Adtranz: A Mobile Computing System for Maintenance and Collaboration

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Abstract

The paper describes the mobile information and communication aspects of a next generation train maintenance and diagnosis system, discusses the working prototype features, and research results. Wearable/ Mobile computers combined with the wireless technology improve efficiency and accuracy of the maintenance work. This technology enables maintenance personnel at the site to communicate with a remote helpdesk / expertise center through digital data, audio, and image.

1. INTRODUCTION

Wearable/Mobile computers [1], [2], [3], [4], [5] combined with the wireless technology improve efficiency and accuracy of the maintenance work. This technology enables maintenance personnel at the site to communicate with a remote help desk/expertise center through digital data, audio, and image. With these capabilities, even non-expert maintenance personnel can accomplish simple repairing tasks with the aid of remote experts at the help desk. The images and text are displayed on a display, which is also equipped with a microphone and earphones. The developing wireless technology allows for real-time transmission of maintenance data gathered from the sensors on vehicles to remote storage and data analysis stations. This project recently completed two prototypes and tested them live on the People Mover at Pittsburgh International Airport prior to field trials on other rail systems.

The system prototypes include two mobile elements, the maintenance technician and the train itself. The mobile technician prototype provides access to drawing, schematics, checklists, and manuals for technician on-board or off-board train. It utilizes high-speed spread spectrum wireless communication that covers tunnels and the maintenance bay to reach the Adtranz's maintenance system. It can simultaneously transmit high quality digital images, photographs, and two-way full-duplex toll quality voice communication to a remote engineer from the site. The technician can gather and feedback knowledge at the scene. It shares usage of bandwidth with the train security camera.

The on-board vehicle system prototype gathers internal status data from embedded sensors in systems such as propulsion and doors. The communication from the vehicle in tunnels to the track-side uses CDPD (Cellular Digital Packet Data) wireless service and WaveLAN spread spectrum radio. The prototype has the ability to use desktop or mobile clients to access train data in real time, and store the data for analysis and prediction of failures.

In the next section, we present Human Computer Interaction (HCI), and user interface design. Software design has been described in Section 3, followed by hardware design in Section 4, and wireless communication design in Section 5. Section 6 concludes the paper.

2. HUMAN COMPUTER INTERACTION AND USER INTERFACE

An Interdisciplinary Concurrent Design Methodology [6], based upon user - centered design and rapid prototyping, has been applied to the Adtranz mobile computing system design. Based on user interviews, and observation of their operations, we generate baseline scenarios. By creating visionary scenarios, we identify opportunities for technology injection. User feedback on scenarios and storyboards lead to a user interface design phase.

Two maintenance scenarios have been designed and implemented: Unusual Fault and Preventive Maintenance (PM). In the first scenario, a failure with the train's propulsion system has occurred. It is manifested as jerky motion, overspeed, and propulsion failure alarms. While one technician drives the train and opens the doors, the other one can use the mobile computer to diagnose the problem, Figure 1. The technician uses reference information, accessed through a mobile computer. The Unusual Fault scenario occurs on-train and diagnosis is performed while the train is in operation.

In the Preventive Maintenance (PM) scenario, a technician is performing a PM task that he/she has not internalized perhaps due to the infrequency of the task. The technician consults on-line manual pages to complete the task, working underneath the stationary train as shown in Figure 2.

The major usage modes include login/logout reference, bookmark, troubleshoot, annotate, and collaboration. Figure 3 is a screen sample for the troubleshooting mode. The computer screen is divided into two areas: content and control. The content area, occupying the left two-thirds of the screen, is where documentation and user collaboration appears. The control area allows the user to select documents, set bookmarks, enter alarms, etc. The bottom of the screen contains a menu bar that allows access to the major usage modes at any time. In the control part of the screen, the user can select an appropriate schematic, which then shows up in the content area. Alternatively, the user can select a previous incident report to find helpful information on solving the problem.

Fig. 1. Unusual Fault Scenario

The troubleshooting mode is designed to maximize the computer's searching capability thus minimizing the user's time to find suggestions on probable causes of malfunctions. The user can select from a list of alarms and/or enter free-form text with the pen to describe symptoms. A list of possible causes then appears in the content area. When the user selects a possible cause, more details are provided including manual reference pages and schematic drawings, Figure 3. Schematic drawings can be browsed by zooming in/out, panning, tracing circuit paths (i.e. selecting a component highlights other components to which it is attached), and displaying text associated with the schematics. Users can annotate text or schematics using the pen based handwriting recognition software. Annotations can be personal, public to a site, or public to all sites.

Fig. 2. Preventative Maintenance Scenario

The reference mode allows the user to enter free-form text with a pen to initialize search for information on any term. Alternatively the user can select a vehicle area for which a list of vehicle systems in that area will be displayed, as shown in Figure 4. Using the pen, the user can select a system (such as electrical, pneumatic, propulsion, etc.) that will, in turn, display a list of devices associated with that system. Selection of a device generates more specific information such as preventive maintenance schedule, preventive maintenance procedures, trouble shooting information, and device description. At the top level of the reference mode the user can also view preventive maintenance schedules and procedures. The user can place a bookmark on any of the reference pages. The bookmark appears in the control area for quick selection and "page flipping".

In the collaboration mode, the user can seek help from other personnel. Users can collaborate by a white board wherein all members of a session can view the same content area including a picture captured by a camera at one site. The whiteboard allows annotation. Information, annotation, and speech is transmitted over the wireless network. It is also possible to initiate a telephone call to personnel who do not have wireless access.

Table 1 summarizes subsystems, their parameters, and design choices. The chosen subsystems appear in bold. This text only discusses the final system choice. The choice of the trouble light / book stand concept by the on-site technicians has made a major

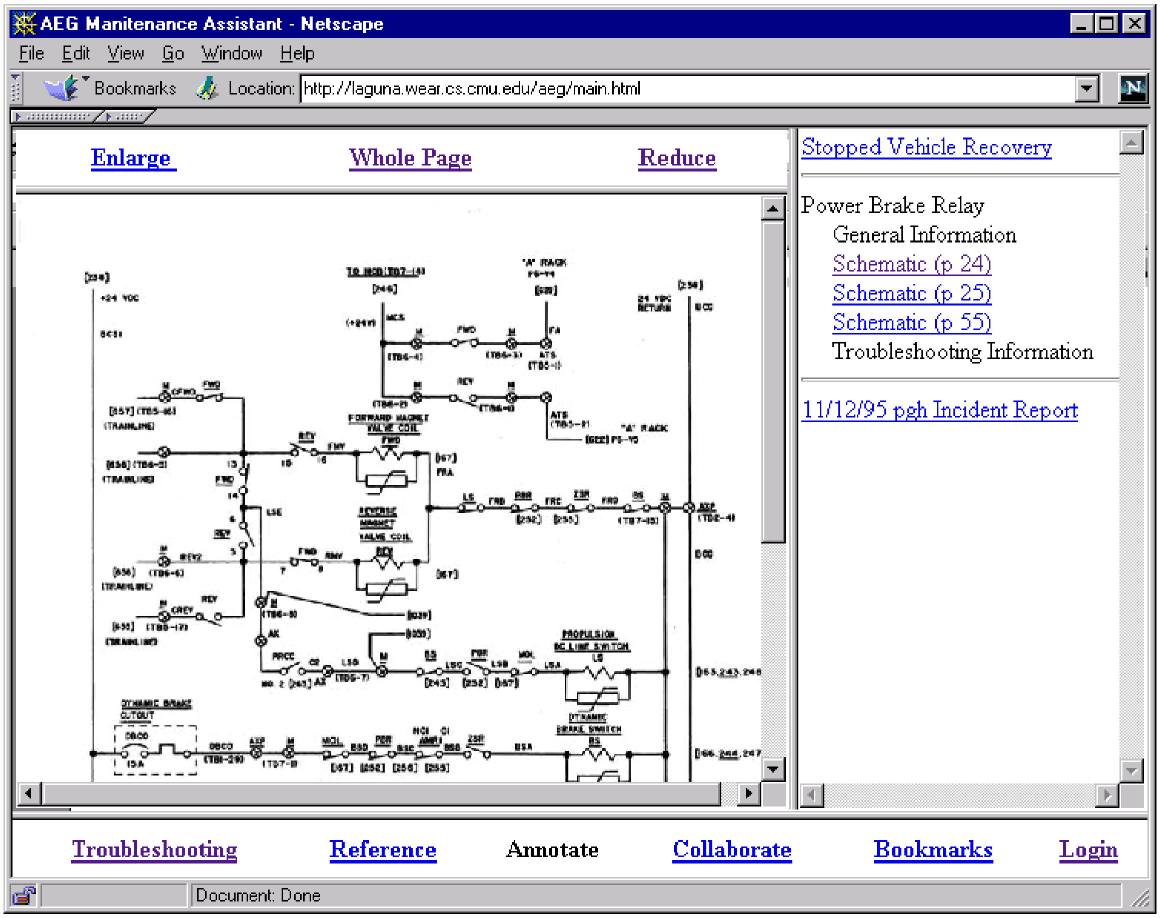

Figure 3: Screen sample for Troubleshooting Mode

impact on the overall design. To meet the required functionality, the following software, hardware, and wireless communication systems were integrated.

3. SOFTWARE

Netscape was chosen for the GUI (Graphical User Interface) development environment. Viewers and editors within Netscape are used to access different data types. The major software subsystems are: HTML Servers, CGI scripts, Collaboration Software (FarSite), and User Interface, as shown in Figure 5.

Data retrieval services are requested by Netscape and the HTML server acts as a database. Two HTML servers are currently available: WebSite and Windows httpd. WebSite is a Windows NT server, set up on an Intel 486 machine supports the Windows mode CGI scripting. WebSite can handle 50,000 requests per hour. Windows httpd can achieve true multi-threading via low level CPU control, and supports dual mode (DOS and Windows) CGI scripting. Windows httpd can serve 25,000 requests per hour.

CGI (Common Gateway Interface) scripts run via httpd on either server machine. The client can access the applications by requesting them from the server. The server will execute the script which invokes the application, and then passes the output back to the client. The CGI scripts can send back a variety of information, including HTML documents and images. The WebSite server supported CGIs written in three languages: Visual Basic, Perl and C. After much consideration and testing we decided to use C. The CGI scripts provide some "under-the-hood" functionality, such as: display the image in the current HTML frame on the screen; restore the current image displayed on the screen to its default starting size; zoom in on the displayed schematic; append the currently viewed selection to the personal bookmark file; launch the FarSite collaboration application with the currently viewed screen.

Inter-user collaboration provides document sharing, annotations and editing, is implemented using FarSite. FarSite supports different image formats and provides a variety of annotation tools, including high-lighting, text entry, standard shapes, and free hand drawing tools. There is a collaboration button on the

Netscape interface which invokes a CGI script launching the FarSite collaboration application. FarSite requires a Winsock compliant Windows network interface, which is available with the WaveLAN.

The legacy databases included electronic drawings, vehicle data, repair logs, 3-D models, and others. The system enabled access to 130,000 engineering drawings located in legacy databases, with a latency of less than five seconds.

Wave Jammer sound card used for voice communication, as shown in Figure 7.

Voice communication process over the WaveLAN network uses a real-time audio program. Voice is digitized using a sound card (Wave Jammer, full or half duplex), compressed, and sent over the WaveLAN network as files using TCP/IP protocol. The following wireless phone applications were evaluated: IPhone, WebPhone, Speak Freely, Digiphone, and CU-SeeME.

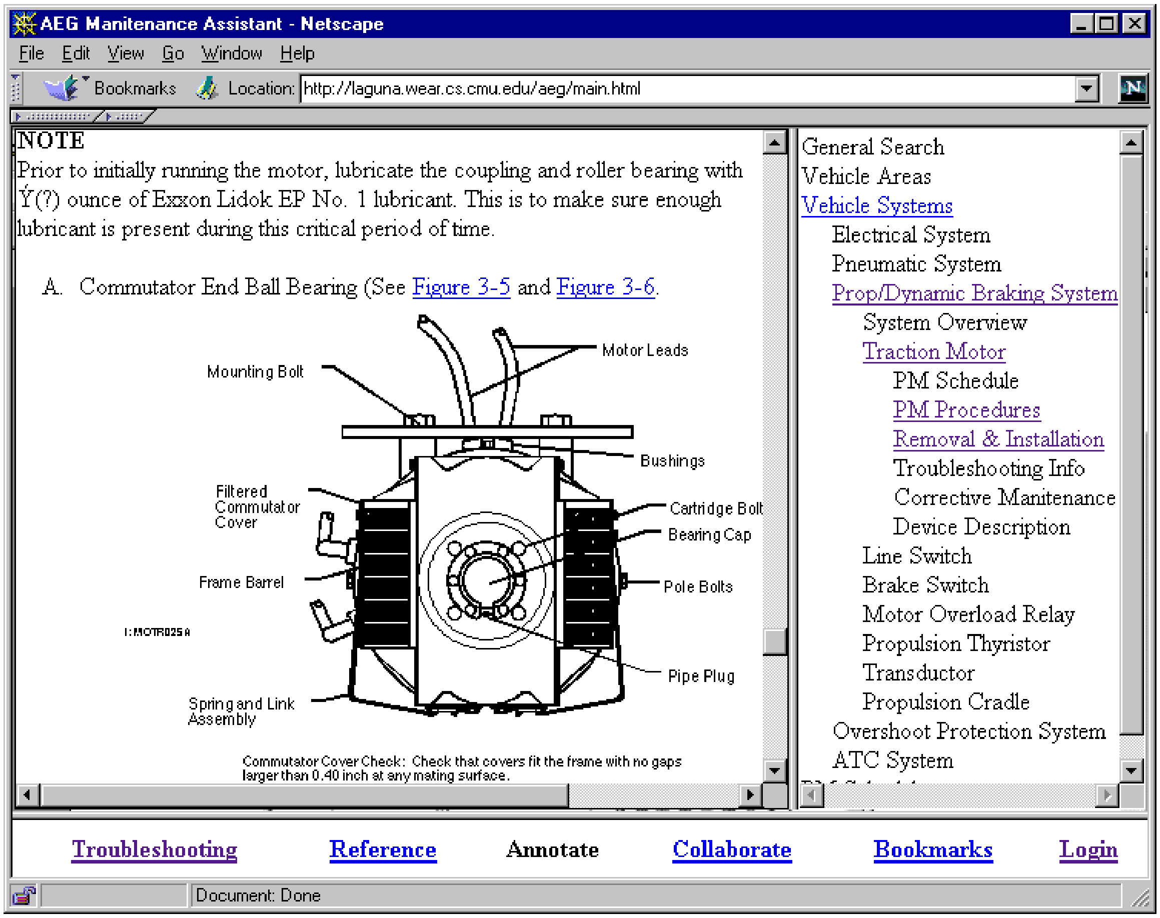

Figure 4 : Screen Sample for Reference Mode

4. HARDWARE PLATFORM

Our mobile computer includes a pen-based system, enhanced with a spread spectrum radio, voice transmission, image capture, and support for a VGA head mounted display. The current computer unit features a 100MHz 486DX2 processor; 16MB RAM memory; 260MB hard disk; two PCMCIA Type II slots; one serial, one parallel and one Infra-Red port; and grayscale 640x480 display. The PCMCIA slots are occupied by an AT&T WaveLAN or CDPD card, and

The IPhone software allows for near real-time voice communication and was the software of choice. The sound quality could be improved using a better compression technique. Communications to other sites requires the WavePoint computer to be connected to the Internet.

The Connectix Quickcam is used for image capture over a serial connector. The Quickcam comes with its own software, which copies the camera's output to the clipboard, or saves it as a bitmap or .tiff file. A second Planar color display, could be used for visual output. The Planar display was chosen due to its very

Subsystem	Parameters and Design Choices					
Base System		**Toolbox System with Pen Based Computer**	Wearable Computer (HMD) with Wireless Connection	Wearable Computer (HMD) with Direct Connection		
	Portability and Appropriateness	Yes	HMD Could Startle Passengers	HMD Could Startle Passengers		
	Communication with Server	Yes	Yes	Yes		
	Integrate All Components in an Easy to Carry Case	Yes	Yes	No		
Wireless LAN		**Spread Spectrum Radio**	**CDPD**	ARDIS / RAM	Cellular Modem	
	Latency	Low	Medium	Medium	High	
	Bandwidth	2 Mbps	19.2 Kbps	4.9 Kbps / 9.8 Kbps	9.6 Kbps	
	Coverage (Tunnels)	Good	Fair	Poor	Fair	
	Mobility	Good	Excellent	Excellent	Excellent	
Voice Communication		**Internet Phone (IPhone)**	Cellular	Web Phone		
	Sound Quality	Fair (With Compression)	Good	Poor (Static Compression Rate)		
	Cost	Initial Purchase Cost	Per Use Cost	Initial Purchase Cost		
	Privacy	Good	Good	Good		
Speech Recognition		**SSI**	TERI	IBM Speech		
	Response Time	1.05 times Real Time	1.15 times Real Time	1.2 times Real Time		
	Accuracy	96 %	90 %	95 %		
Display		**Fujitsu 500**	Planar Flat Panel	Head Mounted Display (Virtual Vision)	Sharp	
	Non – Obtrusive	Yes	Yes	Yes	Yes	
	Appropriate in Situation	Yes	Yes	No	Yes	
	Display Area	640 x 480 / 8.4”	640 x 480 / 10.2”	640 x 480 / 1”	800 x 600 / 8.4”	
	Integrated / External	Integrated	External	External	External	
	Number of Colors	256 Grayscale	16	Monochrome	4096	
	Power Consumption (Watts)	~ 7	10	3.5	12	
Video Capture		**CardCam PCMCIA Card w/ BW Camera**	Quickcam			
	Frame Rate	24 + fps	24 fps			
	Resolution	640 x 480 x 24 bit (16.8 Million Colors)	320 x 240 / 64 Grayscale			
	Hardware Footprint	1.5” Cube	2” Sphere			
Input Device		**Pen**	Touchscreen	Speech	Mouse	Trackball
	Speed	Fast	Fastest	Slow	Fast	Fast
	Size	Pen Sized	Integrated	Integrated	11 x 6.6 x 3 cm	4 x 11 x 15 cm
	Ease of Use	Good	Good	Best	Good	Good
Power Supply		**NiCd**	Alkaline	Lithium Ion	NiMH	
	Capacity / Energy Density	200 to 4000 mAh	2400 to 14000 mAh	1300 to 2250 mAh	550 to 3600 mAh	
	Physical Size (cm)	44 x 10.5 to 61 x 33.5	50 x 14.5 to 61.5 x 34	50.5 x 14.8 to 45 x 34	10 x 43 to 14 x 49	
	Weight (grams)	10 to 147	23 to 127	18 to 42	12 to 360	
	Reusability	2000 Times	N / A	1200 Times	Data Not Available	

Table 1. Design Parameters and Choices

wide viewing angle and large display area (10.2" diagonal).

5. WIRELESS COMMUNICATION SYSTEM

The AT&T WaveLAN card provides up to a 1.6Mbps to a WavePoint unit which is connected to a conventional LAN. This bandwidth is sufficient to support voice, image and data transmission. WaveLAN is based on direct sequence spread spectrum technology using Carrier Sense Multiple Access (CSMA) as the media access protocol. The proprietary antenna provided with the WavePoint unit can support several wireless WaveLAN units within a 600 feet radius. Using different antennas and amplifiers the range can be extended.

A single wireless solution does not fit both the train and the technician neither in propagation environment or in quality of service. The train is stationery in the maintenance bay during maintenance but during normal operation roams a track thousands of feet long. Trains also operate at high speeds, the one in the Pittsburgh International Airport operates at 32 miles per hour. The bay where the technician works on the train is a normal industrial environment calling for ruggedness and weather protection as well as raising propagation problems from steel structures and reflective surfaces. The track however is even more challenging as most trains run for extended periods in tunnels, frequently with little clearance between the tunnel and the train. Trains also are packed with people, making the car an impenetrable barrier to high frequency RF. Speed effects on propagation are made more severe by the waveguide effect of the tunnels.

The train and technician also have different service requirements. The total data rate needed by train sensors is relatively low. The Pittsburgh International Airport trains, for example, generate 160 separate sensor signals with an aggregate communication rate of about 1 Kbps. The latency requirements are also not demanding as a few seconds delay in transmission does not affect the usefulness of the data. Fig. 7 illustrates a screen dump of the diagnostic data.

For the technician, however, the service demands are high. We need to move images each way, e.g. schematic drawings to the technician and digital camera images from the technician to a remote engineer. In the Pittsburgh International Airport system these are compressed to approximately 100 KB per file. The latency requirement for easy cooperation was found to be about five seconds. Most challenging, however, is two-way voice communication. The technician expects voice communications to be telephone quality.

Figure 5: Software Architecture

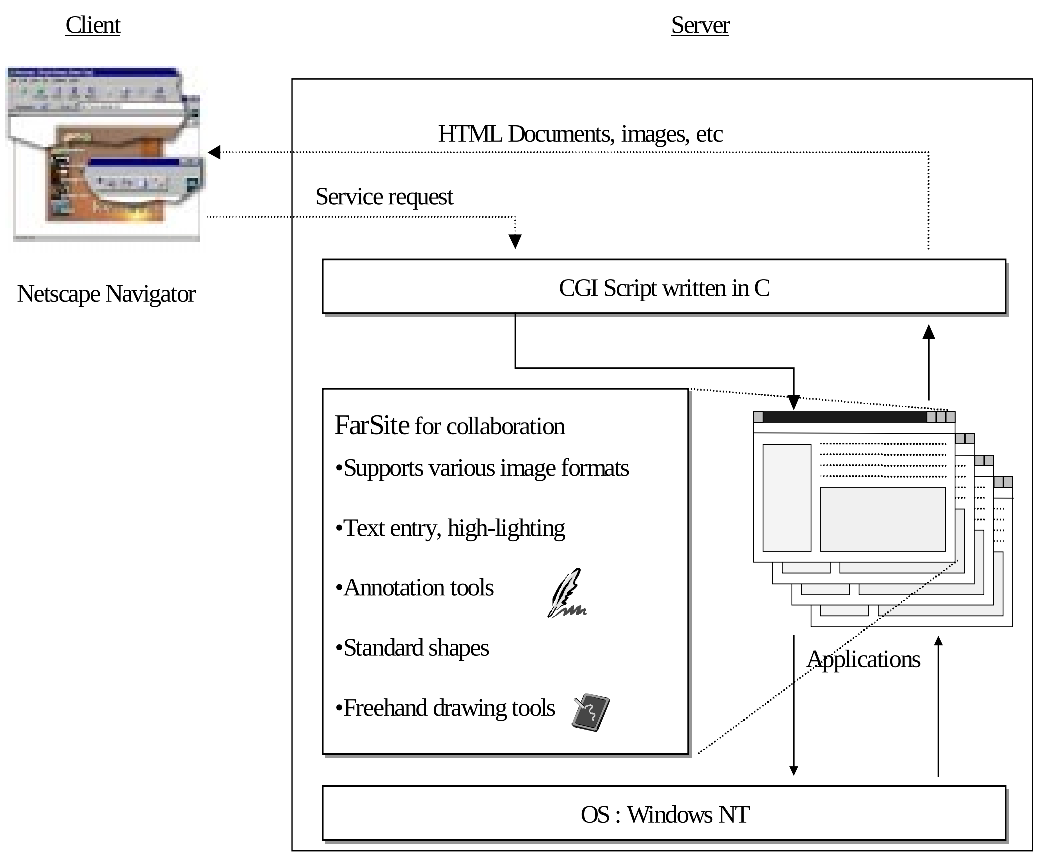

Fig. 6. A screen sample illustrating the People Mover diagnostic data

Based on all of the above, we selected CDPD [7] as the communication system with the train. CDPD uses the existing infrastructure of the analog Advanced Mobile Phone Service (AMPS) cellular telephone network to transmit data, utilizing idle channels in the cellular system to provide a connectionless digital data packet service. Therefore, it has coverage in airports and subways where trains operate, since service providers build reradiators to capture voice revenues. CDPD testing showed a consistent data transfer of approximately 11Kbps, except for the voice call interrupts. At such times, the data rate would momentarily drop to between 1 and 3 Kbps.

For the high bandwidth demand of the maintenance bay we selected WaveLAN from Lucent Technologies [8] as typical of a class of commercially available high bandwidth, shared spectrum technologies.

The challenge for both alternatives was using them for more demanding purposes in more demanding environments than they had been designed for. Both have been essentially used for white collar systems. We moved them to industrial and high-speed environments solving questions of performance and reliability, for example, by use of less common antennas, antenna diversity, better controlling channel selection for stability, and by creating a new packetized voice system.

Working with Bell Atlantic Mobile Systems, CDPD was enabled in the tunnel using two bi-directional antennas. The embedded computer used a Ubiquity CDPD modem attached to a Thinkpad computer. Connection was established to the cell site then carried by landline to Carnegie Mellon and Adtranz sites.

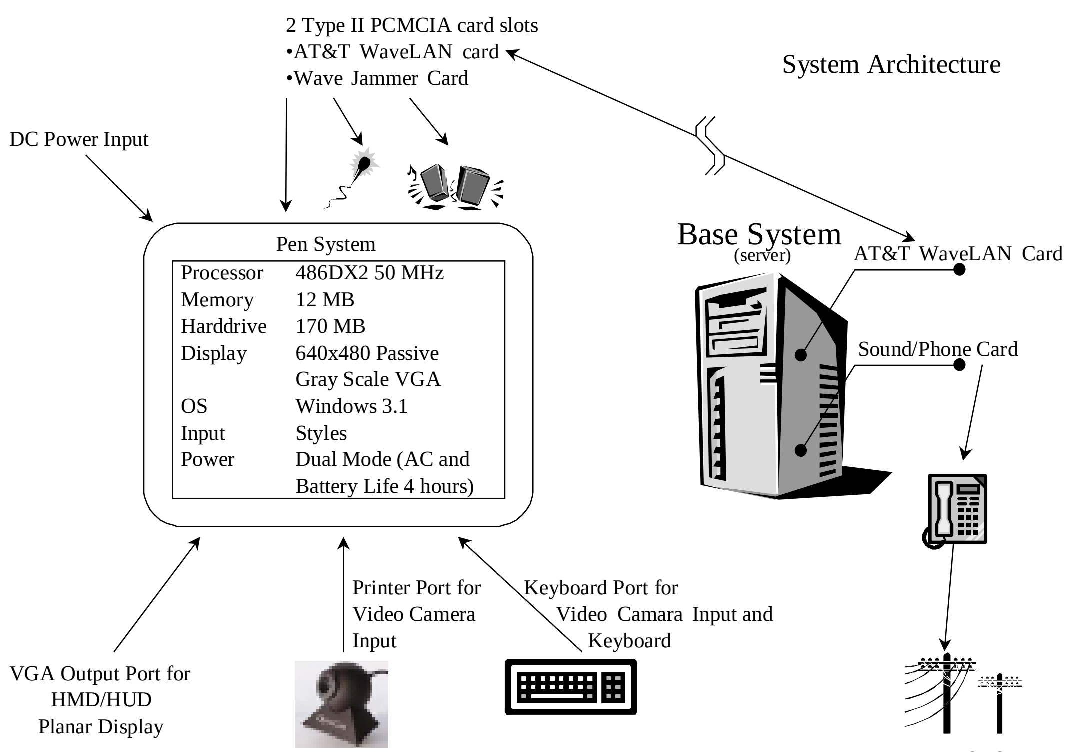

Figure 7: Hardware Architecture

Table 2 shows results of the Wavelan spread spectrum radio tests at the Pittsburgh Airport People Mover Tunnel. We measured the effective bandwidth, signal strength, signal to noise ratio with various antenna configurations. The bandwidth was noticeably lower than the nominal bandwidth (260 Kbps vs. 1.6 MBps). This was due to both the protocol overheads and the processor used in these tests.

Bandwidth (using FTP)	260 Kbps
Signal Strength	80 % at closest range. 35 % at 1000 ft. 5 % at 2000 ft.
Signal to Noise Ratio	75 % at closest range. 30 % at 1000 ft. 5 % at 1750 ft.

Table 2. Wavelan Spread Spectrum Test Results in Tunnel

Artifact	Conceptual Design (%)	Configurational Design (%)	Detailed Design (%)	Implementation / Integration / Evaluation (%)	Total Effort (Person Days)
Adtranz Mobile Computer	11	14	37	38	385

Table 3. Distribution of Design Effort

6. CONCLUSIONS

In this project, we have designed and built a mobile computer system to support maintenance and repair processes, as well as the collaboration with a remote expert. We provided the ability for a technician to retrieve information, navigate through it to follow particular working procedures, collaborate, and facilitate training. We have built a robust wireless communication infrastructure to support these activities. The system was field tested and demonstrated at the Pittsburgh International Airport people mover site. We have demonstrated the potential for use of CDPD as wireless communication infrastructure for train maintenance and control.

Table 3. shows the amount of effort that was put into this project. The total design effort was 385 person days. There were 24 students and six staff designers, representing electronics, software, mechanical, industrial, and HCI design. Most of the time was spent in the detailed design and implementation phases.

7. ACKNOWLEDGEMENTS

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