An Immersive Live / Virtual Bridge Approach with Ultra Wideband Tracking Technology: Phase II

Jay Saffold, Tovar Shoaf, Jason Holutiak
Research Network, Inc
Kennesaw, GA
jsaffold@resrchnet.com
tshoaf@resrchnet.com
jholutiak@resrchnet.com

Pat Garrity, Timothy Roberts
U.S. Army Research Laboratory-Human Research and Engineering Directorate, Simulation and Training Technology Center (ARL-HRED STTC)
Orlando, FL
patrick.j.garrity4.civ@mail.mil
timothy.e.roberts50.civ@mail.mil

ABSTRACT

The U.S. Army Research Laboratory-Human Research and Engineering Directorate, Simulation and Training Technology Center (ARL-HRED STTC) performs research and development in the field of live/virtual and immersive technology with real-time Ultra-WideBand (UWB) tracking technology. This technical challenge has been thoroughly researched for many years and recently UWB technologies have become more mature. The basis of these studies is that live soldiers must be accurately located while virtual soldiers must stay immersed all within a common real environment. A novel integrated system approach previously developed has been updated to take better advantage of new UWB tracking systems, inertial measurement units, and global positioning system sensors. These redundant tracking sensors with uncorrelated error sources have been intelligently fused in real-time and combined with existing inverse kinematic technologies related to immersive systems developed by STTC, to provide a fast update rate tracking solution with full body articulation. The UWB component has also been optimized to allow for faster update rates and more intelligent responder choosing algorithms with transitioning between responder zones in the physical area; with the benefit of reducing the total UWB infrastructure requirements. This paper discusses extending these ongoing efforts to a more simplified system design and initial experimentation to demonstrate an improved soldier tracking and telemetry system which offers seamless indoor/outdoor tracking capabilities for live/virtual bridging with sufficient accuracy for high fidelity demonstration at the STTC facility, Military Operations for Urban Terrain, and other physical locations applicable for dismount training. The solution to real-time 3D location with high accuracy (< 1 ft) suitable for augmented reality over operational environments requires redundant systems with equivalent accuracy (when available), uncorrelated error sources to provide at least one tracking modality in denied conditions, and a high update rate for real-time systems.

KEYWORDS

Dismounted Soldier, Locomotion, Mission Rehearsal, Virtual Environment, Immersion, Ultra-Wideband

ABOUT THE AUTHORS

Jay Saffold is the Chief Scientist for RNI and has over 32 years engineering experience in both military and industry research in game-based training, immersive systems, RF tags, ultra-wideband waveforms, virtual reality, digital databases, soldier tracking systems, millimeter wavelength (MMW) radar, multimode (MMW and optical) sensor fusion, fire-control radar, electronic warfare, survivability, signal processing, and strategic defense architecture. Mr Saffold is the lead developer of the Game Distributed Interactive System (GDIS) and Man Machine Interfaces for Simulation and Training (MMIST) system. He lectures annually for GTRI on remote sensing and signal processing. He holds a B.S.E.E. degree from Auburn University.

Tovar Shoaf is the Lead Software Engineer for RNI with 4 years of experience in the military simulation industry. He holds a BS in Game Development from Fullsail University (2011) which focuses on efficient, real-time input and processing. Prior to working at RNI he worked on flight reconstruction and analysis from both live and simulated flights. Since joining RNI, his main focus has been implementation and modification of software for man-worn tracking systems that fuse information from a range of sensors into stable position and pose data. He has also developed game engine interfaces, game-based trainers, mobile applications, and multiplayer servers. Mr. Shoaf's current interests include real-time position and pose tracking, immersive multiplayer simulation, simulation data recording and analysis, and software/hardware interface integration.

Jason Holutiak is the Lead 3D Artist for RNI and has over 5 years' experience in both military and industry research in game-based training, immersive systems, and 3D content creation for serious game applications. He holds an A.A.S in Multimedia and a B.S. in Computer Animation which focused on the design and implementation of 3D assets for games and film. During his time with RNI, Mr. Holutiak's main focus has been creating 3D virtual environments and assets based on real locations for Live and Virtual bridging demonstrations. His current focus has been the research and implementation of an automated virtualization process that creates game avatars from live humans.

Pat Garrity is a Chief Engineer at the U.S. Army Research Laboratory-Human Research and Engineering Directorate, Simulation and Training Technology Center (ARL-HRED STTC). He currently works in Dismounted Soldier Simulation Technologies conducting research and development in the area of dismounted soldier training and simulation where he was the Army's Science and Technology Manager for the Embedded Training for Dismounted Soldiers program. His current interests include Human-In-The-Loop (HITL) networked simulators, virtual and augmented reality, and immersive dismounted training applications. He earned his B.S. in Computer Engineering from the University of South Florida in 1985 and his M.S. in Simulation Systems from the University of Central Florida in 1994.

Timothy Roberts is a Science and Technology Manager of Dismounted Soldier Simulation and Training Technologies at the U.S. Army Research Laboratory-Human Research and Engineering Directorate, Simulation and Training Technology Center (ARL-HRED STTC). He currently works in Dismounted Soldier Training Technologies conducting research and development in the area of Dismounted Soldier training and simulation. His research interests include dismounted soldier training environments, games for training, virtual locomotion, multi-modal interfaces, path planning, control systems and robotics. He received a B.S. in Electrical Engineering and a M.S.E.E. in Control Systems and Robotics from the University of Central Florida.

An Immersive Live / Virtual Bridge Approach with Ultra Wideband Tracking Technology: Phase II

Jay Saffold, Tovar Shoaf, Jason Holutiak
Research Network, Inc
Kennesaw, GA
jsaffold@resrchnet.com
tshoaf@resrchnet.com
jholutiak@resrchnet.com

Pat Garrity, Timothy Roberts
U.S. Army Research Laboratory-Human Research and Engineering Directorate, Simulation and Training Technology Center (ARL-HRED STTC)
Orlando, FL
patrick.j.garrity4.civ@mail.mil
timothy.e.roberts50.civ@mail.mil

INTRODUCTION

The Army has been researching and developing technologies to track dismounted Soldiers in both outdoor and indoor environments for multiple years. Trainers at various training events need to have an accurate representation of the position and location of all the trainees during the event. Both outdoor and indoor tracking of dismounted Soldiers has been a key interest for the Army for years. Global Positioning Systems (GPS) has been shown to be the state-of-the-art location system that offers reliable outdoor location estimates (Fritsche, Klein, 2009). However in indoor environments, GPS does not work well. The inefficiency is due to the weakness of signals emitted by GPS and their inability to penetrate most building materials (Zhang, Xia, Yang, Yao & Zhao, 2010). For training in Military Operations in Urban Terrain (MOUT) sites, indoor tracking of Soldiers at the sub-meter accuracy is required as leaders must accurately know where their Soldiers are inside of buildings and other covered areas that GPS cannot track to determine whether Soldiers are making tactical decisions in the correct manner and are moving safely, tactically and correctly. Much research has been performed to find an accurate way of tracking dismounted Soldiers in indoor environments. Research programs have used multiple sensor integration to track indoors. GPS has been combined with wireless communications and Time-Of-Arrival (TOA) "Pseudolite" technology to provide location indoors of first responders and Soldiers (Brown, Lu, 2006). Inertial Measurement Units (IMUs), GPS, wireless video, sonar and rotary optical encoders have also been used to extrapolate GPS signals while indoors (Pham, Palaniappan, Mangold, Tracy & Wheeler, 2005). Others have used network assistance with GPS to track indoors (Brown, Olson, 2006). One technology that has been used for indoor tracking is Ultra-Wide Band (UWB) radios. The advantage of UWB is that it is a high accuracy system that does not have a line of sight requirement (Zhang, Xia, Yang, Yao & Zhao, 2010).

Soldier tracking is an important requirement for indoors, but a fully immersive and live tracking system has yet to be realized. An ideal tracking system would allow live soldiers to be tracked in both outdoor and indoor environments and would allow live/virtual bridging to occur allowing for leader visualization of the training event and an effective After Action Review (AAR). This would allow Soldiers and Leaders to review the live mission while viewing a virtual representation of the live events together. Man-wearable inertial based tracking systems can also be used to track not only a Soldier's position and location during the training event, but would allow Leaders to view each body position and to see the position of the weapon, type of body movement, and understand why an injury occurred or to help understand the intent of a Soldier's action. This paper discusses updates to a novel outdoor and indoor tracking system using UWB, GPS, IMUs and motion capture man-wearable systems to create a live/virtual bridging technology for real-time viewing of a live training event and an AAR capability for leaders and Soldiers. The updates relate to system components (hardware), self-survey techniques using the UWB units themselves, and implementation of second generation UWB tracking filters combined with optimizations for "weighted" location estimates produced from individual locations provided by the UWB and inverse kinematic (IK) algorithms applied to the IMU systems (IK-IMU).

BACKGROUND

For many years, the ARL-HRED STTC has been researching and developing tracking systems for indoor and outdoor training events, motion capture systems for bridging live and virtual domains, and developing AARs for increased training effectiveness. Man-wearable, virtual dismounted Soldier systems and AAR capabilities have been researched over the past ten years (Knerr, Garrity & Lampton, 2004). The ARL-HRED STTC has also been researching and developing motion capture based man-wearable, virtual-immersive dismounted Soldier systems for transforming a live Soldier's movements to an avatar's in the virtual domain. Virtual locomotion devices have been researched and developed (Roberts, Saffold & Garrity, 2012) to understand how to control a virtual avatar from a live Soldier's movements. For this live/virtual bridging tracking system to be realized, multiple UWB tracking systems were set-up around a training area to track a person in both outdoor and indoor environments. The person was outfitted in a wireless motion capture suit that comprised of 17 inertial based sensors that track the movement of each hand, upper arm, lower arm, head, chest, back, upper leg, lower leg and foot. The man-wearable, motion capture based suit developed at the ARL-HRED STTC uses commercial off the shelf technologies to translate the movement of a live Soldier to a realistically modeled avatar and replicate the live Soldiers movement in the virtual domain. The avatars movement in the virtual domain can then be recorded and played back in the virtual environment for an AAR allowing the Soldier to view what he/she actually did during the training event. The UWB tracking was used to gain the highest accuracy of the Soldiers position and location while the inertial tracking suit was used to gain the position and orientation of each limb of the Soldier while in the training event.

SYSTEM ACHITECTURE

The live/virtual bridge with UWB tracking technology is based on a family of subsystems available commercially. Each of the subsystems is integrated through standard connections and the Game Distributed Interactive Simulation (GDIS) system. In the phase II effort, two configurations were used. The first is an updated version of the fully immersive system discussed in the previous paper (Roberts, Saffold & Garrity 2013). The second configuration is a lower cost implementation that relies on UWB solely for position estimation. The key subsystem components and their main functions are described below. For the immersive configuration the key components were:

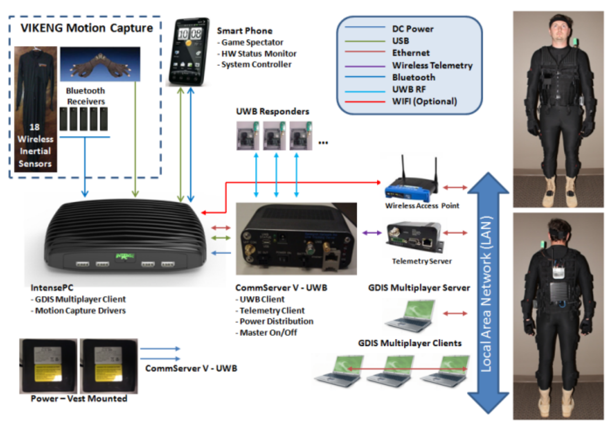

Figure 1. Live/virtual Bridge Architecture and Components (Immersive System)

- **Time Domain P410** - UWB Ranging
- **Virtual Immersive Kinetic Engine (VIKENG)** - Full Body Motion Capture and Inertial System based on the YEI Technologies 3-Space sensor suite.
- **Nexus Smart Phone** - Inertial (Gyro, Accelerometer), GPS, Magnetic Compass, On Board Rendering and Remote Client management
- **IntensePC** - Man Worn Computer
- **CommServer V – UWB**: Long Range Telemetry and master RF server with power distribution system (also houses the UWB query unit).
- **Power:** Two vest mounted 9000 mAH LION batteries
- **GDIS-Unity:** Multiplayer Client and Server with AAR, correlated database, and interface with LAN

Figure 1 illustrates the overall system and components used in the live/virtual bridge for the immersive system. Key data flow components are also shown. All tracking data (body / hand pose, orientation, and position) is consolidated on the remote client and the Nexus smart phone, through a GDIS Bluetooth interface extension, offers visualization and system configuration / status capabilities. With the "Gesture and Location" extensions (along with other GDIS extensions in SimBridge on the man worn computer) running, the GDIS-Unity system positioned, oriented, and posed the avatar in real-time and then sent the full body bone data along with location and orientation estimates back over the wireless network interface to the remote telemetry unit where it was relayed to the master RF server and then to the GDIS-Unity multiplayer server. The multiplayer server logged the messages while simultaneously broadcasting the remote client information to other GDIS-Unity stations on the live/virtual training network. AAR was achieved by playing back these logged data from the GDIS-Unity multiplayer server to the clients, including the remote client's mobile device providing true real-time distributed functionalities.

For the wireless motion capture system, the original version shipped with 3 dongles (Bluetooth servers). Out of the box, each dongle was programmed to handle 5 - 7 wireless sensors simultaneously, decimating the update rate from the server by the number of sensors on the Bluetooth channel (YEI Technologies, 2012). In the VIKENG implementation, two additional dongles were added (bringing the total to 5) in order to improve the update rate to 60 Hz. With the additional dongles, the wireless sensors were remapped to 5 on one dongle (the torso area) and 3 sensors each for the other 4 (arms, legs). The 5 sensor dongle is paired with the sensors that can stand to have a slightly lower frame rate than the rest, the bones that move the slowest.

The suit-less configuration is very similar to the fully articulated immersive system (Figure 2). The key differences relate to the removal of motion capture components, a smaller man-worn computer, the addition of a single wireless orientation sensor, and overall lower complexity. Of course, without the motion capture components this version relies on animations mapped from speed and direction calculations for in-game articulation. The suit-less configuration key components are:

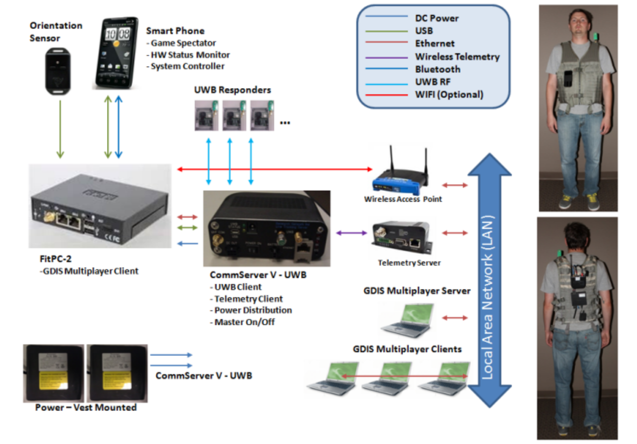

Figure 2. Live/Virtual Bridge Architecture and

- **Time Domain P410** - UWB Ranging
- **Nexus Smart Phone** - Inertial (Gyro, Accelerometer), GPS, Magnetic Compass, On Board Rendering and Remote Client management
- **Fit PC-2** - Man Worn Computer
- **YEI 3-Space Inertial Sensor** – Provides estimate of 3-DOF orientation of the waist
- **CommServer V – UWB**: Long Range Telemetry and master RF server with power distribution system (also houses the UWB query unit)
- **Power** – Two vest mounted 9000 mAH LiON batteries
- **GDIS-Unity** - Multiplayer Client and Server with AAR, correlated database, and interface with LAN

UWB Track Filter (2nd Generation)

Centroiding is an algorithm developed to limit the effect of occasional incorrect data caused by noise or poor calculations. This was the first generation track filter applied to UWB data in previous results. The algorithm finds the average of a set of points and then determines the closest point in the set to the average. When receiving UWB data from multi-lateration solvers, the value may occasionally be incorrect for various reasons (range estimate errors, responder failure, solver error, survey error) which can cause a large error in the final position. The centroiding algorithm is illustrated in Figure 3. In Figure 3, two of the eight UWB location estimates are very far from most of the others. If applied directly, the position calculation would have very large jumps to those points and back. If using an average alone the jump is lessened but still fairly large. By using the centroiding algorithm, a point very close to the dominant group is found. While there may be closer points that are not chosen, this algorithm does very well in eliminating outlying points effects. The current implementation performs centroiding on every eight position calculations.

In addition to the centroiding of raw position calculations, a sliding window average was implemented on the centroided result; the 2nd generation approach. This takes the average of a number of the most recent centroided position estimates to use as the final position. Using a sliding window means that every time a new centroid location is available, the oldest centroided location falls out of the window width and a new average is computed. There are always a constant number of points in the window. The result of this is that the position is behind by half the distance traveled between the first and last points. Figure 4 shows how the sliding window moves over by one centroided position each time it takes an average as a second step on centroided data in the 2nd generation UWB track filter. Each of the sliding windows shown will produce a single averaged position point. Figure 5 illustrates the result of the sliding window process. In Figure 5, one centroided point is illustrated that is inaccurate but because of the sliding window the single bad point only slightly affects the average. The key is to design the window width to be large enough to account for location anomalies while maintaining acceptable position latency. The current implementation averages eight centroided points (windowing sample count) which puts the position behind by about 0.45 seconds for the pulse integration interval (P_{II}) settings used on the UWB responders.

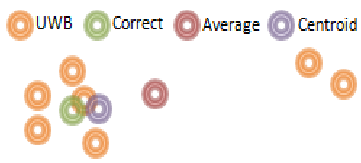

Figure 3. Centroiding Points

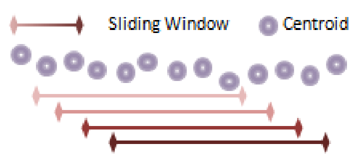

Figure 4. Sliding Window Average

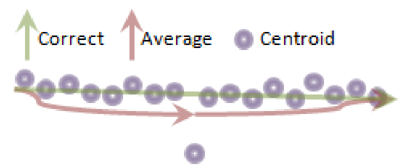

Figure 5. Sliding Window Result

The two stages of track filtering which define the 2nd generation UWB track filter have an impact on the effective system location estimate update rate and latency. The centroiding algorithm decimates the location estimate update rate by the centroiding sample count (N_{cs}). Similarly the sliding window, once an initial position is estimated, will cause the position estimate to further lag behind the real-time location by half of the sliding window sample count (N_{ws}). For a "raw position" estimate (before track filtering), the round robin must get an updated range estimate from one of the UWB units with a minimum processing time delay based on the P_{II} setting (T_{PII}). The unfiltered range estimates must then be converted to a raw position estimate using the selected solver (Levenberg-Marquardt least squares method). The time to solve is machine dependent and also a function of the initial estimate accuracy and the number of iterations used. For the trials used to develop this paper on the man worn computer, the solver time (T_{Solve}) was typically less than 1ms.

For a P_{II} setting of 6, the minimum query time for a range estimate is 13ms (Time Domain 2012). Thus the effective update rate (R_{eff}), corresponding time to position estimate (T_{pos}), and the position latency ($T_{Latency}$) can be estimated based on the P_{II} setting and the sample counts used for the centroiding and windowing from:

$$T_{pos} = N_{CS} * (T_{PII} + T_{Solve}) \quad (1)$$

$$R_{eff} = \frac{1}{T_{pos}} = \frac{1}{N_{CS} * (T_{PII} + T_{Solve})} \quad (2)$$

$$T_{Latency} = \frac{N_{ws}}{2} N_{CS} (T_{PII} + T_{Solve}) \quad (3)$$

The centroid and window sample counts were set to eight (8) which was found to be a good compromise between accuracy and motion characteristics. Table 1 illustrates the effective rates and position latency values for different settings of sample count.

Table 1. Effective Rate and Latency for Track Filter Settings

Centroid Samples	Window Samples	Eff Rate (Hz)	Latency (Sec)
1	1	71.43	0.007
4	1	17.86	0.028
8	1	8.93	0.056
1	4	71.43	0.028
4	8	17.86	0.224
8	8	8.93	0.448
20	20	3.57	2.8

For the data in this paper, the effective update rate for positions in the track filter was about 9 Hz while the position estimate lagged the true human's position by about 0.45 seconds. All position estimates are time- stamped to allow for correlation with other sensor data (including the real-time INU location estimate) that are available at different rates and time intervals.

Integration of Redundant Position Estimates

IK-IMU and UWB location data is time-stamped from the client clock and combined to accurately track a participant in short and long term intervals. IK-IMU has fast update rates and accurate short term position change information, but has compounding error over long periods due to drift. UWB location data has accurate position information but the collection and processing of the data is much slower and taken over a longer time span. The combination of the systems allows for the elimination of each systems limitations and constant, accurate position information is used. Figure 6 is an example of how the data may come in originally over a period of time. The IK-INU position estimate is drifting off from the correct position and the UWB data, while accurate, has large intervals between data points. In this example, the UWB data has already been processed and these data points are centroided and windowed estimates of positions at a past time. The IK-IMU drift has been exaggerated from any seen in the current system to better show the algorithms.

To achieve the most accurate position calculations from this data, the IK-IMU was used as a regular position update and then slowly correct it whenever UWB information is available. UWB position calculations are estimates of a past time so when they are received, their timestamps are behind by about half of their calculation time, close to half a second with current sample count settings. To apply the correction accurately we compare it to the IK-INU position we received at the timestamp of the UWB position rather than the most recent IK-INU position. This determines how far off our IK-INU position information was at that point in the timeline. Figure 7 shows the original data with correction applied. Where the IK-INU would have kept drifting off from the correct position, the UWB data correction pushes it back.

To keep the position from “snapping” back into place every time a UWB estimate is calculated, we apply the UWB correction to the current IK-IMU point at a speed defined in the GDIS application preferences. This creates an accurate, up-to-date position estimate that does not “snap” to a corrected position every time the UWB calculation is complete. Based on the defined speed of correction, the position calculation may be more accurate or more stable. Figure 8 shows how position information may look with three different “correction” speeds. Speed 1 is too slow to apply the needed correction before a new correction is calculated. In this example, speed 1 would result in indefinitely applying the correction, lessening the drift of the IK-IMU but not enough to negate it. Speed 2 is a perfect speed for the situation. It negates the drift completely and gives a stable corrected position only slightly offset from the correct position. Speed 3 is too fast of a correction. The position correction is applied in about half the time of a UWB calculation interval and then the drift moves it away from the correct position again. In real-world scenarios, the difference in positions throughout this example would be very small and with the correction being updated and applied every half second or so, the faster speed’s “jitter” would not be noticeable making it the more accurate option to avoid drift. For the results in this paper, a correction speed value of 0.3 m/s was used.

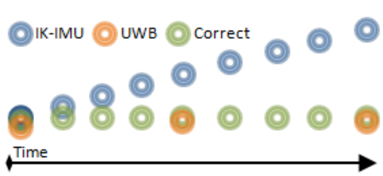

Figure 6. IK-IMU & UWB Position Estimates

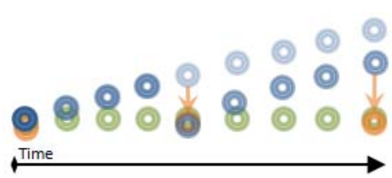

Figure 7. IK-IMU & UWB Position Fusion

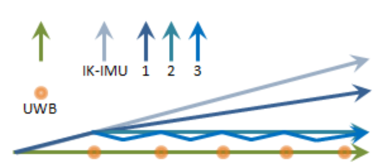

Figure 8. Positions with Varying Correcting Speeds

D-GPS would be used in combination with UWB to create the “correction” points that UWB is doing alone currently since D-GPS information will be available at a different rate. The UWB and D-GPS position estimates would be weighted according to the confidence of their calculated values and combined linearly by the weights. In most situations it is expected that one or the other will be the dominating component, UWB inside fitted building and D-GPS in clear outside areas with weighted transitions occurring when passing from one to the other. Of course, for indoor operations the D-GPS data is denied.

Due to high amounts of 2.4 GHz (Bluetooth and other devices) and 900 MHz (long range telemetry) wireless energy in proximity to the UWB query unit mounted on the vest, the cables themselves were also acting as antennas causing UWB USB connections to drop. To solve this, a Mini-Circuits VHF 2700+ High Pass Filter (coaxial from 2650 to 6500 MHz) was added in-line with the UWB antenna cable. RF chokes were also added to most power cables and other cables not in direct proximity to inertial units.

UWB TECHNOLOGY

The Time Domain P410 unit is a short pulse waveform used to achieve UWB ranging information (Roberts, Saffold, Garrity, 2013)(Time Domain, 2012). A set of range data is collected from surveyed responder stations and then used in a multi-lateration algorithm (similar to GPS receivers) to provide an estimate of the current position. The P410 units use a question and answer approach to determine the range. The onboard unit is controlled by a central computer and is programmed to question an existing responder at a surveyed location. If the responder receives this query, it time tags the question and then sends a time tagged response (with a known delay) back to the questioning unit. The response is then received and the questioning unit then processes the leading edge of the response to estimate the total round trip time delay from the original question message. This round trip time delay is then used to estimate the range separation between the questioning and responding unit. This approach (since not a broadcast) forces limits on data rate for question and answer "polling" to achieve the required number of range estimates to solve the non-linear system of equations. The effective update rate is further limited by the number of pulses (pulse integration index or P_{II}) the user chooses to integrate in order to achieve sufficient signal to noise ratio for detection of the response pulse's leading edge.

Using a round robin approach for the surveyed responders, the multi-lateration (Yang, 2002) – or in this specific case trilateration since range measurements instead of time difference of arrival are made – algorithms are applied to the range list based on a rolling window of values. Once the minimum number of ranges is achieved (3 for X, Y estimates), each time a new range estimate is added to the list, the algorithm takes all the range estimates in the list within a defined time window and uses them to estimate the new position. This approach allows a new position to be estimated without requiring a "re-poll" of all responders in the range list; thus updating position based on the addition of one updated range estimate.

The responder units were placed into key "magic triangle" zones in order to maximize the efficiency of the round robin algorithm and only the "best" four responders were used in the position estimate. After each new position was estimated, the GDIS software (UWB Extension) analyzed the current geometry of local responders to provide the best estimate of zone number, HDOP, and order of responder queries. Additional information in the UWB unit data structure were also used to estimate which responders were working well and which needed to be replaced in the next round robin. These data included estimates of signal-to-noise ratio, leading edge tracking quality, range error estimates, range estimate status enumerations, and range measurement type (Time Domain 2012). At the end of every round robin cycle, the system would poll a different responder unit not currently being used and its information stored in a "potential candidate" list for potential future use in the "magic triangle" zone.

SURVEY CHALLENGES

There is direct correlation between the accuracy of the UWB position estimate and the accuracy of the survey of the responder units (Roberts, Saffold, Garrity 2013). The location of the UWB responder units not only needed to satisfy coverage and Geometric Dilution of Precision (GDOP) (Langley, 1999) but also needed to be surveyed to a precision suitable to meet accuracy requirements. In outdoor environments – which are relatively free of stationary clutter – this was relatively straight forward. In indoor locations – where there was a significant amount of stationary clutter – this was quite challenging. Indoor facilities in the real world have a number of blocking items (cabinets, televisions, etc.) which not only affect line-of-sight (LOS) RF signal propagation but also make it difficult to directly measure distances from responder units and local coordinate system survey points. In order to provide

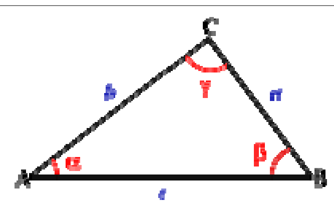

Figure 9. Law of Cosines Triangle Used in UWB Self Survey Modes

estimates of new survey points, a self-survey algorithm was implemented which used two known survey positions and the UWB range estimates from a new location to provide the X,Y data of the new survey point. For the unknown location, the height of the unit was directly measured and then the range to the two baseline points (A, B) from this location (C) was estimated using the P410 units. This formed a triangle with the length of each side known. From this triangle, using the Law of Cosines (Hazewinkel 2001) and the measured height of each of the vertices, the new X, Y position at C could be computed.

The vertex distances to the unknown unit (C) from the two baselines (A, B) were calculated based on an average of 100 ranging estimates from the two known baseline units at A and B. The height data of each of the units in the "triangle" were flattened to place them all on a common horizontal plane. This flattening was also applied to the range estimate data in order to solve for the relative angles between the two baseline units and the unknown unit. If the variance of the range estimates was high, the ranging data was reinitiated until it was acceptably low (below 0.020 meters). As more new units became surveyed in, new baselines were defined allowing "leap-frogging" throughout the entire area where line-of-sight was lost to the original baseline units. This is common practice used by commercial surveyors as well. Visual inspection of the estimated X, Y values for the unknown unit was used to resolve the ambiguity with co-sinusoidal vertex estimation.

LIVE/VIRTUAL DATA CORRELATION

Another major challenge with the live/virtual bridging system relates to coordinate systems and units conversion between the world system and the virtual system. In order to achieve this correlation, one requirement was that the instrumented human subject "spawn" in a known location (matched between live and virtual databases) and orient themselves in the same directions in both worlds. This allowed the establishment of relative offsets from start for the remainder of the data. Since the compass measured data relative to true magnetic north, this offset was critical in achieving the avatar orientation correctly when walking forward, backward and strafing from side to side. This known "tie point" between the live and virtual data sets was critical to keeping track of the avatar in the live/virtual bridge system.

All estimated position data was then referenced to a known spawn location which established the relative offset points in the virtual data base and the live data calculations. A (0,0,0) reference was established in the virtual data base units. The virtual data base also used units of 1 meter per grid point (1 unit in virtual is 1 meters in live) to position the avatar according to the tracking solutions used.

Figure 10 is a screen capture from GDIS-Unity during the live trials near an indoor transition region between Rooms 1 and 2. This was correlated visually to the live test area zone in Figure 10. The avatar was visually noted in the correct location and the full body pose was similarly visually noted. Both during the live trials and AAR session, all clients on the live/virtual training network were able to view the test subject mapped to the virtual environment and avatar in a similar fashion as he passed over key landmarks correlated in the live and virtual fields.

Figure 10. Live and Avatar Correlation at Test Facility

RESULTS

The live instrumented test course was designed to test seamless live/virtual bridging and tracking in indoor and outdoor areas. For the tests, a government test facility was used which offered consecutive areas and clear transition paths between indoor and outdoor locations. This facility was also not specifically designed for demonstration of tracking systems and as such had a number of "normal" indoor clutter items such as stands, posters, network equipment racks, metal cabinets, etc. which offered a real challenge to remote sensing units (UWB systems) as well as magnetic systems which can suffer when in proximity to large metal (ferrous) objects. The test facility also had a number of 2.4 and 5 GHz RF signals present in the environment originating from wireless access points and wireless video controllers which are part of day-to-day operations. As such, the UWB system component was forced to operate in a less than ideal (but not necessarily atypical) RF environment.

For the tracking tests, the subject was asked to move in specific geometric patterns and perform free form "walk-abouts" with emphasis on transition areas between rooms, room stationary objects, and indoor / outdoor boundaries. Towards the end of the experiment, the subject was asked to walk "grid patterns" to demonstrate any gaps in the coverage area and force different solutions of the redundant tracking sensors to be exercised. At a number of locations the subject was asked to stand perfectly still to demonstrate the stability and resolution capability of the system and evaluate random error components.

Figure 11 and Figure 12 illustrate the results using the different versions of the UWB track filter during a "walk-about" in Room 1. "Remote 123" is the ID tag of the man-worn UWB query unit. Location points in "pink" were UWB location estimates flagged as potentially inaccurate (weight value less the 0.25). The position "weight" was based on a number of factors including solver error estimate, HDOP of the responders, distance from previous position, and the average weight of the responder range values used in the solver estimate.

The raw data illustrates no clear "walk" pattern due to the "noise" associated with the UWB ranging estimate, survey error, and solver iterations. The raw data was then filtered according to the 2nd generation UWB track filter implementation of centroiding and windowing. With the 2nd generation track filter the subject's walk pattern becomes much clearer and the number of "bad locations" is significantly reduced.

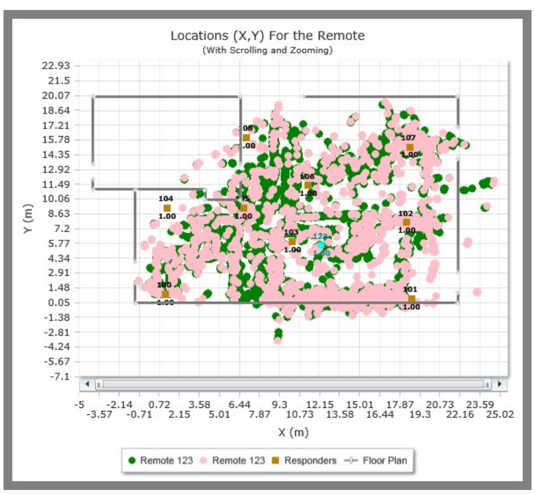

Figure 11. UWB Locations in Room 1 – Walk About – Raw Data

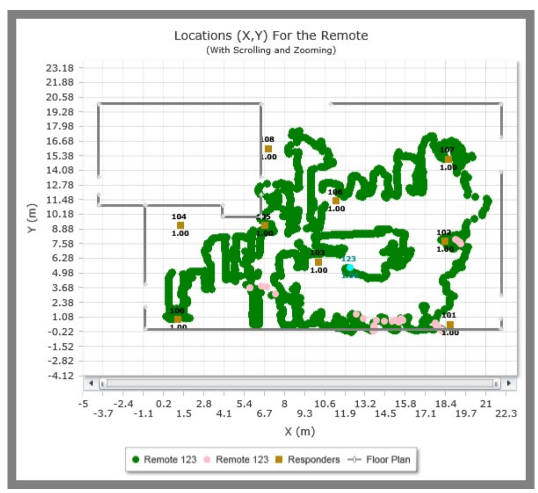

Figure 12. UWB Locations in Room 1 – Walk About - 2nd Generation Track Filter

For the stationary test, both a human standing still and the "vest" dismounted and placed on a chair were used. The chair data are illustrated here. The data from the human standing still is very similar with only a fractional increase in variance. The raw data for the stationary test (Figure 13) indicated good stability of the UWB system over the 2 minute window albeit with some residual position error. The standard deviation of the location data in X and Y dimensions was 0.037 meters and 0.088 meters respectively. From the stability test raw data some bad location estimates are still noted even with the self-survey implementations. The raw location distributions appear very close to Normally distributed indicating that good performance should be achieved with the 2nd generation track filter. Figure 14 illustrates the results for this stationary test with the 2nd generation UWB track filter applied.

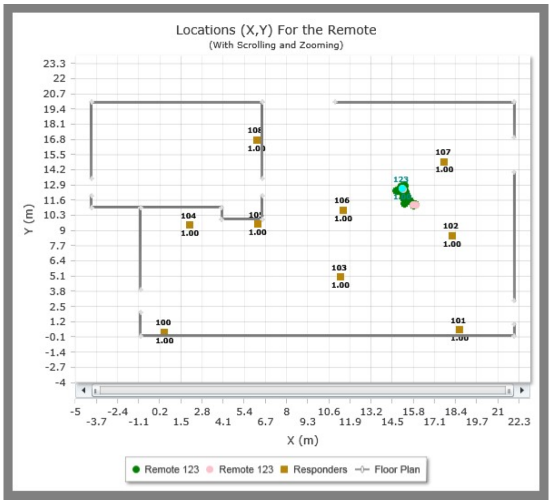

Figure 13. UWB Locations in Room 1 – Stationary - Raw Data

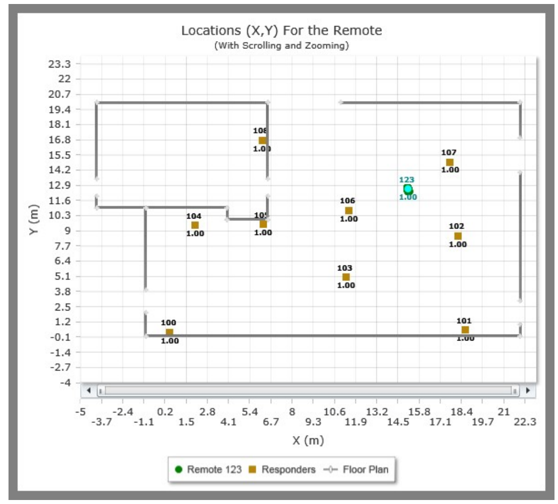

Figure 14. UWB Locations in Room 1 – Stationary - 2nd Generation Track Filter

The track filtering cleaned up the location results significantly over the raw data. Not only are the bad locations eliminated, the standard deviation of the location data in X and Y dimensions was reduced to 0.020 meters and 0.051 meters respectively. The HDOP associated with this unit location was 1.52.

SUMMARY AND CONCLUSIONS

In this paper, a system used for live/virtual bridging in real-time is described and preliminary results of experimentation are presented with track filter and configuration updates. Further study is needed to truly optimize the system components for (a) improved accuracy and (b) improved update rate; however the results presented using the described updates are promising and clearly demonstrate the proof of concept of a real-time live/virtual bridge with AAR. A number of the subsystems discussed are very mature and used regularly by both military and industry for motion capture and real-time telemetry. The UWB system is still considered a research system as demonstrated by the lack of ruggedization in the enclosures, the boards, and the unit level performance. This activity represents only the second phase of this research and additional experimentation and higher levels of system integration will be accomplished in later phases.

While the trial set presented is too low to draw any broad conclusions, the data indicated a number of trends that should be verified over a statistically valid set of trials, conditions, and controllers. Of course, the utility of a live/virtual bridge technology (with AAR) must also be weighed against the specific requirements associated with an application (like augmented / mixed reality) or training exercise. Based on the limited data set and trials, the following key trends were noted:

- Live/virtual bridge and AAR requires rigorous correlation of the virtual database and the subject's position and orientation during spawn and calibration were critical to achieve visual correlation and AAR.
- The UWB tracking system performed well in most areas demonstrating better than 5 cm stability in X and Y position estimates.
- Additional processing using the 2nd generation UWB track filter significantly improved UWB location performance under all configurations and conditions.
- Using the UWB units in a self-survey mode allowed installation time to significantly be reduced and provided for good location estimate results.

- Using full body avatars is not precise enough to quantify location errors which are less than about ¼ the width of a human body (or virtual representation) so stability and resolution tests were performed using a "dismounted" unit on a chair.
- The real time motion capture (VIKENG) was seamless and updated the avatar body well during all trials even over the lower-bandwidth long haul telemetry system.
- The inertial systems performed well over very short periods of time (< 3 sec) in estimating location and over long periods of time estimating orientation. The VIKENG system position estimates using inverse kinematics (IK-IMU) also worked well over short term time windows.
- Subjects clearly navigated the live environment with ease and the system instrumentation did not cause any significant hindrance to primary locomotion modes.
- The AAR system demonstrated good correlation with the live event data and played back well on the distributed network.

REFERENCES

Brown, A. K. & Olson, P. (2006). Urban/Indoor Navigation using Network Assisted GPS. NAVSYS CORP Colorado Springs CO.

Brown, A., & Lu, Y. (2006). Indoor Navigation Test Results using an Integrated GPS/TOA/Inertial Navigation System. NAVSYS CORP Colorado Springs CO.

Fritsche, C. & Klein, A. (2009). On the Performance of Hybrid GPS/GSM Mobile Terminal Tracking. In *Communications Workshops, 2009. ICC Workshops 2009. IEEE International Conference on* (pp. 1-5). IEEE.

Hazewinkel, Michiel, ed. (2001), Cosine theorem, Encyclopedia of Mathematics, Springer, ISBN 978-1-55608-010-4

Knerr, B. W., Garrity, P. J. & Lampton, D. R. (2004). Embedded Training for Future Force Warriors: An Assessment of Wearable Virtual Simulators. Army Research Institute for the Behavioral and Social Sciences Orlando, FL.

Langley, R. B. (May 1999). Dilution of Precision. GPS World.

Levenberg, K. (1944). A Method for the Solution of Certain Non-Linear Problems in Least Squares. Quarterly of Applied Mathematics 2: 164–168.

Pham, P. T., Palaniappan, R., Mangold, L., Tracy, J. and Wheeler, A. (2005). Development of a Low Cost Mobile Platforms for Indoor Tracking, Navigation and Geo-Location. Army Tank Automotive Research Development and Engineering Center Warren, MI.

Roberts, T., Saffold, J. & Garrity, P. (2012). Virtual Locomotion Concepts and Metrics Study: Experimentation and Results. In *The Interservice/Industry Training, Simulation & Education Conference (I/ITSEC)* (Vol. 2012, No. 1). National Training Systems Association.

Roberts, T., Saffold, J. & Garrity, P. (2013). An Immersive Live / Virtual Bridge Approach with Ultra Wideband Tracking Technology. In *The Interservice/Industry Training, Simulation & Education Conference (I/ITSEC)* (Vol. 2013, No. 1). National Training Systems Association.

Siwiak, K. (2001). Ultra-Wide Band Radio: Introducing a New Technology. In *Vehicular Technology Conference, 2001. VTC 2001 Spring. IEEE VTS 53rd* (Vol.2, pp. 1088-1093). IEEE.

Time Domain, Ranging and Communications Application Programming Interface (API) Specification Version 2.1, PulseON™ 400 RCM, 320-0282E, June 2012

Yang, Y.E., Baldwin, J.,Smith, A., Multilateration tracking and synchronization over wide areas, Radar Conference, 2002. Proceedings of the IEEE

YEI Technologies, YEI 3-Space Application Programming Interface (API), 12 April (2012) from http://www.yeitechnology.com/yei-3-space-application-programming-interface

Zhang, D., Xia, F., Yang, Z., Yao, L & Zhao, W. (2010). Localization Technologies for Indoor Human Tracking. In *Future Information Technology (FutureTech), 2010 5th International Conference on* (pp. 1-6). IEEE.