Gen2 RFID Technology: Inventory Control Aboard the ISS?
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ABSTRACT
With a near de-manning of the International Space Station (ISS) due to frustrating, lengthy, and sometimes inaccurate inventory audits, there is a need for an alternative method of inventory management and control aboard the ISS. Radio Frequency Identification (RFID) is an alternative inventory control application which could alleviate the pre-mentioned inventory issues facing astronauts aboard the ISS. The research methodology uses a modified sequential Design of Experiments (DOE) to test and evaluate the quality of commercially available second generation (Gen2) RFID technology. The results from the experimentation are compared to the requirements sent from NASA to verify the feasibility of using Gen2 RFID technology as an inventory control application aboard the ISS.

KEYWORDS
RFID, GEN2, Inventory Control, DOE

INTRODUCTION

RFID Basics

Radio Frequency Identification (RFID) technology originated from the military during World War II but has only been commercially available since the early 1980s. During the past twenty years RFID has been used for a wide variety of applications such as highway and bridge tolls, livestock tracking, tracking air freight, and in auto manufacturing in which managers wish to track individual vehicles through the assembly line. The technology was previously expensive and limited, but as the price of tags, readers, and the associated equipment continues to decrease, a growing number of retailers have begun to explore the feasibility of using RFID systems.

RFID is the generic name for technologies which use radio waves to automatically identify items. RFID has the capability to replace the traditional approaches for item identification and data capture such as manual entry or barcode scanning. There are several methods of identifying items using RFID although most systems consist of a tag which consists of a microchip with a coiled antenna, and an interrogator or reader with an antenna. The reader sends out electromagnetic waves which form a magnetic field when they "couple" with the antenna on the RFID tag. The tag draws power from the magnetic field and uses it to power the microchip's circuits. The chip then modulates the waves that the tag sends back to the reader and the reader converts the new waves into digital data. The data transmitted by the tag may provide identification or location details and/or specific information about the product such as price, color, and date of purchase. The tags are very flexible in that microchips measuring less than a third of a millimeter wide can now store a wide range of unique product information, they can be read from a distance and through a variety of obstacles. RFID technology can also allow some, but not all, the data held on a tag to be read and the tags can be updated after the original data has been loaded. The tags also offer security in that they can be made virtually tamper free.[1]

RFID Benefits and Setbacks

There are many benefits of using RFID over tradition methods of inventory control. The following table, Figure 1, details some advantages of using RFID versus using barcode technology.

RFID Tags	Barcodes
RFID tags can be read or updated without line of sight	Barcodes require line of sight to be read
Multiple RFID tags can be read simultaneously	Barcodes can only be read individually
RFID tags are able to cope with harsh and dirty environments	Barcodes cannot be read if they become dirty or damaged
RFID tags are ultra thin, and they can be read even when concealed within an item	Barcodes must be visible to be logged
RFID tags can identify a specific item	Barcodes can only identify the type of item
Electronic information can be over-written repeatedly on RFID tags	Barcode information cannot be updated
RFID tags can be automatically tracked, eliminating human error	Barcodes must be manually tracked for item identification, making human error an issue
RFID allows for real-time information	Barcodes must be manually scanned to obtain information

Figure 1: RFID versus Barcode Technology [2]

The second generation (Gen2) of RFID technology just recently became available, March of 2006, for purchase and has improved upon the previous first generation of RFID technology. The Gen2 tags **claim** to have several benefits, all of which are customer-driven:

- **Open Standard.** This means the tags are available from multiple sources, which should bring prices down more quickly.
- **Memory and Password.** 96 bit memory plus password in chip. This provides greater storage capability and security against the chip being "hacked" in a retail store.
- **Size.** Chips will be two to three times smaller than current versions.
- **Cross-Vendor Compatibility.** All equipment from different vendors will be interoperable.
- **High Reliability.** Tags have extremely high read rates even with metal and liquid (**close to 100%**).
- **Better Tag Identification.** This eliminates duplicate reads during multiple tag scans.
- **Kills.** Tags can be permanently killed by a reader.
- **Security.** Tags have better security encryption of tag data; readers do not broadcast tag data being read.
- **Timing.** Allows tags to enter reader field late and still be read; Gen 1 tags would be missed.
- **Global Frequency.** Spread spectrum, frequency hopping UHF with frequency-modulation capabilities to minimize interference with or from other wireless devices.
- **Read Rate.** This is ten times faster than current tags, which allows high speed automated operations to deploy RFID tags effectively.[3]

While there are many benefits of using RFID, the first generation of technology proved there can be environmental problems with radio identification. Radio waves used within the identification process can be absorbed by liquid materials and distorted or reflected by metal materials both are instances which limit the abilities of RFID.

PROBLEM STATEMENT

Current Inventory Tracking Issues aboard the International Space Station (ISS)

Astronauts aboard the ISS currently use manual audits to track and control inventory aboard the station. This creates many problems because periodic inventory audits are very labor intensive, time consuming and are only as accurate as the data input by the crew. Current inventory control issues include items periodically vanishing, accurately knowing levels of inventory, crew frustration with audit lengths, and a near de-manning of station due to inaccurate inventory information.

Research Requirements

With the problem defined, NASA provided a list of requirements to meet the needs of inventory control aboard the ISS. The list included the following requirements: bag/container needs to be scanned within 10-15 seconds; tag read accuracy needs to be greater than or equal to 99%; tag size must not to exceed 3" x 2"; and tagged items in each bag/container need be comparable to a specific list of items. Furthermore, NASA requested a list of items which would interfere with readability of RFID tags.

Research Objective

The objective of the analysis is to accept or reject the feasibility of using commercially available Gen2 RFID technology as an alternative for manual inventory tracking aboard the ISS.

RESEARCH METHODOLOGY

The research methodology uses an applied design for six sigma research methodology (Figure 2). The primary tool used for measurement and analysis is a modified sequential Design of Experiments (DOE). A sequential DOE uses information learned from the first or previous experiment to eliminate unnecessary or undesirable experimentation within a series of experiments. This method provides a powerful means to achieve breakthrough improvements in product quality and process efficiency. The following factors affecting the overall quality Gen2 RFID will be evaluated:

- Initial readability of tags
- Tag read range
- Tag orientations
- Tagged materials
- Combinations of RFID equipment

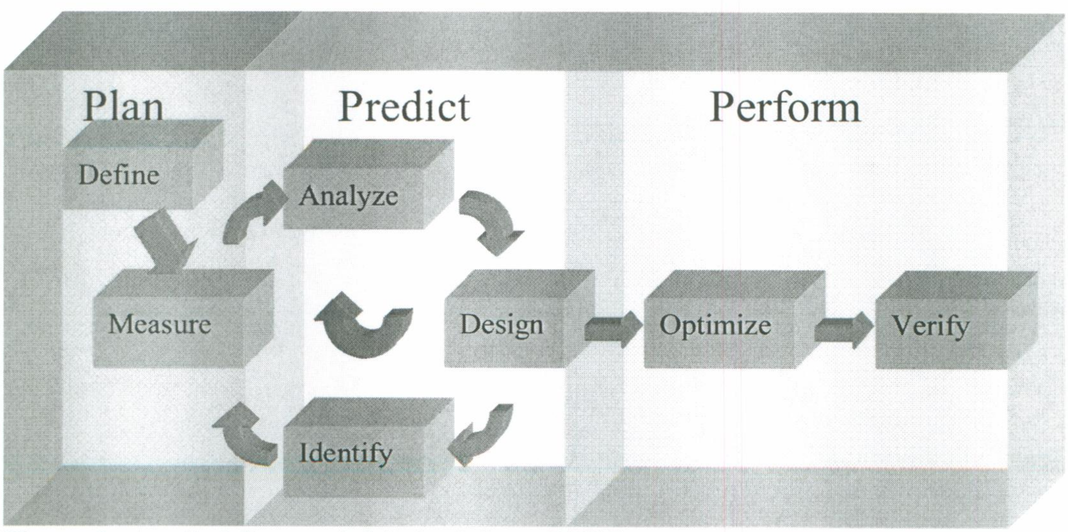

Figure 2: Applied Research Methodology DFSS

Sequential Experiments
Using the aforementioned methodology, four experiments were conducted to evaluate the overall quality of Gen2 RFID.

Experiment 1
The first experiment tested the "off the roll" quality of tags by using an acceptance sampling test. The MIL STD 105E acceptance standard was used to verify if the roll of Gen2 RFID tags had an acceptable quality level. For rolls of 500 tags, 50 random tags were tested for read and write capabilities.

Experiment 2
The second experiment tested tag read ranges. This experiment provided insight on the acceptable distances tags could accurately be read using various types of Readers. The experiment was setup by placing three tags in front of each type of Reader and testing for read accuracy as the tags were moved further away from the Reader. The results from this experiment established the two levels for the "distance factor" in the next experiment.

Experiment 3
The third experiment examined how different factors affected the read accuracy. The experiment tested four different factors; equipment (Tags and Readers); read distance; tag orientation; and tagged materials. This experiment used a standard two level four factor DOE format.

- RFID Readers: mobile Matrics Reader and a stationary Matrics Reader.
- Read distance: small distance of one to three feet was used for both readers and max distance of eight to nine feet was used for the mobile reader while a max distance of twenty feet was used for the stationary reader.
- Tag orientation: layout with horizontal tags orientations and layout with various vertical and horizontal tag orientations.
- Tagged Materials: paper only materials and materials similar to the list provide by NASA which contained both metallic and liquid based items.

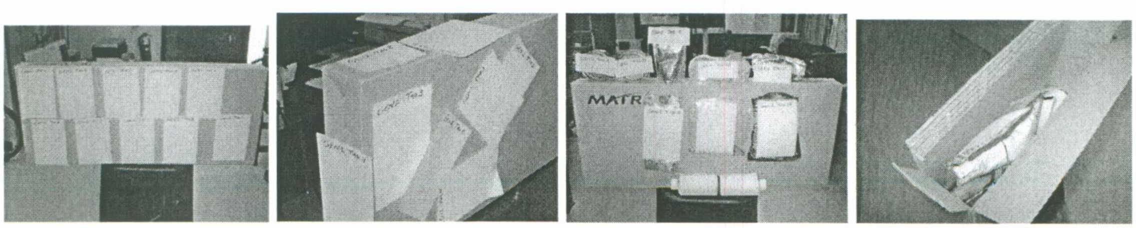

Figure 3: Various Setups for Factor Analysis

Experiment 4

The final experiment used the optimal results from the previous experiments to simulate how well Gen2 RFID would operate for the specific scenario of tracking inventory aboard the ISS.

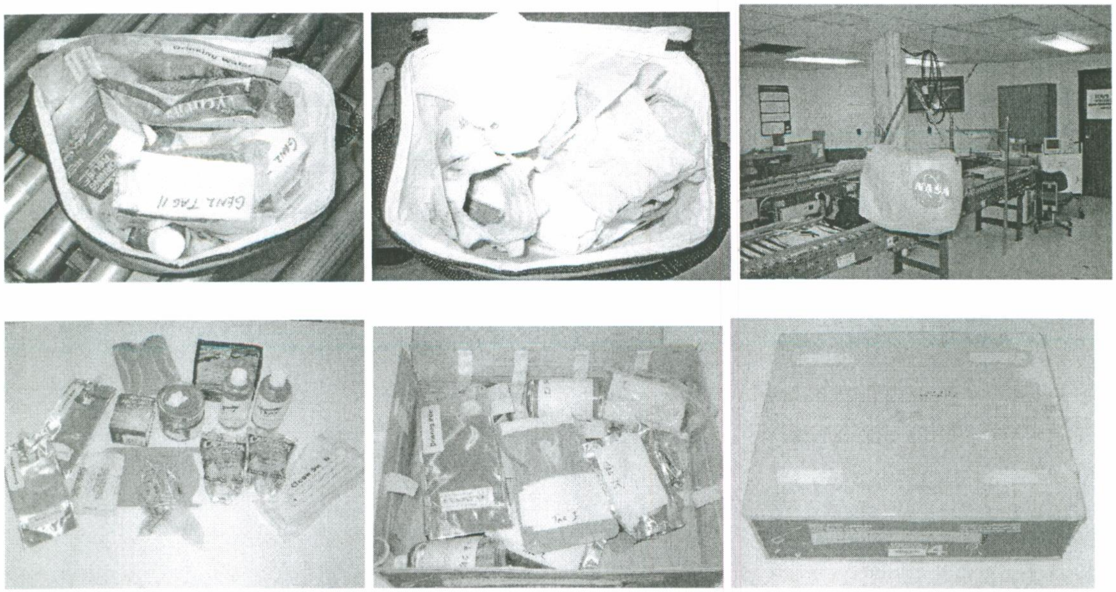

Figure 7: Simulated ISS Experiment

RESEARCH RESULTS

The experiments were conducted and the results of each were measured and analyzed. The final analysis from each of the experiments is discussed below:

Experiment 1

An acceptance sampling test was completed for all Gen2 Tags used within the experimentation. All randomly selected tags had read and write capabilities. The different types of tags tested were: Rafsec "G2" Short Dipole, Impinj Thin Propeller, Omron Gen2 Wave, Rafsec Short Dipole, Rafsec Frog G2, Avery Gen2 AD G12, and Alien Gen2 Squiggle. Since there were no defects found on any of the tags, they were approved for further testing.

Experiment 2

The second experiment used the Matrics "MC9000-G Portable RFID Reader" and the Matrics "XR400 Fixed Reader" with Alien Gen2 Squiggle tags. Since the results from this experiment only established the distinct distance levels for the next experiment, only the Alien Gen2 Squiggle tags were tested. The results from the testing established the following acceptable distance levels for accurate tag reads:

- Matrics Mobile reader: read range 0ft-9ft
- Matrics Stationary reader: read range 0ft-27+ft

Experiment 3

The 2^4 DOE experiment was also conducted with the Matrics "MC9000-G Portable RFID Reader" and the Matrics "XR400 Fixed Reader" with Alien Gen2 Squiggle tags. The results from the experiment proved all the selected factors had a significant impact on the readability of the tags. The results are displayed in figure 4 and the analysis is displayed in figure 5 and figure 6.

Reader	Distance	Orientation	Material	R1	R2	R3
Mobile	1ft-3ft	Horizontal	Cardboard	10	10	10
Stationary	1ft-3ft	Horizontal	Cardboard	10	10	10
Mobile	Max	Horizontal	Cardboard	8	9	10
Stationary	Max	Horizontal	Cardboard	7	6	5
Mobile	1ft-3ft	Mixed	Cardboard	10	10	10
Stationary	1ft-3ft	Mixed	Cardboard	7	7	8
Mobile	Max	Mixed	Cardboard	7	7	7
Stationary	Max	Mixed	Cardboard	2	2	2
Mobile	1ft-3ft	Horizontal	Mixed	7	5	7
Stationary	1ft-3ft	Horizontal	Mixed	3	2	2
Mobile	Max	Horizontal	Mixed	1	2	2
Stationary	Max	Horizontal	Mixed	0	0	0
Mobile	1ft-3ft	Mixed	Mixed	3	3	2
Stationary	1ft-3ft	Mixed	Mixed	0	0	0
Mobile	Max	Mixed	Mixed	0	0	0
Stationary	Max	Mixed	Mixed	0	0	0

Figure 4: Table of measurement results for DOE

Full Factorial Design

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Factors:   4   Base Design:         4, 16
Runs:     48   Replicates:              3
Blocks:    1   Center pts (total):      0
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Factorial Fit: Tag Reads versus Reader, Distance, Orientation, Material

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Estimated Effects and Coefficients for Tag Reads (coded units)
Term                               Effect    Coef  SE Coef       T      P
Constant                                    4.646  0.07795   59.60  0.000
Reader                             -2.375  -1.188  0.07795  -15.23  0.000
Distance                           -2.875  -1.437  0.07795  -18.44  0.000
Orientation                        -2.042  -1.021  0.07795  -13.10  0.000
Material                           -6.042  -3.021  0.07795  -38.75  0.000
Reader*Material                     0.292   0.146  0.07795    1.87  0.071
Distance*Material                   0.458   0.229  0.07795    2.94  0.006
Reader*Distance*Material            1.292   0.646  0.07795    8.29  0.000
Reader*Orientation*Material         0.958   0.479  0.07795    6.15  0.000
Distance*Orientation*Material       0.958   0.479  0.07795    6.15  0.000
S = 0.540062   R-Sq = 98.69%   R-Sq(adj) = 98.07%
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Figure 5: Full Factorial Analysis

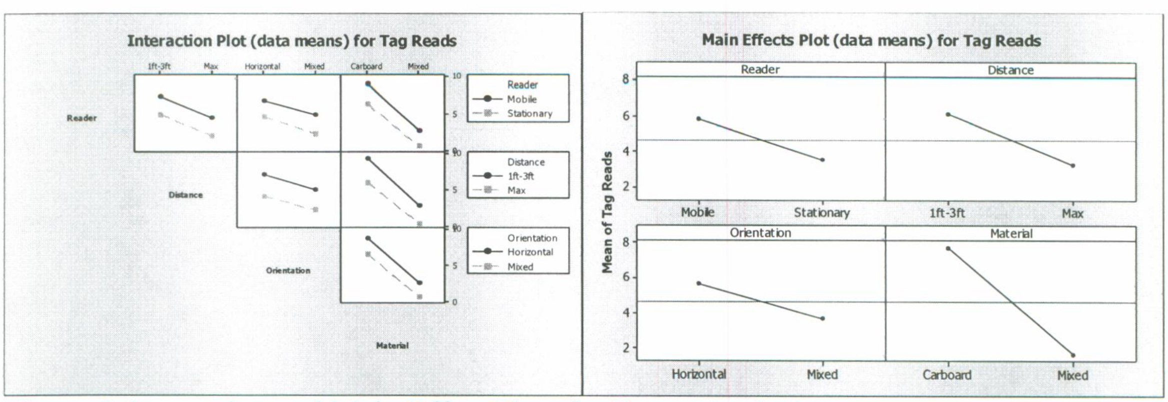

Figure 6: Interaction and Main Effect Plots for Factor Analysis

Experiment 4

The final situational experiment used the Matrics "MC9000-G Portable RFID Reader" to test all the available Gen2 tags: Rafsec "G2" Short Dipole, Impinj Thin Propeller, Omron Gen2 Wave, Rafsec Short Dipole, Rafsec Frog G2, Avery Gen2 AD G12, and Alien Gen2 Squiggle in the simulated environment. The tags were tested within both the metallic Russian box and a softer material based bag. Furthermore, this experiment tested tags on both paper based material and mix materials including metallic and liquid based items. For each of the distinct scenarios, 15 observations were taken. The results from the analysis are show in figure 7, figure 8, and figure 9.

Analysis Variable : Percent of Tags Read						
Storage Device	**Materials**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**N**
Russian Container	Mixed Materials	0.08	0.07	0.00	0.27	105
	Paper Materials	0.23	0.14	0.00	0.53	105
Soft Bag	Mixed Materials	0.38	0.18	0.07	0.87	105
	Paper Materials	0.99	0.03	0.87	1.00	105

Figure 7: Storage Device Analysis on Percent of Tags Read

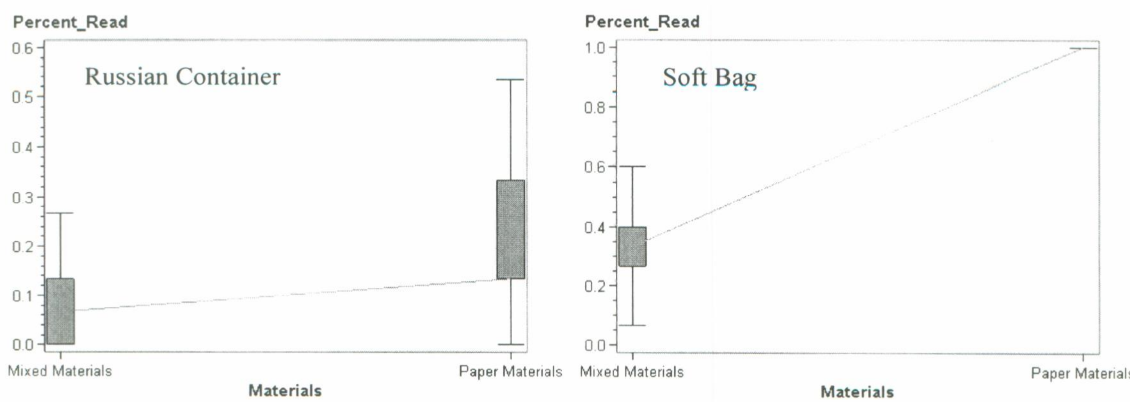

Figure 8: Box Plot of Storage Device Analysis on Percent of Tags Read

Analysis Variable : Percent of Tags Read					
RFID Tag Type	**Storage Device**	**Materials**	**Mean**	**Std Dev**	**N**
"Rafsec "G2" Short Dipole"	Russian Container	Mixed Materials	0.04	0.03	15
		Paper Materials	0.16	0.03	15
	Soft Bag	Mixed Materials	0.25	0.06	15
		Paper Materials	1.00	0.00	15
Alien Gen 2 Squiggle	Russian Container	Mixed Materials	0.14	0.07	15
		Paper Materials	0.39	0.05	15
	Soft Bag	Mixed Materials	0.27	0.08	15
		Paper Materials	1.00	0.00	15
Avery Gen 2 AD G12	Russian Container	Mixed Materials	0.16	0.08	15
		Paper Materials	0.47	0.03	15
	Soft Bag	Mixed Materials	0.76	0.09	15
		Paper Materials	1.00	0.00	15
Impinj Thin Propeller	Russian Container	Mixed Materials	0.06	0.05	15
		Paper Materials	0.10	0.04	15
	Soft Bag	Mixed Materials	0.21	0.05	15
		Paper Materials	0.95	0.05	15
Omron Gen 2 Wave	Russian Container	Mixed Materials	0.08	0.03	15
		Paper Materials	0.11	0.03	15
	Soft Bag	Mixed Materials	0.35	0.08	15
		Paper Materials	1.00	0.00	15
Rafsec Frog G2	Russian Container	Mixed Materials	0.09	0.03	15
		Paper Materials	0.24	0.04	15
	Soft Bag	Mixed Materials	0.43	0.07	15
		Paper Materials	1.00	0.00	15
Rafsec Short Dipole	Russian Container	Mixed Materials	0.00	0.00	15
		Paper Materials	0.12	0.03	15
	Soft Bag	Mixed Materials	0.38	0.04	15
		Paper Materials	1.00	0.00	15

Figure 9: Tag Type and Storage Device Analysis on Percent of Tags Read

CONCLUSION

The testing of Gen2 RFID technology using a series of experiments provided detailed information for examining the read quality of Gen2 tags. The first experiment showed that Gen2 tags had an acceptable initial "off the roll" quality level. This quality level is an improvement from previous generations of RFID because past generations of tags would have tags which did not function. The third experiment, which tested various factors affecting tag reads, provides the best information on Gen2 quality. The full factor analysis verified past problems with RFID still exist. The major issue is the decrease of signal strength when attaching tags to liquid and metal materials. The final experiment verified that multiple types of Gen2 tags had the same aforementioned issue. In the simulated environment the Gen2 tags would read on liquid material with limited signal strength, but still would not read when place on metallic packages or in metallic containers. Furthermore, 100% read rates were only attainable when attaching tags to paper materials and were nowhere close to the alleged 100% read rates with metal and liquid materials. Therefore, with multiple items used aboard the ISS packaged in metallic containers it can be concluded that Gen2 technology does meet the desired needs for inventory tracking and control aboard the ISS.

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