Automation of Space Inventory Management

Consultative Committee for Space Data Systems
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Overview

- Space-Based Inventory Management
  - Current state
  - Handheld RFID readers
  - RFID portal
  - RFID “Smart” Shelf

- Real-Time RFID Location and Tracking
  - Ultra-Wideband (UWB)

- Surface Acoustic Wave (SAW) RFID

- Bionet Middleware
ISS Inventory Management Present State

- ~10,000 items are tracked with the Inventory Management System (IMS) software application

- Hand-held optical barcode reader used for inventory audits

  Crew/Cargo Transfer Bags must have Ziploc bag contents removed, audited, replaced:
  ~20 mins crew time, 
  1 CTB/crew/day

- ~500 CTBs on ISS at any given time (2008)
RFID Space Inventory Introduction: Handheld Readers

- Handheld RFID readers are likely to be the first operational RFID system on ISS
  - Will have dual barcode capability, also, to facilitate transition
- Read accuracies < 100% for single CTB read, but fairly effective when reader scanned or “painted” around CTB exterior
- Requires 20s/CTB read and little vehicle infrastructure (battery powered with 802.11 capability)
- Tested on CTBs (10in. x 17in. x 9.5in) containing tagged Ziplock bags filled with tagged personal items (52 tags total)
- Tested on Ambulatory Medical Packs (AMPs - 12.5in. x 24.5in. x 8in.) with sub-kits filled with tagged pharmaceutical items (330 tags total)
Handheld RFID Reader Evaluation

Four commercially available readers tested by five different individuals (I1-I5):

<table>
<thead>
<tr>
<th>Reader 1 30 dBm</th>
<th>I1</th>
<th>I2</th>
<th>I3</th>
<th>I4</th>
<th>I5</th>
<th>average</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reader 2 28 dBm</td>
<td>48</td>
<td>48</td>
<td>49</td>
<td>48</td>
<td>48</td>
<td>48.2</td>
<td>92.7%</td>
</tr>
<tr>
<td>Reader 3 30 dBm</td>
<td>42</td>
<td>42</td>
<td>44</td>
<td>45</td>
<td>43</td>
<td>43.2</td>
<td>83.1%</td>
</tr>
<tr>
<td>Reader 4 30 dBm</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>49</td>
<td>48</td>
<td>48.2</td>
<td>92.7%</td>
</tr>
</tbody>
</table>

CTB tags (52 tags total)

<table>
<thead>
<tr>
<th>Reader 2 28 dBm</th>
<th>I1</th>
<th>I2</th>
<th>I3</th>
<th>I4</th>
<th>average</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reader 3 30 dBm</td>
<td>267</td>
<td>264</td>
<td>266</td>
<td>263</td>
<td>265</td>
<td>80.3%</td>
</tr>
<tr>
<td>Reader 4 30 dBm</td>
<td>122</td>
<td>125</td>
<td>130</td>
<td>120</td>
<td>124.3</td>
<td>37.7%</td>
</tr>
</tbody>
</table>

AMP tags (330 tags total)
Portal-based RFID Inventory Management

- More automation desired for viable RFID inventory system
- Portal-based interrogator reads CTBs entering/exiting habitat
- Requirements:
  - High read accuracy
  - Low power (→ triggered operation)
  - Tag directionality determined
- Four antenna system (two external, two internal) implemented in habitat mockup
- Pressure pad on porch used to trigger tag reads
RFID Portal Evaluation

- CTB (52 tagged items) carried on left, right, and in front of test subject
- Reader tested in “continuously on” and “triggered” modes
- Transmit power of 30 dBm used for all tests
- CTB carried starting 40 feet out, pressure mat mounted five feet out
- Results averaged over five trials

### Accuracy vs. Position

<table>
<thead>
<tr>
<th></th>
<th>Avg. front</th>
<th>Avg. right</th>
<th>Avg. left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item level</td>
<td>75.5%</td>
<td>75.3%</td>
<td>75.7%</td>
</tr>
<tr>
<td>Ziplock level</td>
<td>95.1%</td>
<td>94.7%</td>
<td>93.7%</td>
</tr>
</tbody>
</table>

### Accuracy vs. Operation Mode

<table>
<thead>
<tr>
<th></th>
<th>Avg. (triggered)</th>
<th>Avg. (continuous)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item level</td>
<td>76%</td>
<td>75%</td>
</tr>
<tr>
<td>Ziplock level</td>
<td>95%</td>
<td>94%</td>
</tr>
</tbody>
</table>
RFID “Smart” Shelves and Receptacles
RFID “Smart” Shelves and Receptacles

- RFID reads on densely packed containers difficult
  - high metal /liquid content esp. challenging
- RFID smart containers can provide supplemental inventory data
  - smart shelve: additive (log items into database as added)
  - smart trash can: reductive (remove items from database as containers discarded)
- Testing of RFID trash can indicates near-100% read accuracy
  - Ziploc bags, food vacuum packs, conductive drink pouches, battery packs, pharmaceuticals, etc.
- Work on zero-g RFID trash can in progress
RFID for Real-Time Location and Tracking

- **Ultra-Wideband (UWB) active-tag RFID technology**
  - Transmits sub-nanosecond, high bandwidth impulses (~GHz)
  - low power spectral density make system non-interfering
  - short pulses reduce fading and multipath effects

- **Tested UWB real-time location system (Sapphire DART by Multispectral Solutions)**

- **UWB tags are transmit-only devices**
  - each sends unique pulse-train ID (one pulse/second)
  - 30cm (1 ft.) tracking accuracy
  - read ranges up to 90 m
  - tag battery life > 7 yrs
Surface Acoustic Wave (SAW) RFID

- SAW RFID tags do not rectify incident electromagnetic power
  - modulate, re-radiate interrogation signal using series of reflectors
  - operate at much lower interrogator transmit power, much longer range (compared to IC tags)
  - can incorporate telemetry readings (e.g., temperature)
  - tolerate temperature, radiation, shock better than IC tags

- SAW tags being investigated for planetary ops support (Passive Adaptive RFID Sensor Equipment - PARSEQ)
  - sensing surface of habitation module remotely
  - interrogating lunar road signs, dropping “breadcrumbs” for navigation
  - locating expended equipment in salvage yards
  - tracking crew/vehicles in habitat proximity
  - providing navigation aids to landers
Custom SAW Tag Interrogator

- Ranges over 100 feet achieved with 100 mW transmit power
- Digital adaptive beamforming to enable multi-cluster interrogation
- Over 10 tags read per cluster
- Angle-of-arrival, range, and temperature returned from SAW tag
BioNet Middleware

- Long-term habitat operations likely will entail:
  1. both wired and wireless data-producing hardware
  2. all hardware requirements not known a priori

- NASA Command, Control, Communications, and Information (C3I) Interoperability specification proposes an architecture to co-ordinate operations among subsystems developed by many different sources

- BioNet middleware is preliminary C3I instantiation used in NASA-JSC lunar habitat wireless test bed:
  - integrates wired/wireless data-producing hardware
  - provides application development framework to separate design of data production and data consumption subsystems
BioNet Middleware

- BioNet focuses on enabling a “system of systems”
- Provides publish/subscribe asynchronous messaging between distributed applications and distributed data-generating endpoint sensors/systems
- Facilitates incorporation of heterogeneous wired and wireless sensing/control devices into unified data system with standardized application interface
BioNet Middleware

- Provides software development framework, standard services, and network communications for distributed applications
- Hides complexity of (heterogeneous) network communication from developers who want read/write without regards to lower-layer communications specifics
- Provides critical integrated system services:
  - naming
  - device discovery
  - service discovery
  - security
  - data compression
  - data grouping
BioNet Middleware
Conclusion/Forward Work

- Desire to have as much functionality as possible with as few RFID protocols/interrogators required
  - On-going work for real-time location using EPCglobal Class 1, Gen 2 (UHF)

- Handheld RFID technology provides acceptable accuracy when “painted” over CTB

- RFID trash receptacle appears promising for wrapper tracking
  - Near 100% accuracy

- Battery-power UWB RFID tags and system provides 12 inch accuracy
  - Possible use for larger, critical items

- SAW-based RFID could find niche applications for NASA
  - Longer range and extreme environments (e.g., lunar surface, ground facilities)
  - Capability to provide sensor telemetry

- BioNet middleware has proven highly effective for integration of a large number of disparate devices and networks