Wireless Communications Between System Under Test and Portable Maintenance Aids

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Abstract: *As the Department of Defense (DOD) downsizes there is a great need to reduce the maintenance burden. Currently, systems in the DOD inventory utilize numerous hardware, interconnecting devices, and data and protocol to communicate diagnostics and maintenance information to external systems or maintainers. These communication devices always end up to be a big burden to the systems' maintainers, in terms of weight and volume. Moreover, these interconnecting devices require the portable maintenance aide to be tethered to the weapon systems. This greatly confines the maintainers' mobility and hence wastes maintenance manpower. The Advanced Technology Office (ATO), US Army Test, Measurement, and Diagnostic Equipment Activity (USATA), in Sep 1996, initiated proof-of-concept that a wireless remote-controllable communication device could be developed to untether maintainers with maintenance aides and systems or weapon systems. This paper will provide a report on the development and design of this wireless remote-controllable communication device.*

I. INTRODUCTION.

The DOD maintenance and sustainment is at a crossroads. Funding for new, more reliable, and more maintainable systems has been reduced significantly over the past years while the older weapon systems are being kept well past their expected life. New technology recently developed by the DOD and industry exists to make a major impact on weapon systems to reduce maintenance costs, and increase sustainability.

System maintenance encompasses several areas of specialization: Diagnostics/Prognostics – fault isolation/part degradation prediction; Repair procedures (remove/replace); Hierarchical system status reporting schemes (i.e., Built-in Test); and Logistics (i.e. parts ordering, availability, status etc.). Traditionally, maintainers have performed these tasks as discrete functions, moving from one operation to the next with clear boundaries of separation defining the specialized procedures that maintainers performed. As systems have become more advanced and complex the clearly defined maintenance boundaries that once existed are no longer so evident. Automation has blurred the boundaries of traditional maintenance procedures resulting in problems such as information overload for the technician, conflicting system health status indications, nonsensical system responses, and proliferation of test equipment and test procedures to name but a few. To combat these system maintenance issues we have armed maintainers with a host of personal maintenance aids, all of which are designed to allow the maintainers to overcome these problems. While these maintenance aids have proven to be valuable tools to the maintainer they are not without drawbacks. The chief complaint from maintainers regarding the use of the personal maintenance aids has centered around the issue of mobility. Tethering oneself to a weapon system in order to perform maintenance tasks has proven to be cumbersome and debilitating to the maintainer in the performance of their duties.

Due to the personnel drawdown which has occurred within all branches of the military, it becomes even more imperative that automated maintenance efficiencies are

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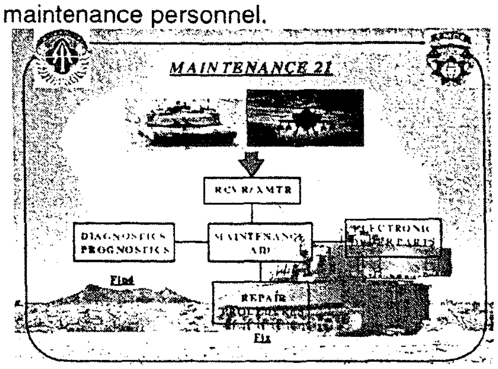
improved/developed to offset the loss of maintenance personnel.



Since 1991, the ATO, USATA has been addressing various components of maintenance and sustainment issues and providing state-of-the-art solutions. For troubleshooting procedures, we provided model-based diagnostics (1993) [1]; for repair procedures, diagnostics driven interactive electronic technical manual (1994) [3]; for paper parts ordering, electronic part ordering (1996); and, for integrated maintenance aid, a wearable, remote, voice controllable, hands-free information system, Maintenance Analysis Repair Support System (MARSS) (1996) [5-7]. Since 1996, we addressed the issue of obtaining automated maintenance data from the weapon system, in order to completely enhance the task of operating the weapon system, increase the efficiency of system maintenance and sustainment, increase operational readiness, and reduce the logistics cost.

Traditionally, the systems in the DOD inventory utilize numerous hardware, interconnecting devices, data and protocol to communicate diagnostics and maintenance information to external systems or maintainers. These communication devices are inclined to be a big burden to the systems' maintainers, in terms of <u>weight</u> and <u>volume</u>. Moreover, these interconnecting devices require the portable maintenance aid to be tethered to the weapon systems. This greatly confines the maintainers' <u>mobility</u> and hence reduces maintenance effectiveness.

In order to reduce maintainer's hardware burdens and increase maintenance efficiency, our goal was to develop and demonstrate that a device can be built to be plugged into a data bus, (Mil-Std-1553, J1708, J4, or DCA bus), of a system under test and perform the wireless interfacing and outside communication to an integrated maintenance aid, (an information computer system). The design consideration was an open architecture concept to allow the greatest flexibility and for interoperability and future expansion. For purpose of proof-of-concept, the MARSS or equivalent information system and the Mil-Std-1553 bus would be used as testbed.

The Georgia Tech Research Institute, with extensive experience in Mil-Std-1553 testing, was selected to implement this concept of wireless communication system.

This report will provide some key information concerning: Design considerations; Trade-offs Analysis; Criteria and limitations.

II. DESIGN CRITERIA.

The main goal of this effort was to reduce maintainers' burden, (weight, volume, and power requirements) while increasing flexibility of hardware architecture, adaptability, maintenance accuracy, and efficiency. Moreover, as there was only limited funding available, reliability and cost were also main consideration factors.

To address the above objectives in a structured manner, research on existing embedded systems was initially conducted. Embedded system technology, referred to as PC104, was pursued and the following components evaluated:

1. PC104 CPU Board
2. PC104 PCMCIA Adapter Card
3. PC104 Video Card
4. PC104 Memory Card Adapter
5. PCMCIA MIL STD 1553 Bus Interface
6. PCMCIA Wireless Networking LAN
7. Storage devices

Based on quality and quantity of technical support, product cost and reliability, candidate vendors were evaluated via the World Wide Web prior to component purchase. According to a Massachusetts Institute of Technology (MIT) report, Ampro products tend to be reliable with moderate sophistication. Ampro also offers a full line

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of PC104 components. Minimizing the number of vendors eliminates multisource compatibility, thereby reducing hardware debug efforts and delivery time. Throughout the development process, Ampro demonstrated excellent technical support.

III. HARDWARE COMPONENTS SELECTION.

In general, the components selected were chosen with careful trade-off analyses. The trade-off analysis factors included reliability, capability, physical sizes/dimensions of each board, power usage requirements, compatibility/adaptability, flexibility for expandability and interfaces, weight, and cost.

PC104 TECHNOLOGY (Core Module/4Dxi)

Based on design criteria stated in section II, the physical dimensions (3.6" X 3.8") of each board and power usage requirements, PC104 technology was selected. There are over 150 vendors manufacturing hundreds of variants of PC104 components [2] Ampro, DGE, and Megatel product lines were evaluated prior to the decision of the Ampro Core Module/4DXi for the Wireless Communication System (WCS). The WCS processor modules primary functions are peripheral support and routing of interface signals to the wireless LAN. These two functions do not require the processing power of Pentium, and hence a 486module running at 100MHz was selected. This provides the capability to run the Windows 95 operating system and sufficient expansion so that future data compression algorithms can be incorporated into the system in order to support multiple simultaneous WCSs on the wireless LANs limited bandwidth. Pre 486 processor technologies were not considered due to incompatibility with Windows 95. Moreover, the Ampro Core Module/4DXi features a 100MHz 486 DX4 processor and is capable of supporting up to 52M bytes of onboard DRAM. It also has an IDE controller, a bi-directional parallel port, dual FIFO-buffered serial controllers, and a 16-bit PC104 expansion bus. The Core Module/4DXi also has a socket for bootable "Solid State Disk". Typical operating requirements range between 110mA (when sleeping) and 980mA (when active) of power. The Ampro's had minimum delivery time cycle and low hardware defects that keep overall hardware costs low. Furthermore, PC104 is an embedded computer standard, and combines the advantages of PC architecture with a modular approach allowing greater flexibility than a standard PC. PC104 modules that are 8 or 16-bit can be stacked along with 32-bit PC/104-*Plus* (PCI) modules provided similar type modules are adjacent to one another [4]. PC104 components are easily modifiable and can be refitted with other PC104 components allowing for future expansion of a current system. The key differences between PC104 and regular PC bus are PC104 components are compact in size (3.6" X 3.8") and are joined with other PC104 components via a stackable bus [2].

WIRELESS COMMUNICATION SYSTEM (WCS)

The WCS is required to be a small, lightweight, portable computer that is capable of interfacing between the MARSS or any equivalent information management system and an Army weapon system platform via a MIL-STD 1553 bus interface and IEEE-488 data bus. The WCS is not specific to the MARSS and is designed to accept any wireless client computer (provided network communication is on the same specified radio frequency) and communicate. The WCS can easily be reconfigured to allow other interfaces such as the J1708, J4, or DCA bus interface. A J1708 has been procured; however, it has not been integrated or tested in the WCS.

Several operating systems were considered including DOS, Windows 3.1x, Windows 95, Windows NT, and Windows CE. Windows CE for embedded systems was not available during the summer of 1997. Based on literature research, it indicated that Windows CE might be a desirable operating system when released. In order to avoid compatibility issues with the MARSS, Windows 95 was selected as the operating system. Both Windows 95 and Windows NT require a considerable amount of disk space; therefore, sufficient storage must be available. Windows 95 and Windows NT both require the use of a video card; therefore, in order to insure progress of the WCS prototype, a video card was used.

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Issues and Solutions:

Initially, a PCMCIA hard drive was to be used as the storage device for the WCS. However, PCMCIA hard drive boot up with Windows 95 requires the boot ROM to be modified. Window 95/NT PCMCIA hard card boot by the WCS PC104 system is considered unreliable by Ampro technical support. Utilizing True Flash Filing System (TrueFFS) technology with PCMCIA drives allows booting off of a PCMCIA card. TrueFFS is a linear flash system and is very effective only on small hard drives (2-4MB). TrueFFS operates by allocating data in the first available slot and then assigns that slot a specified address.

In order for additional data to be stored, the computer must search starting from the first address until an available slot is found. The slot is then assigned an address. This method is too time- consuming for the WCS, since the minimum storage required for Windows 95 to operate is 40MB. A Flash Disk System was then considered. Flash Disk systems are limited to approximately 64MB of storage. Power requirements for a Flash Disk System is considerably less than a hard card. However, further discussions with Ampro technical support indicated that this technology has not been successfully integrated with Windows 95 by technical support or customers. A small footprint hard drive running off of the on-board IDE interface (integral to the Ampro Core Module/4DXi) was then considered the primary solution. In addition to PC-104 Core Module /486Dxi, the WCS is built utilizing the following components:

1. PC-104 MiniModule /SVG-II
2. PC-104 MiniModule Dual Slot PCMCIA Adapter
3. SBS 1553 ASF-PCMCIA Adapter
4. DEC RoamAbout PCMCIA Adapter
5. Storage Device (MK1403MAV 1.44GB Hard Drive)

PC-104 MiniModule /SVG-II: Again, to ensure compatibility with the Core Module/ 4DXi and eliminate compatibility issues resulting from multiple vendors, the Ampro MiniModule/SVG-II was selected. The Ampro MiniModule/SVG-II supports 24-bit "true color" VGA display and also supports DOS, Windows®, and most other popular operating systems. It has a 16-bit PC104 bus that allows for either 8 or 16-bit operation. The Ampro MiniModule/SVG-II typically operates with 350mA. Although the final product will not use a video card, the delivered WCS uses a PC104 video card as a means for debugging the WCS prototype.

PC-104 MiniModule Dual Slot PCMCIA Adapter: The Ampro Mini Module /PCMCIA was selected for the PC104 PCMCIA Adapter to ensure compatibility with the Core Module/4DXi and to eliminate compatibility issues resulting from multiple vendors. The Ampro MiniModule Dual Slot PCMCIA Adapter is a dual slot PCMCIA adapter that supports Type I, Type II, and Type III Flash, ATA hard drives, modems, network cards, and other I/O cards. The Ampro MiniModule Dual Slot PCMCIA Adapter is capable of "hot swapping" cards (removing and installing cards without shutting down power to the system) and typically operates with 20mA of power. The MiniModule/PCMCIA is used to interface with the MIL-STD 1553 Bus PCMCIA card. The MiniModule Dual Slot PCMCIA Adapter is used in conjunction with a DEC Roam About wireless LAN PCMCIA unit to provide communication with the MARSS.

SBS 1553 ASF-PCMCIA Adapter: The SBS MIL-STD-1553 Advanced Bus Interface for PC Systems was chosen as the MIL-STD 1553 adapter because of the delivery time. A Gateway Solo 2100 Multimedia Notebook Pentium 133 was purchased in order to emulate a weapons system and generate 1553 bus traffic. Additional 1553 bus hardware was necessary for successful testing including the following hardware:

- Dual redundant bus with dual stub couplers
- Four 15' cables
- Four terminators
- Two, two-stub couplers

Issue and Solutions: When the WCS is initially turned on, the SBS MIL-STD-1553 Advanced Bus Interface is not functional. During the first several minutes, the SBS MIL-STD-1553 Advanced Bus Interface exhibits errors such as the vendor supplied DLL not recognizing the card, built-in test

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failure, and DSP startup timeout. The DDC BU-6550M2-300 PCMCIA card was also proven to be unstable upon initial startup taking up to one hour to stabilize. When the Gateway Laptop (weapons system containing the DDC BU-6550M2-300 PCMCIA card) is initially booted, the card self-tests without problems; however, after several minutes the DDC BU-6550M2-300 PCMCIA card will fail most tests, though it is still recognized in the PCMCIA slot. The DDC BU-6550M2-300 PCMCIA card has also been tested on another laptop computer and experienced the same problems. The SBS MIL-STD-1553 Advanced Bus Interface and the DDC BU-6550M2-300 PCMCIA card were the only available PCMCIA cards for our testing. Possible solutions to resolve the issue are: either to have a dedicate card for the MIL-STD-1553 or to ruggedized the connection of the PCMCIA card.

PCMCIA Wireless LAN Adapter: Several vendors, Digital, DCB, and Aironet were evaluated prior to the selection of the Digital RoamAbout 915 DS/PC Card (DEINA-AA) for the WCS. Currently, the MARSS is using the Digital RoamAbout 915 DS/PC Card to transmit data to other wireless PC networks. To ensure compatibility with the MARSS and avoid multisource compatibility issues, the Digital RoamAbout 915 DS/PC Card was selected as the desired "wireless" communication device between the MARSS and the WCS prototype. The Digital RoamAbout 915 DS/PC Card acts as the WCS network adapter that allows communication without the use of a tether. The Digital RoamAbout 915 DS/PC Card (DEINA-AA) has a PCMCIA Type II interface and has a data transfer rate of 2Mb per second. It operates on spread spectrum radio technology at 902-928 MHz; but due to the frequency spectrum, this product can only be sold in the U.S., Canada, and Mexico. The Digital RoamAbout 915 DS/PC Card (DEINA-AA) has a range of 244 meters in open environments, typically requires 36mA when sleeping, 300mA when receiving, and 600mA when transmitting of power.

MK1403MAV 1.44GB Hard Drive: Several storage devices, PCMCIA hard disk, Flash Disk, and an IDE hard drive, were considered and evaluated. In order for a PCMCIA hard disk to be utilized in the WCS, the boot ROM must be modified to allow successful boot from the PCMCIA card. Windows 95/NT PCMCIA hard disk boot by the PC104 system is considered unreliable by Ampro technical support. Utilizing a Flash Disk will eliminate this problem. However, this limits available disk space to only 64MB. Flash Disks are based on EEPROM technology, which limits the card to less than 100,000 read/write cycles. This limits the WCS from future hardware configurations and software upgrades and reduces the flexibility of the WCS. Moreover, Windows 95 installation upon a Flash Disk has been unsuccessful. A small hard drive running off the IDE controller on the Ampro Core Module/4DXi was considered the best solution.

A Toshiba MK1403MAV hard drive has an ATA-2/ATA-3 interface connects to the Ampro Core Module/4DXi 43-pin IDE controller. The hard drive has 1.44GB of storage, measures 3.94" long X 2.75" wide X .50" high, and weighs 155 grams. The Toshiba MK1403MAV hard drive has an average access time of 13 msec and has a bus transfer rate of 16.6 megabytes per second. It is capable of operating with 100G's of shock or .5G's of continual vibration. Typical power usage of the Toshiba MK1403MAV is 30mA during sleep, 80mA during idle, 130mA during startup, 400mA when seeking, and 420mA when reading or writing.

WIRELESS COMMUNICATION SYSTEM (WCS) HOUSING

The WCS housing is galvanized steel of dimensions 6"x6"x6". A housing was modified to allow a permanent fixture for all of the WCS components. Keyboard, mouse, and monitor connections were added to the rear of the WCS prototype to allow quick connections of these devices. The keyboard, mouse, and monitor are necessary in order to aid in debugging the WCS prototype. A circular AMP® quick release power connector was added, as was an internal speaker. AMP connections are proprietary, therefore, only AMP® connectors can be used with other AMP® connectors. A power light and system-reset switch were also allocated on the rear of the housing. Four holes were drilled on the bottom of the WCS housing to

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allow a permanent mount for the PC104 stack.

IV. SOFTWARE.

The software developed for this project has, when possible, used demonstration code, libraries developed, and supplied by the manufacturers of the interface products. In the case of the SBS 1553 PCMCIA interface, the manufacturer was in parallel code development and debug, resulting in four major version updates, and numerous minor versions, during the course of the project. In this case, design and testing of the SBS device drivers and data capture capability was frozen upon release of the first version where consistent results could be obtained (Version 4.0).

Two sets of software were developed under this project to demonstrate software technologies that may be used in design of production WCS software. Both sets of software are based upon network client/server models where the WCS acts as the data server and the MARSS acts as the data client. They are described as follows:

MIL-STD-1553 WIRELESS DATA ACQUISITION DEMONSTRATION SOFTWARE

In the first client/server set, the SBS 1553 PCMCIA interface card is used to access data via Remote Procedure Calls (RPCs) from the MARSS client. In the RPC model, the client/server pair works as a single program with data transmission between the two sections of code, running in two separate machines, appearing to the programmer as local procedure calls. This technology has two advantages over standard client server applications:

- Legacy code, written for a monolithic test platform, can be split apart with minimal code rewrite. The code would still function as a single unit even though elements of the code would be split between the two machines.
- Placing the low level drivers on the server machine, and the test procedure code on the client system separates the code that tends to be updated more frequently and places it on the client where it is more easily updated. The server code then needs to be serviced only when major updates to driver code occurs, such as replacement of interface hardware with upgraded versions.

In addition to the above, the RPC standard allows for cross platform integration, thereby allowing code written for one computer to communicate with code written for another processor and operating system.

RPC communications may use any of the following protocols:

- Named Pipes
- Internet Protocol Address (TCP/IP)
- DECNet Phase IV
- DECNet Phase V
- NetBIOS

Of these protocols, TCP/IP is the most widely used and was the one chosen for communications between the RPC client and server programs.

IEEE-488 WIRELESS DATA ACQUISITION DEMONSTRATION SOFTWARE

The IEEE-488 board purchased for WCS demonstration was delivered with a fully functional Windows 95 DLL and Visual Basic interface module. The IEEE-488 Wireless Data Acquisition Demonstration software was therefore written in Visual Basic 5.0, utilizing the vendor supplied DLL, interface module, and Visual Basic's Winsock TCP/IP controls. The Winsock control that this set of client/server programs uses is based upon a messaging construct versus the RPC used for the 1553 data acquisition system. As with the RPC 1553 acquisition demonstration, the WCS is set as an information server, MARSS as the information client. Two logical TCP/IP channels are opened between the programs via the wireless link: One as a command path and the other as a bus traffic data path. The dual path structure is not necessary; however, the dual path architecture facilitates command and data class differentiation, and as a consequence, separates the methods for handling the two structures.

The advantage of this type of Client/Server architecture is future code reuse. Object-oriented languages, such as C++, and

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object-oriented Ada, Basic, and Pascal, enforce a framework on code that compels the programmer to produce units and libraries that do not require a priori knowledge of the underlying functions. A majority of the functions necessary for development of the IEEE-488 data acquisition system may be reused in other programs of similar function. The program written for the IEEE-488 was written and debugged as a new development effort in less than one half the amount of time require to modify the existing code for the RPC-1553 data acquisition.

V. SUMMARY.

A WCS has been built and successfully demonstrated. Wireless data communication between a surrogate MIL-STD-1553 data bus and a client computer over a 2 megabit per second network has been demonstrated. The WCS has been designed utilizing components in common with the MARSS. All components of the WCS design are Commercial-Off-The-Shelf (COTS) products, with multiple sources identified to facilitate inexpensive procurement of production components. The PC104 architecture of the WCS provides a compact physical design. The dimensions of the prototype's electronics with PCMCIA adapter, video, and CPU are 2.6" high x 3.6" wide x 3.8" deep. Addition or deletion of each interface board changes device height by approximately 0.6". The WCS has a nominal operating current requirement of 2.0A (over 40% of the total due to wireless link and 1553 interface), yielding approximately 2 hours of operation per charge from a 4 amp hour battery unit. Expansion of the WCS stack to include upgrades and expansion has been demonstrated by adding an IEEE-488 interface board and demonstrating its function.

VI. CONCLUSIONS.

A COTS multi-purpose and wireless interface can be designed and produced to transmit MIL-STD-1553 data bus traffic to the MARSS or equivalent information system. PC-104 technology seems to provide the best solution to the problems of minimizing size, weight, and power requirements.

Multiple WCSs connected to a wireless net may quickly overload the networks capabilities. MIL-STD-1553 is a 1 Mbit/sec data link; therefore, each WCS transmitting 1553 data may take up to 50% of the wireless network's bandwidth. This essentially limits the network to one WCS connection (more if a 1553's traffic load is less than 100%). Simultaneous use of a 1553 data bus monitor and PC remote control product such as Symantic™ pcANYWHERE™ may overload the wireless link. Therefore, WCS data acquisition software must provide means of control of the WCS from client PCs.

Legacy software can be converted for use on the WCS with minimal code rewrite utilizing Remote Procedure Calls. The speed and reuse advantages of object-oriented languages, along with extensive software development tools and libraries, indicate new software development should be pursued in either C++, Ada97, or an object-oriented Basic or Pascal.

VII. FURTHER INVESTIGATIONS.

The issue concerning the instability of the WCS's initial turn-on, (the SBS MIL-STD-1553 Advanced Bus Interface was not functional during the first several minutes) needs further investigation to ruggedize product.

Compression of the MIL-STD-1553 data stream may provide a significant reduction in individual WCS wireless bus loading. Both commercial and special purpose data compression/decompression schemes should be investigated, and if feasible, implemented in order to allow multiple WCSs to transmit 1553 data simultaneously.

A J-1708 interface was procured for the WCS; however, time was not sufficient to integrate it into the system. The Government possesses J-1708 diagnostic software and interface hardware. Re-hosting of a diagnostic program to a MARSS/WCS system would demonstrate the capabilities of the system and provide the Government with a testbed for further development of hands free maintenance.

The network technologies demonstrated in the WCS are not limited to communication

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through the wireless LAN. TCP/IP is the Internet protocol; therefore, the data transmission capabilities of the WCS can be extended to Internet type networks. The extension of the WCS to a global Internet will allow experts from remote locations to observe and control tests, as well as, confer in real-time with technicians and engineers in the field.

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