

# NASA's WIRELESS AUGMENTED REALITY PROTOTYPE (WARP)

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## Abstract

The objective of Wireless Augmented Reality Prototype (WARP) effort is to develop and integrate advanced technologies for real-time personal display of information relevant to the health and safety of space station/shuttle personnel. The WARP effort will develop and demonstrate technologies that will ultimately be incorporated into operational Space Station systems and that have potential earth applications such as aircraft pilot alertness monitoring and in various medical and consumer environments where augmented reality is required. To this end a two phase effort will be undertaken to rapidly develop a prototype (Phase I) and an advanced prototype (Phase II) to demonstrate the following key technology features that could be applied to astronaut internal vehicle activity (IVA) and potentially external vehicle activity (EVA) as well: 1) mobile visualization, and 2) distributed information system access. Specifically, Phase I will develop a head mounted display with a wireless communication link to the "station." Phase I will integrate a low power, miniature wireless communication link with a head mounted display and commercial biosensor. The Phase I design will emphasize the development of a relatively small, lightweight, and unobtrusive body worn prototype system. Phase II will put increased effort on miniaturization, power consumption reduction, increased throughput, higher resolution, and "wire removal" of the subsystems developed in Phase I.

## INTRODUCTION

The Wireless Augmented Reality Prototype was conceived in late 1996 as part of NASA's Office of Life and Microgravity Sciences and Applications (OLMSA) ongoing effort to develop technology capabilities to support humanities quest to use and explore space. Initiated in January 1997, WARP is a means to leverage recent advances in communication, display, imaging sensor, biosensor, voice recognition, and microelectronic technologies to develop a prototype system capable of real-time personal display of information relevant to the health and safety of Space Station personnel. The original concept for the system is depicted in Figure 1.



FIGURE 1. Original WARP Concept

WARP will allow an unteathered astronaut floating in the Space Station, and wearing a lightweight head mounted display (HMD) and outfitted with a suite of miniature biosensors to communicate through a two way wireless communications link to the Space Station communication infrastructure. On the miniature head mounted display (HMD) the astronaut will be able to view his or the other astronauts' biosensor data (e.g., heart rate or oxygen saturation), imagery (e. g., wiring diagrams), or text (e. g., instructions for how to perform CPR on another astronaut) transmitted from the Space Station or Mission Control on earth. A miniature camera worn on the astronaut will allow the viewing of his environment back on earth (e.g., a patient being administered to), and real-time video teleconferencing. Control of these various capabilities will be via voice commands and speech recognition software thus allowing hands free operation.

The Jet Propulsion Laboratory (JPL) is working in conjunction with partners at the University of California at Los Angeles (UCLA), and McDonnell Douglas Aerospace in the development of WARP. An initial prototype including a subset of the ultimate capabilities will be completed within one year to demonstrate the concept and technologies. This prototype is to be followed by a refined prototype with additional capabilities, reduce size and power requirements (resulting in smaller batteries), and incorporating emerging technologies (e.g., DARPA digital wireless camera, miniature color display technology, battery advances, and solar cell technology).

**SYSTEMS ARCHITECTURE**

In defining the system architecture, several approaches were investigated that could lead to a Phase I demonstration system sooner than the planned twelve month effort, while at the same time provide a sufficient capability for a representative demonstration and lead naturally into an advanced Phase II system. The requirements for the demonstration system are listed in Table 1 and a conceptual drawing is shown in Figure 1. The initial WARP system architecture that was settled on will provide for transmission of compressed video and audio from the base station to the astronaut. At the same time it will allow compressed audio and biosensor data to be transmitted from the astronaut to the base station. This approach is thought to be the fastest way to demonstrating the basic WARP capabilities. The transmission of video will allow the head mounted display on the astronaut to present the required biosensor plots as well as other basic PC functions operating at the base station, all via voice control. Essentially the astronaut will be controlling a PC at the base station remotely via the voice link and have the display remoted to his local head mounted display. This allows the astronaut to make use of the computational, storage, and connectivity capabilities available at the base station.

TABLE 1. Requirements for Demonstration System.

<u>High Level Requirements</u>
- build ASAP in order to demonstrate technologies and their capabilities
- miniature head mounted display (HMD) on IVA astronaut that resembles the original concept of Figure 1
- commercial biosensor data transmitted from IVA to base station
- voice link to/from IVA astronaut
- voice control of HMD display
- HMD must display biodata, imagery (graphics & text)
- must operate reliably in space station "metal box" environment
- must operate reliably while IVA astronaut is moving about space station
- size, weight, and power (battery powered) must be minimized on the IVA astronaut
<u>Derived Requirements</u>
- transmit compressed video of base station PC VGA display to get bio-data/graphics/text to IVA astronaut HMD
- communications link maximum range = 10 meters
- camera on IVA will be incorporated in Phase II

In an effort to build the WARP demonstration system rapidly, existing commercial-off-the-shelf (COTS) hardware and software are being utilized to the extent possible. The base station will utilize an industrial type passive backplane type PC equipped with off-the-shelf boards and voice recognition software. The communication link will require some development for the demonstration system, but to the extent possible commercial based chip sets are being utilized in the design. The video compression mechanism will be based on a standards based video compression product. The biosensor is being selected in collaboration with the NASA Ames Advanced Sensor Systems group and will be commercially available device. The head mounted display is a new design which concentrates on wearability (leveraging heavily off of existing product designs) by the industry leading manufacturer of

small lightweight HMD's. Integration of all these technologies into a fully functional reliable system is one of the key challenges of WARP.

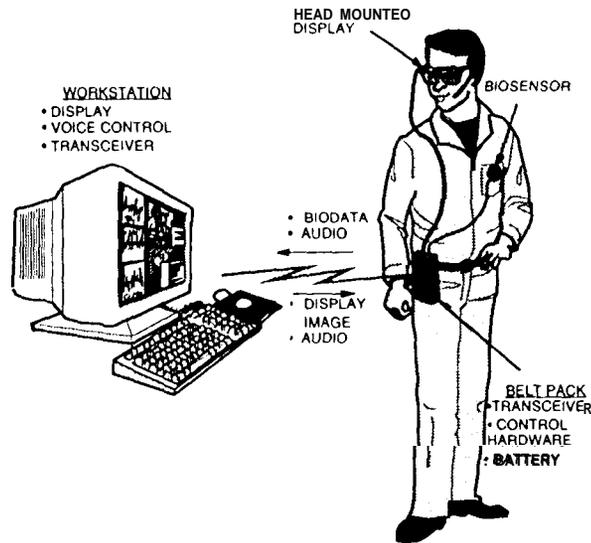


FIGURE 2. Demonstration System Concept.

Based on the basic system architecture a series of demonstrations have been devised that will allow the rapid validation of the system concept and an incremental building up of capabilities and improved functionality while experimenting and adding/eliminating options in order to optimize the system configuration. These demonstration systems are briefly discussed below.

#### Demo A

The first demonstration consisted of entirely commercial off-the-shelf belt-worn PC/HMD system running a software audio/video codec on the CPU. The belt-worn PC system has a wireless LAN connection to the base station PC. This 100% commercial system will allow us to evaluate a partial WARP capability implemented in a miniature commercial PC and at the same time provide a limited operational demonstration in the very short term. This demonstration showed the limitations of software codecs (low resolution, not motion friendly, require full processor), the bulkiness of current HMD's.

#### Demo B

The second demonstration was intended to be more representative of the ultimate WARP system in that it integrated a hardware audio/video codec together with breadboard version of the primary candidate for the miniature communication system. Additionally the base station computer was configured as it will be in the ultimate demonstration with a voice recognition operating system that was controlled via the wireless link. This demonstration, while quite large (e.g., rack mounted codecs) showed the feasibility of video codec based approach. The throughput performance and reliability of the communication system was tested (and determined that improvements are needed), and voice recognition software was shown to operate over a compressed audio link.

#### Demo C

Currently in the process of being fully specified this demonstration system will have a size on the order of a sub-laptop computer and have most of the desired WARP functionality as shown in the Figure 3 block diagram, but will not be fully customized to minimize power and size. Additionally Demo C will have the capability to transmit compressed video both to and from the IVA astronaut.

#### Demo D

This demonstration is being developed concurrently with Demo C and will result in a miniaturized belt worn version of the system shown in Figure 3 and will have improved communication system performance and improved video image quality. Demo D is the early initiation of the Phase 11 system.

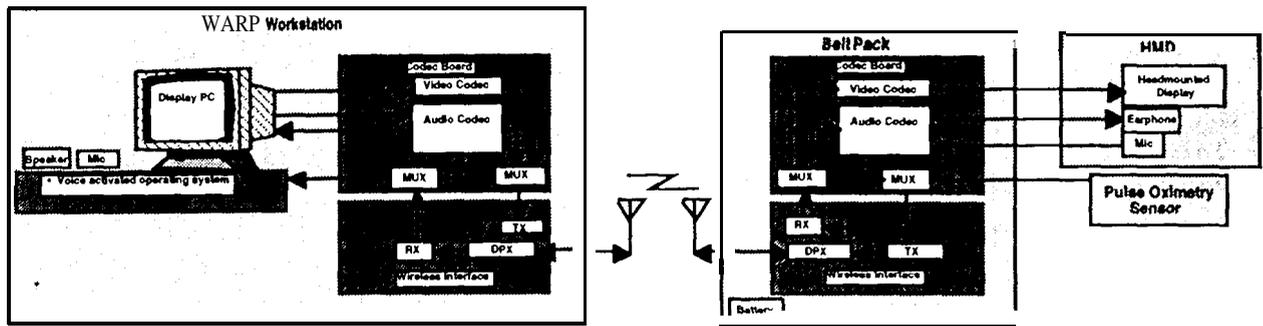


FIGURE 3. Demonstration System Block Diagram.

### COMMUNICATION SYSTEM

One of the greatest challenges in developing the WARP is designing a wireless communications system for indoor wireless communications that will perform reliably in the harsh environment of the Space Station. The first priority was to verify that in fact it is possible to communicate inside a "metal box" that resembles the space station environment. Through extensive testing of the communications system in a metal trailer "space station simulator" it has been shown to be possible and the results of these tests have been incorporated into the design of the demonstration system. This radio frequency communication channel is equivalent to operating within a large metal box which has the effect of the transmitted signal reflecting off of the metal surfaces and arriving at the receiver at different times thus creating destructive self interference. Methods of counteracting this interference that are realizable in a small, low power implementation are being investigated.

The communication system design that must operate in the very high multipath space station environment must necessarily utilize a non-coherent demodulation scheme because of the difficulty of tracking the phase in this environment. At the present time Differential Phase Shifted Keying (DPSK) and Frequency Shift Keying (FSK) have been tested and are candidates for the modulation. Spread Spectrum as well as antenna diversity techniques and retransmission schemes are also being investigated as means of improving the reliability of the communications link. Through a combination of these techniques it is expected that channel throughput greater than 384 kbps can be achieved. A variety of RF frequencies have been tested, but the determining factor in frequency selection will be availability a relatively large portion of spectrum in the space station that will allow the transmission of compressed video. It is believed the system stands a good chance of avoiding interference and of being certified in the 2.5 to 2.7 Ghz band..

The ability of WARP to build a miniature communication system in a relatively short period of time will necessarily leverage heavily off of wireless LAN technology that is currently available. The greatest potential for innovation is in the arena of internal space station high bandwidth wireless communications that would allow higher quality video to be transmitted to and from the astronaut. The demonstration system will necessarily utilize commercial components and should be able of achieving data rates approaching 1 Mbps in the space station environment. With an eye toward the future a collaboration has been initiated with UCLA under the WARP effort in which communication system designs and implementations that can reliably achieve 10+ Mbps data rates in the space station are being investigated.

### Preliminary Communication System Tests

Extensive, one-way, testing of breadboard 280 MHz and 2.4 GHz radio systems has been done both in the lab environment as well as a simulated Space Station module, consisting of a 40 foot fully enclosed metal trailer with various metallic obstructions. The basis for this breadboard system was the Harris Prism wireless LAN chip-set, using simple monopole antennas optimized for 280 MHz and 2.4 GHz, respectively. This chip set allows either differential BPSK or QPSK and implements a pseudo-noise code spread-spectrum radio with data rates up to 2 Mbps. The Prism system does not provide explicit multipath correction; however, the chips do have the capability to support antenna diversity, and receive-acknowledge protocols to retransmit faded data.

Another chip set, by Broadcom, was used in initial testing because of the potential it offered for achieving multiple megabit/sec data rates. Unlike the Prism, this system did allow for adaptive equalization within the digital functions of the baseband processor. The system did not perform well in the space station simulation, however. It is likely that the equalization technique used, developed specifically for performance in the fairly benign and steady-state conditions of a cable modem application (e.g., not Doppler frequency offset), could not adjust rapidly enough to the dynamic conditions of the simulator with moving human occupants.

The frequency-dependent aspects of signal scattering in the simulator trailer could be easily observed by looking at the received signal on a spectrum analyzer. The received spread signal exhibited varying numbers of 5-10 MHz bands which would dynamically peak and decay versus the overall pattern. The pattern of bands would change drastically from even small motions of people in the simulator, illustrating the large impact of having mobile RF absorbers (i.e., people) in the otherwise static environment.

The simulator test setup used a bit error rate tester to produce simulated data at the transmit end and display channel characteristics at the receive end, including individual bit errors detected. During a test, the receiver portion of the set-up (representing the astronaut) would be moved around in the simulator. It was possible to spatially locate areas where maximum interference was occurring by finding locations that produced the greatest amount of errors.

Various configurations were tested including: low (72 kbps) through high (1 Mbps) rate data, different transmit power levels, QPSK vs BPSK, and different spatial distributions of the obstacles and human observers. In all configurations it was easily possible to arrange the two ends of the test set up such that error-free performance could be obtained running over the course of hours. The distinguishing performance criteria between configurations were strictly the number, size, and depth of peak interference locations which could be found in 3-D space. With the best configurations, finding locations to produce any errors at all could be extremely difficult, and not repeatable. In poorly performing configurations, it was easy to find areas which could continuously produce errors.

Clearly, bit error rate performance of the tests were hard to quantify. Depending on location of the transmitter and receiver, the test set up could perform at better than 10<sup>-6</sup> or worse than 10<sup>-4</sup>. The BER experienced in a real-world situation would obviously be some average of the error rates achievable over all the spatial locations traversed by the astronaut during a WARP session. Reducing the number and physical size of the interference regions by choice of radio configuration would make it more likely that the astronaut belt-pack receiver would only cross a fading area momentarily before small movements of the astronaut's body would move it back into a clear zone.

The main result of the testing was to show that by far the most significant factor in reducing the number and size of interference locations was data rate. By example, one test compared the benefit of reducing the power amplifier output by 27 dB (@280 MHz) with the performance improvement obtained by reducing the data rate from 575 Kbps to 287 Kbps--an Eb/No difference of about 3 dB. Reducing the transmitter power output had little impact on the system performance. Reducing the data rate by half, however, produced an obvious improvement, going from a reasonably stable system with some interference points to a link in which almost no errors could be induced. The primary reason for such behavior is that when the data rate is reduced the bit period is lengthened and as a result the RMS delay spread of the received multipath signal becomes a smaller fraction of the bit period resulting in less inter symbol interference.

## **HEADMOUNTED DISPLAY**

The design of the head mounted display (HMD) began with the artist's concept image of a display and functional requirements. One of these requirements is that it be wearable for the performance of "normal" duties and for extended periods of time. For the headset, it was determined that COTS (commercial off the shelf) designs could not provide the wearability and functionality that WARP requires. After an extensive industry survey a manufacturer was chosen that could provide rapid prototyping and in-house design and fabrication; the design leverages heavily for its optics and circuitry on some of their former products produced for other government agencies and industry.

Design efforts focused on producing the most lightweight and wearable HMD possible and resulted in HMD shown in Figure 4. It will provide its wearer with video display, stereo audio, and a noise canceling microphone. Accommodation has also been made to allow the addition of a miniature video camera for future integration as communications bandwidth is available. The headset will weigh less than 3.5 ounces when completed, this is approximately 10 ounces less than similarly equipped headsets available that are "state of the industry." The Phase I headset will provide NTSC video through a single bounce optical prism.

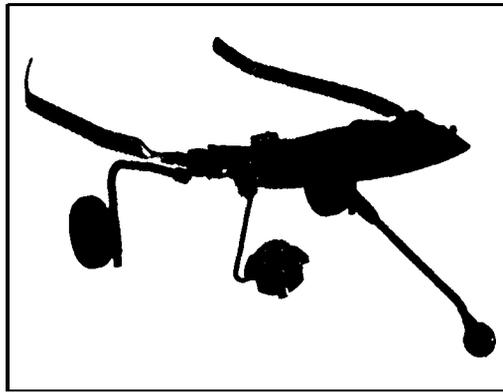


FIGURE 4. Mockup of Phase I Demo Head Mounted Display.

The HMD can be worn over prescription eyewear and with hi-focal prescription eyewear. The optic can be “flipped-up” out of the line of sight and the video display will go into “sleep” mode to conserve power until it is brought back down into the field of view; the audio and bio-sensor systems continue operating during “sleep” mode. This headset will not block peripheral vision which is an advantage for a device that is to be worn consistently. The headset also can be adjusted and “formed” to the individual’s head shape as needed. Also, the optic and display circuitry can be positioned for either right or left eye dominance. The Phase II HMD is planned to be VGA rather than NTSC in an effort to improve image quality.

#### **AUDIO/VIDEO CODEC**

The audio/video codec will be a single board, standards based codec that will accept analog audio and analog video (i.e., NTSC or VGA) and digitize and compress these inputs and multiplex the compressed data with an external data stream. The standards are: ITU H.261 based video, ITUG.722 bawd audio, and ITU H.221 based multiplexing. The base station A/V codec takes the base station PC display as the video source. The IVA codec outputs the received and decompressed base station display video on the HMD. The codec interface to the communications system is planned to operate at 384 kbps; of this 384 kbps the audio will utilize 32 kbps and the digital bio-sensor data will utilize 8 kbps with the remainder allocated to compressed video. The quality of the video at these data rates is equivalent to video teleconferencing quality video. The codec will be unique to the WARP effort in that it will be an autonomous stand alone board (i.e., no PC required for operation) and be reduced to a size commensurate with the belt worn system. Though the codcc technology exists to allow to make such a product no commercial boards currently available to meet these requirements.

#### **BIOSENSOR**

The serial type data interface on WARP provides reserved bandwidth on for bio-sensor data. The WARP Phase I system will incorporate a commercially available Pulse Oximeter sensor. This sensor will allow the measurement of pulse rate and oxygen saturation of the blood. Data from the sensor will be returned to the base station, recorded and can be displayed for the headset user or at the base station for observation by other astronauts. Phase H is planned to include an “on body” wireless human performance and fatigue monitoring system that permits candidate biosensors to communicate wirelessly with a belt-mounted transceiver/control module.

#### **CONCLUSION**

The WARP effort is now performing the detailed system design of the architected functionality. A baseline hardware design is nearly complete, though a number of questions still remain and are currently being addressed. Throughout this design effort testing to verify the performance of the candidate subsystem designs is on going. The WARP effort is entirely directed at building a demonstration system ASAP, and after this is accomplished second phase efforts will improve on the initial demonstration system by adding additional capabilities such as two way video. Additionally, subsequent to the final demonstration more thought and design effort will go into looking at the issues of translating the demonstrated technology into a design for an operational Space Station system including multiple access capability.

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