

Innovative Wireless Secure Data Transmission Technology (IWSDTT)

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ABSTRACT

In the past decade, the ability to connect and communicate with others via wireless technologies has extended beyond personal messaging to include various data paths and connection scheme(s) to support entertainment, commerce, military devices, and a myriad of other functions. With this rapid expansion, however, many challenges emerge. For example, systems that work to incorporate a wide range of wireless devices and technologies in a confined training space can quickly clutter the Radio Frequency (RF) space available in that environment. As such, many commercial technologies for short distance communication (Bluetooth, Zigbee, etc.) occupy the same RF space as higher performance wireless standards (802.11 a/b/g/n) and can cause random interference with one another resulting in significant data drop. In a tactical environment (including mission rehearsal), such interference and signal losses are unacceptable as war-fighters lives may directly depend on reliable communication and connectivity. Limited fidelity and transmission latency also have a big impact on training realism. Thus, the development of a modular, scalable, RF technology independent wireless high definition (HD) video transmission system, that supports remote high end graphics rendering Image Generation (IG), improves training realism, reduces equipment weight, and minimizes information dropout by managing the RF spectrum, will be a highly effective training solution in supporting war-fighters immersion in a wireless virtual training environment. This paper will explore the development and lessons learned of those critical capabilities that directly impact military training such as obstructed transmission range from the IG to Head Mounted Display (HMD), power source requirements, transmission security issues, as well as system portability and the integration of innovative technologies used in military training.

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INTRODUCTION

This paper reflects the research undertaken under a small business innovation research (SBIR) topic, A07-184: High Speed Wireless 3-D Video Transmission to Support Virtual Dismounted Training. The purpose of the research was to develop a system that would support existing components used in virtual soldier training systems, but remove the need for the trainee to carry their own graphics platform.

Troops on the ground interact with their environment at very close distances, much closer than that of aircraft or other vehicles in their operating environments. Traversing on the ground while using common obstructions for cover requires proximity to objects in direct contact with them. Achieving immersion requires a sense of realism with appropriate visual cues that closely mimic the real world. In a simulation environment, scene detail, such as ground and object surface textures, should have patterns that resolve to very small displacements (on the order of a cm or less). Object models should be of sufficient complexity to provide realism, using many polygons to replicate surfaces at short range.

Providing such level of detail will require state of the art high performance graphics processing with performance exceeding that of other training applications. While such computing platforms have made great strides in reducing platform size and power consumption over the last decade, the best processing commercially available technologies still require levels on the order of hundreds of watts. A single nVidia GTX680 processor (the latest consumer model at the time of this writing) consumes up to 195 watts while running a high performance 3D application [1]. These devices support modes of parallelism as well, allowing multiple graphics controllers to drive the same scene to improve fidelity linearly with little overall system cost increase (such cards sell on the order of \$ 500 each).

It is highly desirable with close combat training systems to allow such technologies to be readily available to the trainee, and allow for an easy upgrade path to take advantage of future advances in graphics technologies. As such, the intent of this topic was to research and develop a platform that would remove the graphics processing systems from the trainee, providing a high definition (HD) video link that accurately reproduces imagery from a stationary graphics engine. Support for other information required to complete the connection between the trainee and the simulation platform must also be provided. Data to support motion tracking, bi-directional communications (COMS) audio, simulated weapons or other user controls, and future man worn or held devices are all necessary pieces of a total wireless solution.

The most robust solution should also consume predictable, low power, and include capability to supply required power to other essential components of a total dismounted soldier training system so as to minimize battery components. Current state of the art helmet mounted display systems have resolution on the order of 1280x1024 pixels / scanlines. 1280x720 (including stereo) is also becoming a widely accepted format because of consumer HD technologies.

Such devices will eventually target HDTV (1920x1080) resolution as technologies used in microdisplays trend toward this popular consumer video format. As such, any wireless system developed to support current and near future helmet mounted displays should be capable of operating up to 1920x1080 resolution.

BACKGROUND

At project onset, a myriad of wireless technologies were being considered to create commercial standards for levels of bandwidth essential for quality transmission of HD video. Ultra-Wide Band (UWB) was being promoted as the path that offered the best potential. While a few UWB standard protocols were in various stages of development (802.15, for example), no one standard was emerging as a winner. The UWB Working Group formally disbanded shortly after this project began (2007), leaving the marketplace fragmented, forcing us to look elsewhere for appropriate technologies.

Early in this stage of UWB open competition, one vendor emerged with working prototype HD wireless video systems available for sale to developers. PulseLink released a set of transmitter and receiver pairs, packaged for typical stationary use. Details of their technology were available at a high level to understand their available video bandwidth. HD resolution support was possible using the prototyping kit. Testing in static operation (no motion between transmitter and receiver) worked as advertised, but it was quickly realized that obstructions between the multi-antenna transmitter and receiver caused significant signal dropout, which resulted in loss of video information (content and timing signals) at the receiver. Obstructions including moving persons were enough to cause noticeable signal and resulting video image loss. In order to demonstrate this technology, care had to be taken to maintain line of sight between the transmitter and receiver, so the transmitter was mounted high on a tripod and the receiver antennae were extended by coaxial cables to mount on the top of the HMD.

The PulseLink technology was advertised only as a UWB product, using patent pending data protocols that would support 500 Mbps data rates. The symptom of dropout during non-line of sight (NLOS) operation closely mimicked that of 60 GHz radio technology. 60 GHz radio technology offers the capability of obtaining Gbps data rates, as the Federal Communications Commission (FCC) spectrum provides ~ 7GHz of space within this open communication band. But, the short wavelength also comes with challenges. Attenuation of these ultra-high frequency signals through regular operating medium is great. Open air attenuation is on the order of 15 dB/km. Precipitation can add another 17 dB/km of attenuation. Indoor objects also provide signal attenuation that can greatly affect system operation. A single studded wall can yield attenuation of 27 dB through the wallboard and single wooden stud [2]. Techniques used to compensate for these losses have been tested in office environments, achieving mixed results. Line of sight (LOS) operation yields results that support Gbps data rate, but that performance drops off quickly with obstructions and moving objects (mostly people). The wavelength (~5 mm) can provide multipath reflections off objects, but signal integrity drops off rapidly when using alternate pathways than LOS [3]. As such, it was determined that 60 GHz radio technology's problems associated with obstructions would make it unsuitable for a man worn training system, where the trainee must be able to move freely around objects and other trainees.

A decision was made at this point to develop an RF technology independent design that would be capable of working with any new wireless data networking. 802.11 standards specifying data rates of 100 Mbps or more were emerging. At these rates, high quality transmission of high resolution video is possible with video compression.

Requirements

Given target data rates for various RF technologies, the following table outlines data compression requirements to carry various video formats on those data links.

Table 1: Data rate Requirements for Video and Other Data

Data Requirements (uncompressed)			
Telemetry Information	Amount of Data	Data Rate	
- Position / Attitude tracking (head, weapon, body)	3 x 16 x 32b @ 60Hz	0.09216	Mb/s
- Physiological Data	128 x 32b @ 60Hz	0.24576	Mb/s
- Hi Fidelity Audio	16b @ 44 kHz	0.704	Mb/s
- Microphone	16b @ 5 kHz	0.08	Mb/s
- Misc other data	1024 x 32b @ 60Hz	1.96608	Mb/s
Telemetry Total		3.09	Mb/s
* Video - 2 channel (up to 1600 x 1200)	2 x 1600 x 1200 x 24b @ 60Hz	5529.6	Mb/s
Total Data Requirements		5533	Mb/s
* Video - 1 channel (up to 1920 x 1080)	1 x 1920 x 1080 x 24b @ 60Hz	2986.0	Mb/s
Total Data Requirements		2989.1	Mb/s

We anticipate that all data sources on the trainee, other than required video, could require as much as 3 Mbps uncompressed data flow.

So, given this information, the following table summarizes data flow and data compression requirements for a high resolution stereo and single channel video as well.

Table 2 : Compression Ratios required for Stereo or Single Channel Video

Available Bandwidth per channel	802.11n Single Band	IEEE 802.15 Standard UWB Short 2.6m Range	802.11n Four Band	UWB (1.0) Short 3m Range	UWB (2.0) Short 3m Range (planned)	60 GHz Radio (planned, not yet specified)	
* Data Link Bandwidth - peak	150	480	600	1000	2000	5000	Mb/s
* Overhead for protocol, etc.	20%	20%	20%	20%	20%	20%	
* Net Useable Bandwidth	120	384	480	800	1600	4000	Mb/s
* Video - 2 channel (up to 1600 x 1200)	5533	5533	5533	5533	5533	5533	Mb/s
Data / Video Compression Required	46.1	14.4	11.5	6.9	3.5	1.4	:1 Ratio
* Video - 1 channel (up to 1920 x 1080)	2989	2989	2989	2989	2989	2989	Mb/s
Data / Video Compression Required	24.9	7.8	6.2	3.7	1.9	0.7	:1 Ratio

Achieving required compression ratios for various data link bandwidth could be accomplished using many techniques. Those used in broadcast video, for example, achieve good quality at very high compression ratios in order to fit within the limited transmission bandwidth available for over the air broadcast. However, the mechanism

that allows for high data compression also inherently introduces latency. Using multi-frame compression that sends periodic full (compressed) video frames with intermediate (delta) frames in between can limit required data transmission by determining the changes between successive full frames to create intermediate ones. The separation between full frame transmissions defines the minimum latency for such compression schemes.

In applications such as broadcast video, this latency does not create a problem for the viewer as they have no time of reference for when such video was initiated. In an application involving a viewer whose actions directly affect the imagery they expect to see, such latency is both noticeable and can cause unwanted conditions to occur.

A trainee in an immersive HMD environment may have many actions they perform that directly affect the scene they see. Head motion, body translation, or interaction with sensors (visual or other) or handheld devices (including weapons) can all induce changes to surrounding imagery. The trainee's initiation of any such change provides a point in time reference upon which the viewer will naturally expect a response. Introduction of latency can cause various undesirable conditions ranging from loss of the feel of immersion, to motion sickness (especially with regard to visual cues).

Since training systems rely upon some sort of computer generated scene components (image generator, video game, etc.), even a hard wired system will have some inherent latency. If such time intervals are short enough, latency compensation mechanisms may not be required. But, if total system latencies become too large, mitigation techniques (motion prediction, etc.) may be necessary [4]. It becomes highly desirable for the wireless transmission system to introduce minimal latency such that it alone does not add latency that would require latency compensation.

Current image generators or video gaming technologies require time equal to several video frames in order to fully render new scenes based upon trainee actions. A transmission system that adds significantly to this latency (even a single video frame) could easily require latency compensation to be applied. A system that would operate within the limits of sub-video frame latency would be ideal, as its added latency would be minimal in comparison to the graphics source.

Motion JPEG (Joint Picture Experts Group) video compression supports full frame video compression and can be tailored to operate with sub-video frame latency by breaking up the image into smaller blocks. The size, placement, and transmission order of the sub-blocks can then be handled in a manner that allows the decoder to reconstruct these pieces such that imagery is ready to display in approximately the interval that would be 1.5 times the sub-block interval within the video raster. This method requires that both encoding and decoding have parallel processing capabilities that allow multiple sub-blocks to be operated on simultaneously.

In a previous study, RPA performed a comparison between MPEG and Motion JPEG (M-JPEG) using a series of video sequences from an image generator. At lower compression ratios, both achieved excellent video reconstruction when compared on a pixel by pixel basis over each frame in the sequence.

Table 3: Reconstruction Performance of MPEG vs. M-JPEG of Various Scene Content

Test Case	Set Size in Bytes	Compression	Ave Difference	Ave Accuracy	Ave Norm	Ave Norm Acc
Day Road						
Original	1230782982					
M-JPEG Target 3.8	259662370	4.7399	0.0000%	100.0000%	0.0000%	100.0000%
M-JPEG Target 7.6	82025634	15.0049	0.5553%	99.4447%	0.1356%	99.8644%
M-JPEG Target 15.7	63993421	19.2330	0.6715%	99.3285%	0.1659%	99.8341%
MPEG 9	135710208	9.0692	2.8441%	97.1559%	0.6943%	99.3057%
MPEG 18	69187584	17.7891	11.8774%	88.1226%	3.2103%	96.7897%

Dusk Lights						
Original	1183596414					
M-JPEG Target 3.8	158926762	7.4474	0.0000%	100.0000%	0.0000%	100.0000%
M-JPEG Target 7.6	37707308	31.3890	1.5712%	98.4288%	0.0938%	99.9062%
MPEG 18	65902592	17.9598	9.4624%	90.5376%	0.5725%	99.4275%
Day Airfield						
Original	1081358850					
M-JPEG Target 3.8	284500094	3.8009	1.5840%	98.4160%	0.3823%	99.6177%
M-JPEG Target 7.6	142294433	7.5994	2.7400%	97.2600%	0.6811%	99.3189%
M-JPEG Target 15.7	68845037	15.7071	3.9809%	96.0191%	1.0024%	98.9976%
MPEG 5	199330816	5.4249	4.0422%	95.9578%	1.0280%	98.9720%
MPEG 15	71159808	15.1962	4.6022%	95.3978%	1.1707%	98.8293%

Developing a low latency, real time video compression / decompression device (CODEC) would allow for the system to take advantage of any RF technology, allowing the design to improve with continuous advances made in wireless communications (WIFI) data bandwidth.

Wireless Video Advancements

During the Phase 2 effort, several UWB related technologies were continuously monitored and began to appear in the marketplace. Wireless home digital interface (WHDI), Intel wireless display technology (WIDI), and WirelessHD are some of those that have been adopted by many users and made available for purchase. Of these, WIDI and WirelessHD operate in a 7 GHz band around the 60 GHz carrier spectrum. As previously mentioned, 60 GHz becomes greatly attenuated by obstructions, eliminating them as candidates for our man worn system. WHDI, however, operates in the 5 – 7 GHz spectrum, using multiple 20 MHz bands for each transmitter / receiver pair to achieve bandwidth required for HD video transmission. The 5 – 7 GHz band is that used by WIFI technologies such as 802.11n, among others, and is specified and designed to work in environments with many obstructions (such as in a typical office environment). WHDI specifies that it can support uncompressed HD (1920x1080) video at 60 Hz update rate. It does, however, convert video to a 4:2:2 format, one commonly used by HD studio and broadcast equipment. 4:2:2 does provide a form of compression allowing 4 adjacent (24b) pixels to be represented by 8 bytes of data instead of the 12 bytes provided in raw video format.

Given that WHDI is using the 5-7 GHz band, expectations were that this technology had a good chance of meeting the SBIR program goals. As such, the test system was adapted to incorporate a small form factor, high definition multimedia interface (HDMI) receiver into the portable unit.

Testing was performed on WHDI for both transmission capabilities (distance with obstructions and line of sight) as well as video reconstruction accuracy. With multiple walls (three drywall with a combination of steel and wooden studs) and moving people between the transmitter and receiver. In this test, it was found that 10 meters could be operated with good video transmission and reconstruction. Line of sight of at least 30 meters was also achievable.

Latency testing of the WHDI system was measured and found to be a constant 860 usecs. For a typical 60 Hz video frame rate (16.67 msec), the delay of less than 1 msec meets our goal of

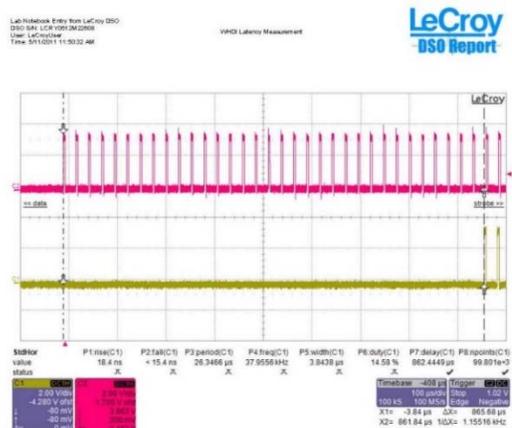


Figure 1: WHDI Measured Latency

sub video frame latency, and is less than what would have been achieved with the M-JPEG solution. The receiver video is always synchronized to the source in the WHDI transmission scheme, which eliminates problems that could occur with asynchronous video timing between transmitter and receiver as well.

WHDI performance was determined to be adequate for this SBIR program. Since WHDI has built in video format conversion, M-JPEG compression is not required. Portions of this development still were necessary for use with WHDI hardware components, however, to allow for interfacing to typical HMD systems in the marketplace, so these portions of video, audio, data, and power handling were maintained.

Support for Telemetry Information

Video standards exist for all of the expected resolutions and refresh rates that would be applied to HMD systems. Standards for other data sources that could be present on the trainee, however, generally do not exist.

Other man worn (carried) devices could include:

- Head motion trackers
- Body motion trackers
- Simulated weapons
- Communications (COMS) audio – bidirectional
- Simulation control devices
- Future devices – handheld, worn, mission specific, etc.

While standard hardware interfaces are often used for these devices (USB, Ethernet, RS-232/422, Bluetooth, analog, etc.), data protocols are generally device manufacturer specific. Such vendors offer specific software for their devices in the form of drivers or application programming interfaces (API) which must be used in the final system to accept the device data and route it to simulation software. All vendors offer this software for Intel x86 based platforms, and generally provide this for at least two operating systems (Windows™ and Linux). Since these interface must exist on the man worn (portable) portion of the system, it makes sense to provide x86 compatible support within that unit. With the prevalence of Intel processors in all types of personal computing devices, including handheld and other portable systems, there are choices to provide x86 compatibility and low power. Intel Atom™ processors have been specifically designed for low power operation.

This choice of CPU platform also can provide the hardware interfaces necessary for providing broad support for many man worn devices. USB, Ethernet, RS-232, and analog audio are providing directly from Intel Atom™ based systems.

Given that the interfaces to these portable subsystems are now remotely located from the host simulation system, a wireless communication path for this must be provided. The WHDI operates in the 5-7 GHz spectrum, which is also available to high data rate 802.11 WLAN components. To maximize the number of WHDI channels that can operate within range of one another, it is desirable to dedicate that spectrum to video transmission. Telemetry data is much lower rate than the video as can be seen by Table 1. In a nine player example, at roughly 3 Mbps data rate per trainee, at least 27 Mbps would need to be accommodated on the telemetry data link.

802.11g WLAN systems operate in the 2.4 GHz spectrum allocated for WLAN devices. It can also support up to 54 Mbps data rate [5]. This provides a 2:1 margin for the nine player example. Thus, by managing the RF spectrum of the total system, we can minimize interference of individual components and maximize the number of trainees.

In a wired system, the man worn devices would be connected directly to the host simulation system (or image source). In the wireless system, these components are remotely connected over the 802.11 WLAN. Special software can be developed to allow many such devices appear as though they are directly connected to the host computing system(s).

Security

Information assurance (IA) is a key requirement in any critical military computing platform. Training systems are critical technology and thus require such protections as necessary to their mission and connections into other military systems.

WHDI video transmission supports AES 128 bit encryption. Thus, all video information can be secured. The video transmission path is one way only, sending encoded and encrypted video data from the stationary transmitter to the portable receiver. The video path in itself provides no means to access the stationary components within the video transmission pathway.

In addition, while WHDI does have a limited bandwidth back-channel that connects from the receiver to the transmitter, this has additional layers of security possible. In addition to encryption, this data connection can be limited on the graphics source side to a dedicated purpose on the graphics hardware source to provided display identification information (EDID) only. This connection can also be completely severed if necessary and the graphics card sent local EDID codes, eliminating the RF back-channel connection into host computing platforms all together.

By handling all other telemetry over a standard 802.11g WLAN, standard IA practices can be applied. AES 128 bit encryption has been tested under real-time conditions without introducing latency which affects the overall system operation. DoD approved WLAN components can be used in compliance with military directives. And, software that monitors all data transmission can be incorporated that ensures only data expected by the total simulation system is present over the WLAN. Such data is known given the specific components and features used in the man worn portions of the training solution. This allows intrusion detection if any data detected over this RF data path does not meet anticipated data given the training system design.

CONCLUSIONS

Taking advantage of wireless technologies that can support both high resolution video and data associated with other man worn / carried devices can provide a total simulation system that is not limited by computing platform size, weight, and power tradeoffs. With a wireless system that can accommodate both current and future helmet mounted display (HMD) systems, the best possible simulation environment can be realized.

The stationary computing and graphics platforms can be upgraded regularly, as performance improves over time, without impact to the wireless system worn by the trainee. HMD's can also be upgraded as their performance improves towards HD resolution without impact.

With a low power x86 based CPU platform on the portable unit, new sensors, weapons, and other devices can also be readily upgraded or added to the total training system.



Figure 2: Man Worn Transceiver and Battery

Squad level training can be configured with nine video transmitter systems and one or two 802.11g WLAN channels all operating in the same area. Each trainee will wear a 3.5 lbs. device (total – receiver and 95 Wh battery) that can operate the receiver and HMD for a minimum of 4 hours. Support for stereo video operation can be accommodated via system configuration, which vary depending upon required video resolution. Future support for inherent HD stereo (as defined in the HDMI 1.4 specification) is expected in near term WHDI components.

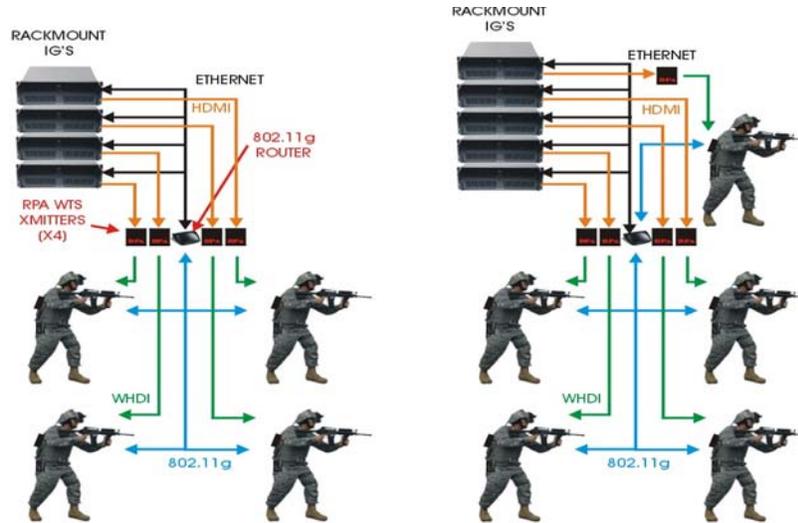


Figure 3: Possible Squad Level Wireless Training Configuration

In short, the application of the wireless transmission technology would significantly enhance the training experience by liberating the soldiers from tethering to the IG or, in the case of backpack applications, relieving the soldier from carrying heavy backpack computers with limited computing power. Using the HD wireless link supports the latest high end IG technology to further facilitate soldiers' immersion in the virtual training environment.

Such a system can meet all required specifications of a high performance wireless training application, including providing low latency video and telemetry data transmission and processing, SWaP (size, weight, and power) needs for portable operation, and a high level of security necessary to train critical missions and support all types of training system networking.

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