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MDARS Product Assessment System

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1. Abstract

The Mobile Detection Assessment Response System (MDARS) is a joint Army-Navy effort to develop and automate robotic security and inventory assessment capabilities for use in government storage facilities. The MDARS system consists of a command and control console running the *Multiple Robot Host Architecture (MRHA)* controlling up to 32 interior and/or exterior robotic platforms. The *Product Assessment System* has been developed by the Naval Command Control and Ocean Surveillance Center (NCCOSC) as part of the MRHA to track the locations of selected items in the warehouse inventory. Specialized interactive RF transponder tags are placed on high-value or sensitive items. The tags, each with a unique identification number (Tag ID), and their physical locations are monitored by a *Tag Reader Computer* mounted on each robot. Information on Tag IDs and locations are uploaded from the remote platforms to a database server via the MRHA. This paper discusses the design and developmental testing of the MDARS *Product Assessment System* in an operational warehouse environment at Camp Elliott in San Diego, California.

2. Background

The MDARS Program is managed by the US Army Physical Security Equipment Management Office (PSEMO), Fort Belvoir, VA, with Mr. Jerry Edwards serving as MDARS Lead Project Officer responsible for overall program management. Separate development efforts target: 1) warehouse interiors, and 2) outdoor storage areas. The Naval Command Control and Ocean Surveillance Center (NCCOSC), San Diego, CA is responsible for providing overall technical direction, systems integration, and the development of the command and control console and related software (Laird, et al., 1995). Cybermotion, Inc., Salem, VA, has been awarded a Broad Agency Announcement (BAA) contract to further develop the remote platform to be used in interior warehouse scenarios (Holland, et al, 1995). The initial application will employ eight *K2A Navmaster* robots configured as remote security and inventory assessment platforms patrolling interior warehouse environments. Robotic Systems Technology, Inc. (RST) has been awarded a BAA contract to develop the exterior remote vehicle (Myers, 1995).

The Microcircuit Technology in Logistics Applications (MITLA) Program Management Office at Wright-Patterson Air Force Base, Dayton, OH, is the focal point for *radio frequency identification* (RFID) within the Department of Defense. As such, this agency is responsible for maintaining in-depth knowledge of the state of the art, and making that knowledge available to DoD customers. Ongoing developments in over 20 coordinated efforts are underway at a number of military installations in the United States (Lawlor, 1993).

The Physical Security Equipment Management Office submitted an informal request for an RF tag market investigation to MITLA in early December 1993, as well as a list of potential suppliers previously compiled by the MDARS developers. A review of the stated MDARS needs as compared to existing capabilities within the industry was subsequently conducted, with the more difficult core requirements for a long-range omni-directional system that could read/write to at least 10 or 12 feet addressed first. MITLA reported that to the best of their knowledge, only Savi Technology, Inc., Mountain View, CA, had a system (at that time) that could perform remote read/write operations in an omni-directional pattern at distances greater than 50 feet.

3. System Overview

The MDARS *Product Assessment System* is physically separated into two groups of components respectively located at the host console and on the robotic platforms as depicted in Figure 1 (Everett, 1995). The hardware located on each platform consists of a Savi *Interrogator*, which communicates with interactive RF transponder tags attached to high-value inventory items, and a *Tag Reader Computer*, which controls the *Interrogator* and transmits data back to the host console's *Product Assessment Computer (PAC)* via the *Scheduler* and *Link Server* computers. The *PAC* receives tag data from multiple robots, storing the information in the *Product Database Computer (PDC)*. The *Product Database Computer* is a database that keeps track of the tags read in by all robots as well as those entered manually by the user. The *Database Access Computer (DAC)* is the user interface to the *Product Database Computer*, allowing for manual entry of information, for editing of existing tag information, as well as for querying the database and generating and viewing various tag reports.

3.1 Host Subsystems

The Host subsystems consist of the *Product Assessment Computer (PAC)*, the *Product Database Computer (PDC),* and one or more *Database Access Computers (DACs).* The computational resources for these subsystems are all commercial PCs, with various 80X86-based processors. The *PAC* and *DACs* run under the *Windows NT* operating system, the *PDC* runs under the *MS-DOS* operating system.

The *PAC* receives tag data from the remote platform, formats it, and passes it to the *PDC*. Tag data includes the unique Tag ID, the signal strength of the response from the tag, and the (X,Y) position of the platform when it received the signal from the tag. The *PAC* collects a number of such sets of data, formats them into a packet along with current date/time, and uses *SQL* commands to store the data in a table on the *PDC*. Application software was written in the Ada language, with actual *SQL* commands being issued by routines from the Gupta C language applications interface library.

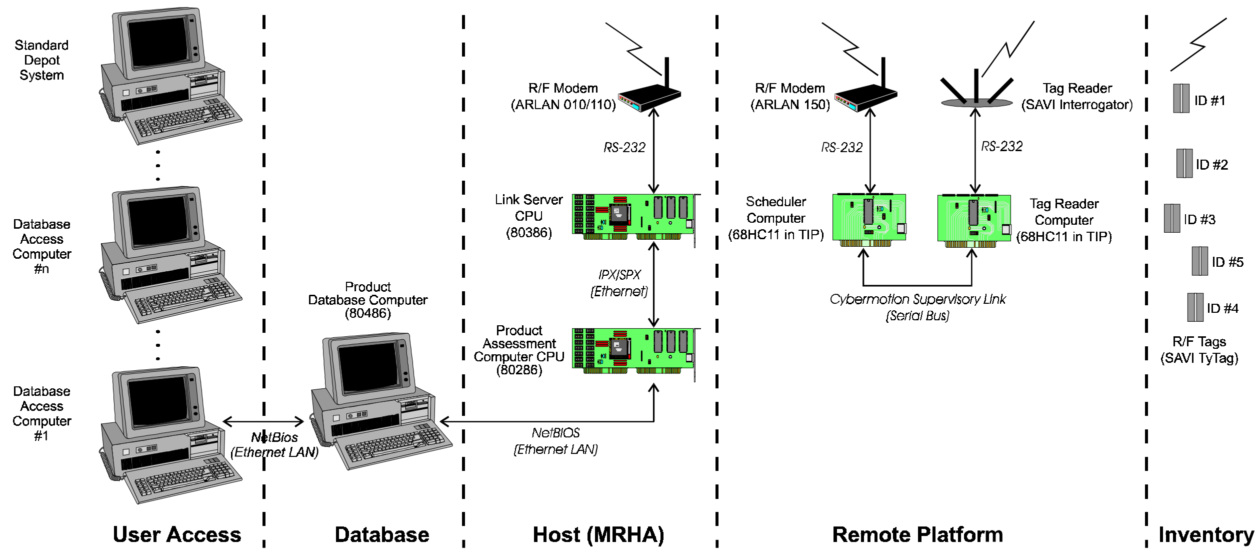

Figure 1. Block diagram of the MDARS *Product Assessment System*.

The *Product Database Computer (PDC)* stores tag identification and location data passed to it by the *PAC* and the *DACs*. It also responds to queries from the *DACs*. The *PDC* is a SQL relational database server. The database server software used is the multi-user *SQLBase* from Gupta Technologies, Inc. The *PAC* and *DACs* are *clients* of the PDC in this client/server database architecture.

Warehouse and inventory personnel use the *DACs* to perform manual data entry, to request database reports and to perform database administration functions. Another major function of the *DAC* is to determine the best estimation of the location of each tag. A future version of this subsystem will provide connectivity to the *Standard Depot System (SDS)* and *Depot Supply System (DSS).* The user interface is windows-based, using menus, windows and dialog boxes very similar to other standard windows applications. The *PAC* applications program was written in the Ada programming language. The *DAC* applications program was written in Gupta's fourth-generation language, *SQLWindows*. Figure 2 shows the top-level menu of the *DAC* user interface.

The various subsystems of the *PAS* use different means of communicating with one another. The *Platform* subsystem collects tag information remotely using a SAVI *Interrogator* (RF Tag Reader), and passes data to the *Host* subsystem via an ARLAN R/F Modem. The *Host* subsystems communicate with each other via an *Ethernet* LAN.

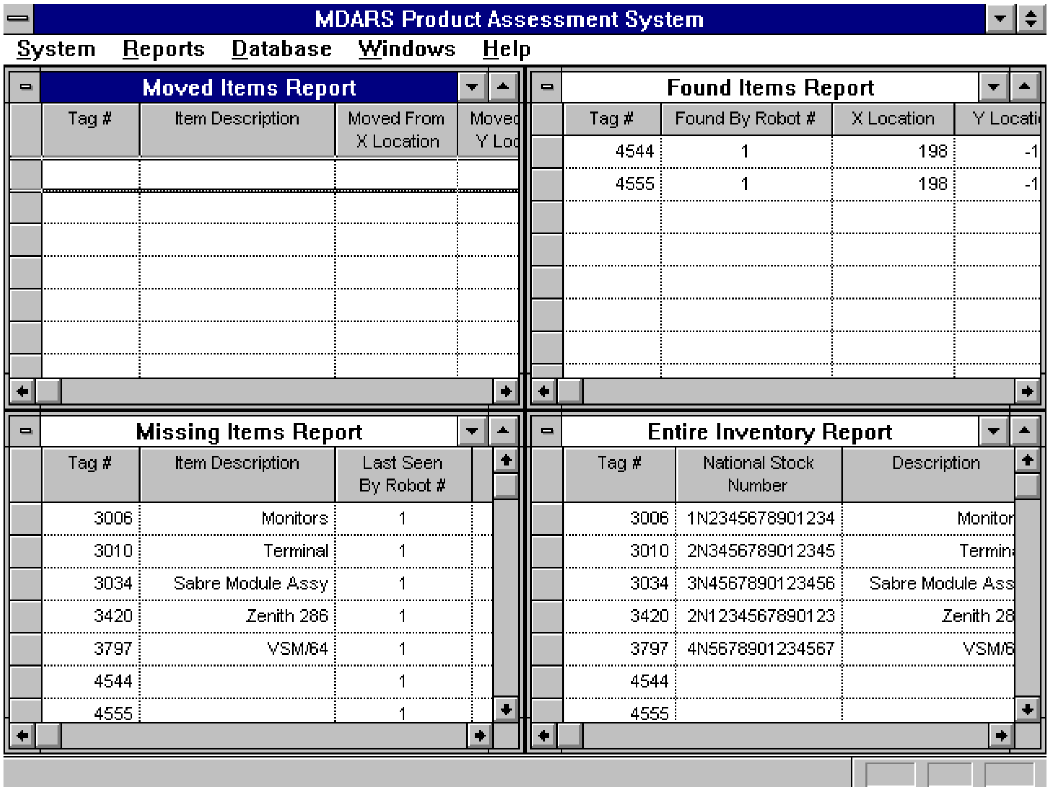

Figure 2. *DAC* User Interface showing four typical user-requested report windows.

3.1.1 Factors Influencing Database Selection

- **SQL Requirement:** Government policy stipulates SQL will be used for relational databases as the interface between programs and the supporting DBMS.
- **Ada Requirement:** The database selected for the *PAS* must support the Ada language as an application program interface/precompiler.
- **Tagging Strategy:** The specific tagging strategy employed on MDARS was a major factor influencing the PAS database requirements.
- **DoD Standardization:** MITLA recently awarded a $70 million contract to Savi Technology Inc. to establish an asset tracking and management system. MDARS must remain fully compatible with standardized RFID systems employed throughout DoD.
- **Host Hardware:** The PAS database should run on hardware identical to other CSCIs in the Multiple Robot Host Architecture.
- **Cost:** Acquisition and development costs, as well as site licensing fees, if applicable, had to be reasonable and in keeping with the MDARS budget.

3.1.2 Database Tradeoff Analysis

A preliminary analysis conducted by Computer Sciences Corporation (CSC), Eatontown, NJ, compared three commercial off-the-shelf database products for integration into the MRHA to fulfill the depot inventory control mission requirement. Information was gathered from product brochures and technical briefs, as well as telephone conversations with technical support personnel from the respective manufacturers. Several products were reviewed and discarded based on known systems requirements and factors of influence as cited above. Only three leading candidates were more extensively evaluated due to time and funding constraints. To summarize the preliminary findings:

- The *Gupta Structured Query Language (SQL)* base is well suited for the PC network environment.
- *Informix On-line* is better suited for the medium corporate-flavored environment.
- *Oracle 7* is better suited for the Management-Information-Systems-level computing environment.

The NCCOSC development team performed an informal survey of commercially available products for the PC market, and GUPTA surfaced as one of the most cost effective, easy-to-use packages supporting multiple platforms for growth. Consequently, the Gupta multi-user *SQLBase* database, C language applications programming interface (for use on the *PAC*), as well as *SQLTalk/Windows* and the *SQLWindows* programming interface (for use on the *DACs*) were selected for initial development. Current software engineering efforts entail designing and coding the *DAC* software in Ada.

3.2 Remote Platform Subsystems

The hardware resident on each *Interior* robot (Holland, et al., 1995) consists of a Savi *Interrogator* for bi-directional communication with interactive RF transponder tags attached to high-value inventory items (Savi, 1994a), and a controlling *Tag Reader Computer*. When commanded by a *virtual-path program instruction*, the *Tag Reader Computer* collects all tag information from the *Interrogator* and buffers it in internal blackboard memory for later transfer to the *Product Assessment Computer*. The *Interrogator* is an off-the-shelf unit designed for unlicensed operation (below FCC Part 15 power levels) at either 315 or 433.92 MHz (Lawlor, 1993). Early models employed three 12-inch stub antennae mounted external to the half-spherical housing, 120 degrees apart for full omni-directional coverage. The current version (Figure 3) incorporates a pair of antennae inside the housing for a rugged, less-obtrusive profile. No provisions have yet been made to integrate the product assessment hardware onto the *MDARS Exterior* platform, which is still in the early stages of development (Myers, 1994; 1995).

The Savi *Interrogator* is a microprocessor-controlled RF transceiver capable of omni-directional read/write operations to transponder tags located up to 150 feet away. It first sends out a wakeup signal consisting of a 3.49-second pulse modulated at 30-KHz, then uploads 10 bytes of data from each responding tag. Savi's proprietary *Batch Collection* algorithm allows the system to accurately identify thousands of tagged assets at a single read location in a matter of minutes (Savi, 1993). Individual tags can then be directly addressed for more complex data transfers, such as storing item-unique maintenance or special handling instructions in tag memory for future reference during the product life cycle.

Figure 3. The Savi *Interrogator* is an off-the-shelf RF transceiver with a tag read/write range of up to 150 feet.

Table 1. Selected specifications for the Savi *Model CLIN 0003AA Interrogator*.

Parameter	Value	Units
Frequency	315 or 433	MHz
Range	300	feet
RF pattern	360	degrees
Memory	64K	bytes
Data rate (RF)	9600	baud
RS-232	9600	baud
RS-485	38.4K	baud
Power	6-15	volts DC
	100	milliamps
Size (diameter)	12	inches
(height)	4.5	inches
Weight	6.5	pounds

Two types of RF transponder tags are currently used by the *MDARS Product Assessment System*: 1) the Savi *TyTag* and 2) the Savi *SealTag*. Both units are equipped with an onboard piezoelectric beeper that can be activated on command from an *Interrogator* to allow individual tags to be easily located by warehouse personnel (Savi, 1994b). The *TyTag* (Figure 4) operates on a 6-volt 600-mAh Lithium flat-pack battery and will automatically issue a low-battery warning (i.e., set a status bit in the tag's data stream) at 5.16 volts. The minimum operating voltage required to achieve a 25-foot line-of-sight range is 4.16 volts, and typical battery life is two years with two data collections per day. *TyTags* are intended for indoor operation only and are available with 128 or 256 bytes of non-volatile memory.

The *SealTag* (Figure 4) is enclosed in a rugged environmental package suitable for exposed outdoor operation and is available with an extended non-volatile memory of up to 128 kilobytes for mass storage of information such as product history or container manifests (Savi, 1994b). A 6-volt 1400-mAh lithium battery provides an expected service life of four years assuming two data collections per day, and battery status is automatically monitored as in the case of the *TyTag*. A real-time clock is incorporated to facilitate time-stamping data or event occurrences.

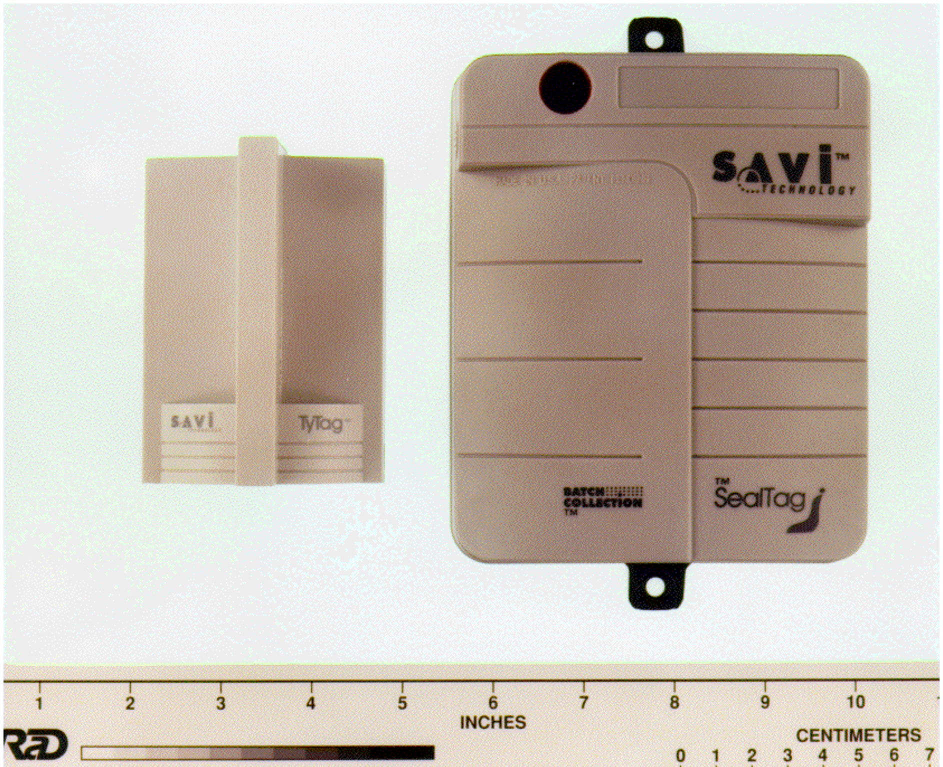

Figure 4. The Savi *TyTag* (left) and *SealTag* (right) are battery-operated RF transponders that can be attached to high-value or sensitive items for near-real-time localization.

An inverted-TTL RS-232 serial interface and four binary I/O lines are provided on the *SealTag* to communicate with auxiliary equipment and/or monitor external events. A change in logic level of an input line will toggle the state of an associated bit in the data stream read by the *Interrogator*, greatly expanding the versatility of the system. For example, an input line on a *SealTag* will be used in the *MDARS Exterior* program to monitor the physical status (i.e., open or shut) of high-security locks, and will upload this information along with the lock serial number to the patrolling MDARS vehicle upon request. In this fashion, the same hardware used to verify inventory inside a locked space can also be used to collect binary type information describing related conditions (i.e., flooding, fire, smoke).

For the *Interior* program, the software to control the Savi *Interrogator* runs on the *Tag Reader Computer*, a Motorola *M68HC11*-based single-board computer developed exclusively to fit in the *Turret Interface Panel* of the Cybermotion platform (see again Figure 1). Communication between the *Tag Reader Computer* and the *Interrogator* is via a 9600-baud RS-

232 serial link. The main loop of the software continuously monitors a command register awaiting direction to perform a *tag-read* operation, whereupon the *Interrogator* is instructed to transmit a *wakeup signal* and perform a subsequent tag collection. After the tag collection is completed, the *Tag Reader Computer* uploads the collected tag IDs from the *Interrogator*, and packetizes the data into its onboard memory for later collection by the MDARS *Product Assessment Computer* at the host console.

Table 2. Selected specifications for the *TyTag* and *SealTag*.

Parameter	*TyTag*	*SealTag*	Units
Frequency	314.975	433.92	MHz
Transmit power	< 10	< 10	microwatts
Range	200	300	feet
Memory	128 or 256	256, 8K, 128K	bytes
Environment	indoor	indoor/outdoor	
Audible beeper	yes	yes	
Real-time clock	no	yes	
Power	6	6	volts DC
(standby)	4	10	microamps
(active)	25	25	milliamps
Battery life	2	4	years
Size (length)	3.6	5.5	inches
(width)	2.35	4.5	inches
(height)	1.6	2	inches
Weight	5	10	ounces

Listed below are some of the additional capabilities of the tag-reader software.

- Write to EEPROM of *Interrogator* to adjust power level of wakeup signal.
- Instruct *Interrogator* to send out a *tag-wakeup* signal.
- Determine battery status of each tag read.
- Determine signal strength of received signal from each tag.
- Read in the 24-hour clock of *Interrogator*.
- Store current X-Y coordinates of the platform.
- Instruct a specific tag to activate or deactivate its beeper.
- Perform a search to find a specific tag.

4. Current Status

Extensive testing was conducted by the MDARS development team during January 1995 at the Camp Elliott warehouse facility (Figure 5) in San Diego, CA, specifically to assess the accuracy of several tag-position-estimation algorithms (Elaine, et al., 1995). The test was also designed to determine the impact of performing tag-read operations at two different stop intervals (37.5 and 75 feet) along the route, using 173 Savi *TyTags* placed at known locations throughout the warehouse. For survey intervals of 37.5 feet, the best performing algorithm achieved an average 14-foot positional uncertainty (i.e., the difference between estimated and actual tag locations), while for survey intervals of 75 feet the uncertainty was increased to approximately 20 feet. Several algorithms were tried and evaluated in an attempt to determine: 1) if a single tag-read location is sufficient to determine a tag's location, 2) if better results are obtained by averaging several tag-read locations, or 3) if weighting results based on the measured signal strength improves the assessment.

Figure 5. An earlier model of the Savi *Interrogator* mounted on top of the *MDARS Interior* robot.

A number of data selection methods were evaluated to determine whether position-estimation results improve when more or fewer data values are used. The analysis was also intended to determine whether results are better when only the current survey set is used or when past survey results are also considered in the assessment. Preliminary conclusions drawn from the tests and analysis are as follows:

- All assessment methods used in the analysis performed better than the original algorithm used in the prototype *DAC*.
- The best assessment method used the average X-Y location of the tag weighted by a normalized signal strength derived from the top three data points, ranked by signal

strength. Using this method, an average 14-foot positional uncertainty can be achieved with a tag-read interval of 37.5 feet. Comparisons are on **average** errors. Actual assessed position of a tag for any particular run can vary significantly depending on a number of environmental factors, such as multi-path interference.

- Algorithms which weighted the perceived distance by the measured signal strength worked better than those which did not take signal strength into account.
- Reducing the tag-read interval by 50 percent (i.e., from 75 feet to 37.5 feet) produced a 24- to 42-percent reduction in actual versus assessed position error, depending on which assessment and data selection method was used.
- Tag-read operations from at least three locations are needed for optimal performance of all the tested algorithms.

Since the testing and analysis was completed, the *DAC* software has been extensively redesigned and expanded in functionality to include more automated processing and an interface to external databases used by large DoD warehouses such as *DSS* and *SDS*. This next-generation version of the *DAC* software is being written in Ada using the *Windows NT* operating system.

5. References

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