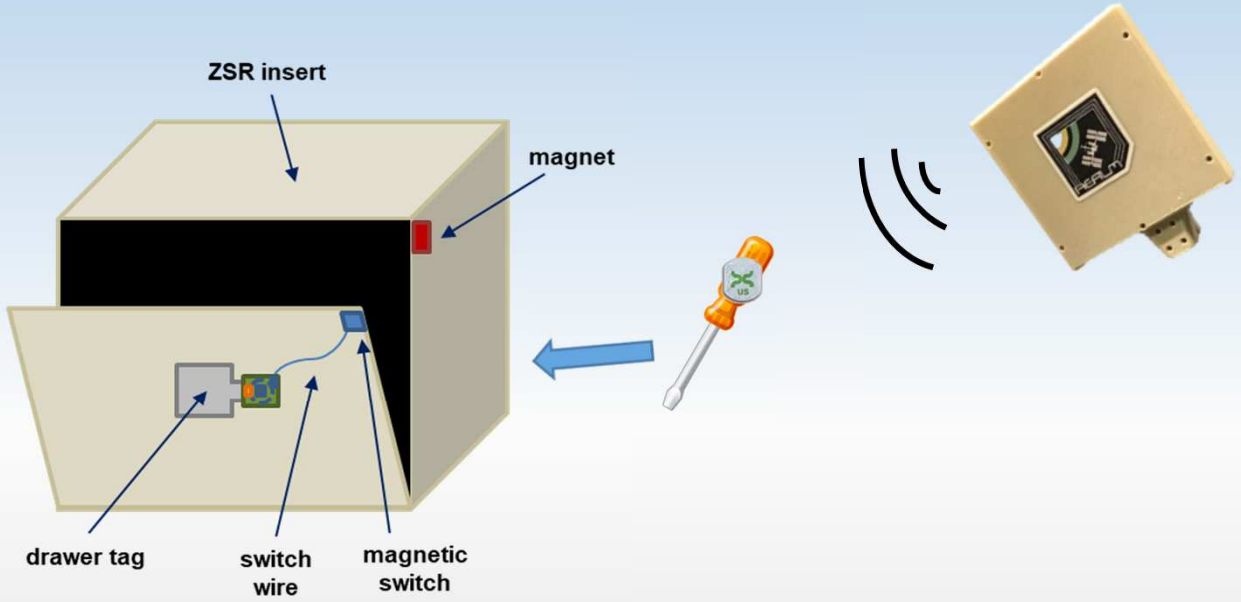
NOD1S4 ZSR textile inserts



Drawer Monitor System



REALM Smart-Sensing drawer tag



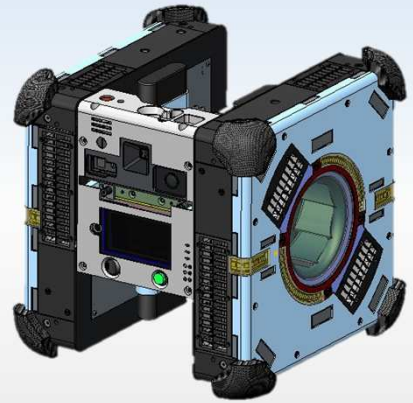
ZSR sensor tag installation

- RFID tags on drawer monitor drawer state (open/closed)
- Tags provide state history to RFID readers on-demand
- State information is used in inference to determine item locations
  - Example: screwdriver “disappears” from antenna field-of-view, coinciding with door state change

REALM-2: RFID Recon

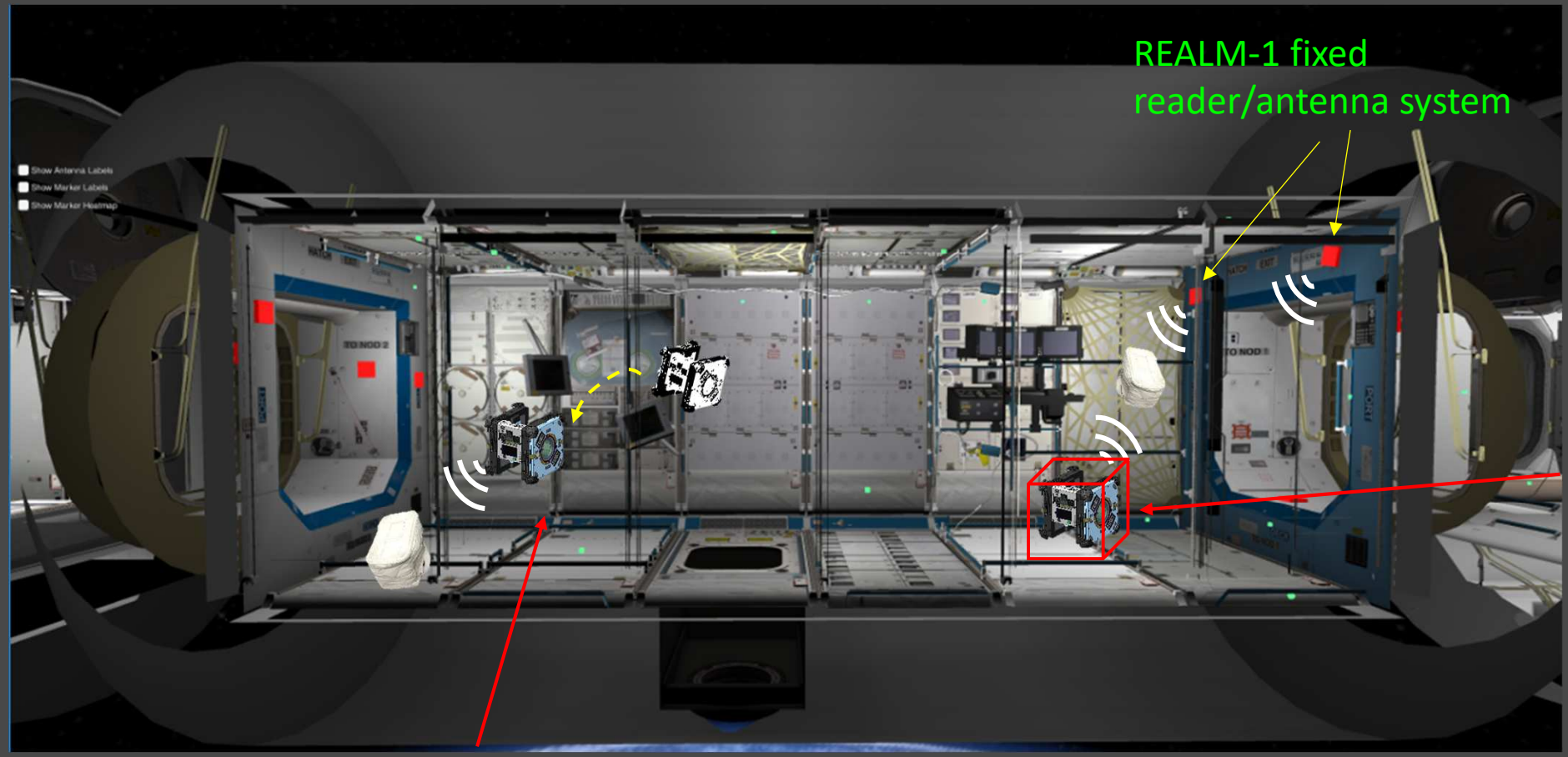
REALM-2, “RFID Reconnaissance”

- REALM-2 is a collaborative effort based on an RFID system as a payload on the NASA Ames Research Center’s *Astrobee*



- REALM-2 Commissioning Date: October 2020
- Objectives:
  - Determine role of a robotic free-flyer in the REALM system
    - Extend coverage area, possibly reducing amount of fixed reader infrastructure required
    - Improve localization using REALM-1 system as a coarse solution

REALM-2 Location Refinement Missions



CEP Context Mission

CEP system determines optimal Astrobee position for new sample points

Homing Mission: Feedback from tag guides Astrobee to location

Summary

- Significant progress in the past year with machine learning applied to fixed-antenna RFID localization of assets
- Looking at refining ML approaches to match computational assets available on remote space habitat
- Audit accuracy is expected to increase significantly with smart stow
- Drawer monitor tag system is expected to expand logistics awareness without requiring smart stow infrastructure everywhere
- REALM-2 RFID Recon missions will provide another opportunity to expand coverage and improve key performance parameters such as localization and inventory audit accuracy

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