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

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ABSTRACT

The U.S. Army Research Laboratory, Human Research and Engineering Directorate, Simulation and Training Technology Center (STTC) have been performing research and development in the field of live/virtual and immersive technology with real-time Ultra-Wide Band (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 has been developed which takes advantage of new UWB tracking systems combined with existing technologies related to immersive systems developed by STTC. This paper discusses extending these ongoing efforts to develop, test, and 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 Army facilities, Military Operations in Urban Terrain (MOUT) sites, and other physical locations applicable for dismounted training. The location technology is a component in a family of systems available on military equipment. The solution to real-time 3D location with high accuracy (< 1 ft) suitable for augmented reality over all operational environments requires redundant systems with equivalent accuracy (when available) and uncorrelated error sources. The family of redundant system's approach allows for development and demonstration of fused information from an UWB Radio Frequency (RF) tag, assisted Inertial Measurement Unit (IMU), Global Positioning System (GPS) and integrated into common training interface components. The baseline set of motion capture, tracking, real-time processing, and After Action Review (AAR) capability described is based on existing Original Equipment Manufacturing (OEM) products and years of experience with immersive training multi-modalities, and development of serious games for training.

KEYWORDS

Dismounted Soldier, Locomotion, Mission Rehearsal, Virtual Environment, Immersion

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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. Many 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 has also been used to extrapolate GPS signals while indoors (Pham, Palaniappan, Mangold, Tracy and 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).

UWB radio is the generic term describing radio systems having very large bandwidths, for example, “bandwidth greater than 25% of the center frequency measure at the -10 dB points” or “Radio Frequency (RF) bandwidth greater than 1 GHz,” (two definitions under consideration by the U.S. Federal Communications Commission (FCC)) (Siwiak, 2001). UWB is a radio technology used for transmitting information spread over a large bandwidth which should allow the spectrum to be shared with other users.

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 so everyone could review what the Soldier did during the training event. Man-wearable inertial based tracking systems can also be used to track not only a Soldiers 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 Soldiers action. This paper discusses 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.

BACKGROUND

For many years, the 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 (Dean, Garrity & Stapelton, 2004) (Knerr, Garrity & Lampton, 2004). The 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, 2010) (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 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 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. The key subsystem components and their main functions are described below.

- **Time Domain P410** - UWB Ranging
- **Virtual Immersive Kinetic Engine (VIKENG)** - Full Body Motion Capture and Inertial System
- **Nexus Smart Phone** - Inertial (Gyro, Accelerometer), GPS, Magnetic Compass, and On Board Rendering and Remote Client
- **Fit PC-2** - Man Worn Computer
- **CommServer** - Long Range Telemetry and master RF server
- **Interface Box** - Power Distribution and Conditioning with on-board signal routing
- **GDIS-Unity** - Multiplayer Client and Server with AAR and interface with live/virtual training network

A redundant tracking system approach was used in the system design. Each of the basic tracking units estimate current position and a weight is added based on a set of accuracy metrics for each subsystem.

Figure 1 illustrates the overall system and components used in the live/virtual bridge. Key data flow components are also shown. All tracking data (body pose, orientation, and position) is consolidated on the remote client and the Nexus smart phone through a GDIS Bluetooth interface extension. This extension was running (along with other GDIS extensions in SimBridge on the man worn computer). From there, the GDIS-Unity system positioned, oriented, and posed the avatar in real-time and then sent the full body bone data back over the Bluetooth 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. Each of the primary subsystems is described further in the next sections.

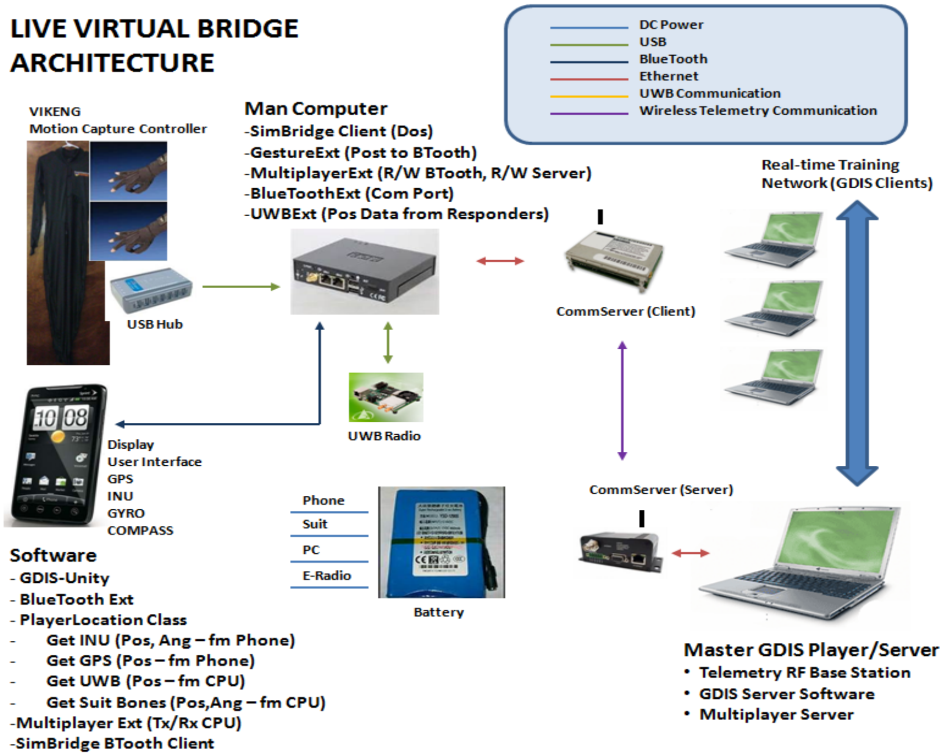

Figure 1. Live/virtual Bridge Architecture and Components

UWB Technology

The Time Domain P410 unit is a short pulse waveform used to achieve UWB ranging information (Figure 2). A set of range data is collected from surveyed stations and then used in a multilateration algorithm (similar to GPS receivers) to provide an estimate of the current position.

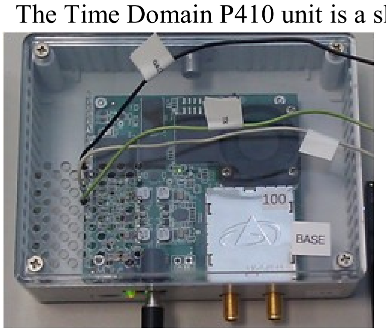

Figure 2. Time Domain P410 UWB Unit

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 the user chooses to integrate in order to achieve sufficient signal to noise ratio for detection of the response pulse's leading edge. Table 1 illustrates the minimum time to process a range request (question and answer sequence) as a function of "Pulse Integration Index" as reported by the vendor.

Table 1. Q&A Processing Time vs. PII

PII	Min Time	Update Rate
4	7 ms	142.86 Hz
5	9 ms	111.11 Hz
6	13 ms	76.92 Hz
7	20 ms	50.0 Hz
8	36 ms	27.78 Hz
9	67 ms	14.93 Hz
10	132 ms	7.58 Hz

Using a round robin approach for the surveyed responders, the multilateration (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.

The design of the P410 units thus requires a trade-off between effective update rate and maximum separation distance of the surveyed infrastructure. In order to minimize the number of total units used to provide full indoor and outdoor coverage, the PII of nine was chosen as the best compromise.

The indoor and outdoor units were placed into key "magic triangle" zones in order to maximize the efficiency of the round robin algorithm. 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 and order of responder queries.

Survey Challenges

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 better than the overall requirement for position accuracy. 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 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 could be computed.

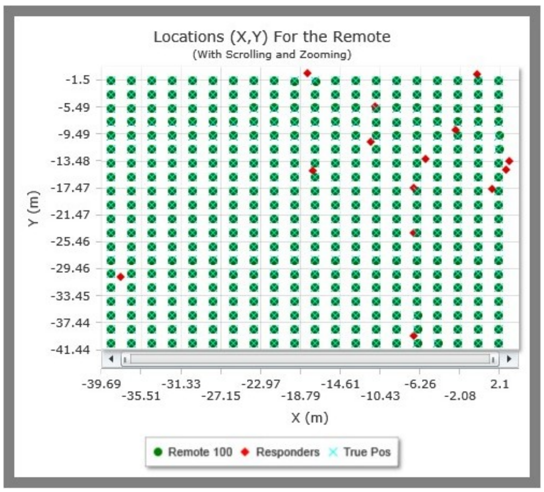

Figure 3. Location Simulation with 5 cm Survey Error

The use of the UWB units to estimate triangle sides implies that the measurement inherently included the error of the system itself. For the P410 in LOS conditions, range measured errors on the order of 5 cm were observed. This meant that the infrastructure potentially had similar survey errors and thus the estimated position during the trials would not be accurate to the true position by a proportional amount and number of ranges used in the trilateration (Figure 3). Wherever possible, direct measures of survey locations were used for the responder infrastructure. At the test facility, only about 30 percent of the unit locations were "self surveyed".

Magic Triangle (HDOP)

One other critical component to achieving good position estimates using multilateration is GDOP. Since the system only required 2D position estimates, the derivative Horizontal Dilution of Precision (HDOP) was estimated. It is well known that the best HDOP is achieved using three range estimates when the range estimates come from survey locations which form a triangle to the center position (Langley, 1999) as illustrated in Figure 4. This is due to the range error projection on the ground location from each of the fixed responders and minimizing the overlap error. Thus the indoor, outdoor, and transition areas in the tests location were broken into zones based on a set of these magic triangles in order to mitigate additional position errors from dilution of precision.

Figure 5 illustrates the HDOP estimated for the primary test area and the sets of overlapping magic triangle zones. It is generally thought that HDOP values less than two offer the best compromise for position estimates in multilateration approaches (Langley, 1999) for precision tracking.

Figure 4. Good GDOP (or HDOP) Geometry

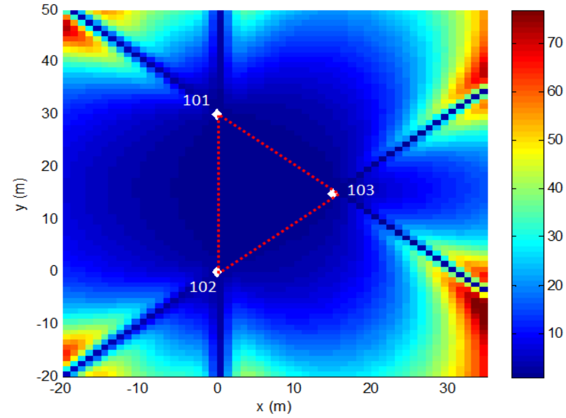

Figure 5. HDOP Estimate from Primary Indoor Location (Magic Triangle 1)

In cases where the system is overdetermined, GDOP and hence HDOP cannot be directly estimated by the classical equations due to the singularity produced when trying to invert a non-square matrix. The overdetermined system produces a range derivative matrix which is m x 3 where m is the number of range estimates used in the solution for 2D position. Under these conditions, an approximation to the inverse was used according to pseudo inverse functions derived by Moore-Penrose. (Penrose, 1955, 1956). This singular value decomposition approach was slower to compute than using a square matrix. A square matrix is achieved when precisely three ranges are used in the multilateration approach.

Multilateration Approaches

The choice of the multilateration algorithm is also critical to providing the best estimate of position along with speed and update rate. Two approaches were considered. The first was a closed form of the hyperbolic equations first proposed by Bancroft (Bancroft, 1985). The second was a standard least squares solver (iterative) approach first developed by Levengberg (and independently by Marquardt) known as the Levenberg-Marquardt algorithm (Levenberg 1944) also known as the Damped Least-Squares (DLS) method.

The Bancroft algorithm requires that the system be overdetermined. That is, for X, Y location, a minimum of four range estimates must be obtained. The Levenberg-Marquardt (LM) solver, while slower, would work under minimum conditions where only three range estimates were available. During the installation and research, a set of tests involving a solver simulation were performed to illustrate the sensitivity of the two approaches to range (or psuedorange) estimate errors (random and bias). The Bancroft algorithm proved to be very intolerant to these real-world errors and thus was not used in the final multilateration solution.

While both solutions struggle to produce accurate position estimates in this error condition, the Bancroft algorithm often produced estimates of not-a-number or NaN (solution was singular over 30% of the time) for the position location. The LM solver never produced NaN and generally was much more tolerant to range estimation errors (both random and bias types) albeit at the expense of speed (iterative solver).

Inertial Systems

Two primary inertial systems were used to estimate both the position and orientation of the live participant. The first inertial system used was the VIKENG which is a man-wearable suit that uses motion capture to relate live motions of each body part to a virtual avatar. The base suit is comprised of an Xsens MVN motion tracking suit (Roetenberg, Luinge & Slycke, 2009) that uses various inertial sensors placed on the hands, upper arms, lower arms, feet, lower legs, upper legs, the head chest and back for accurate human tracking in 6 Degrees of Freedom (6-DOF) for each inertial sensor.

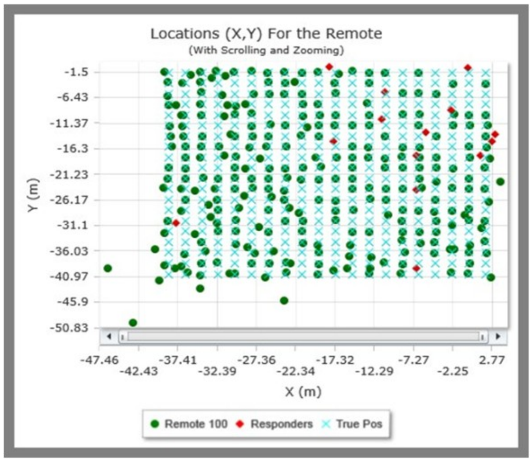

Figure 6. Bancroft Results (0.5 m Random Range Error)

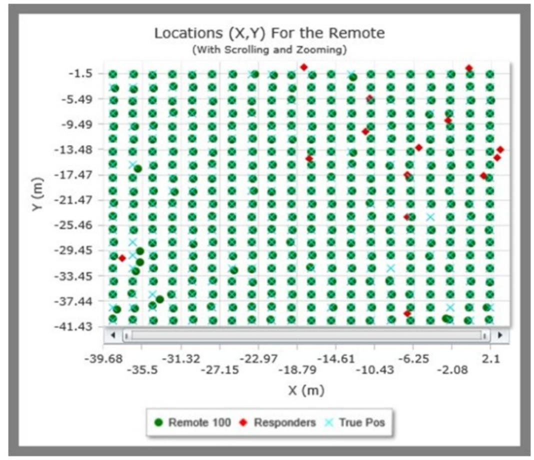

Figure 7. Levenberg-Marquardt Results (0.5 m Random Range Error)

In addition to the VIKENG motion capture component, a Nexus smart phone with accelerometer and gyroscope sensors was also used to estimate position; on a full body scale. The accelerometer and gyro data have been Kalman filtered directly off the phone and were accessible using the Android Software Development Kit (SDK) and the Unity 3D engine. The inertial and rotation data were available in units of “gravity” which was compensated for at start, and then integrated to estimate position over the time stamp window. The accelerometer (and gyro) data were integrated to produce an estimate of current velocity and current position where each update provided a new set of data. These data were also combined with a compass on the phone to estimate heading for versions which did not include the VIKENG motion capture component.

The other sensor and subsystems included:

Magnetic Systems – the smart phone compass was used for orientation estimates. The compass heading was available using the Android SDK and the Unity3D engine software and was time-stamped at each poll update. The compass data is based on the angle relative to true magnetic north and this angle was stored at spawn (exercise start) to allow relative angle changes from this reference to orient the total body of the avatar. The full body suit was also used to estimate orientation in the trials.

GPS - The primary GPS system used in the system for position estimates was the receiver available from the Nexus smart phone. This unit was an “all-in-view” GPS receiver which processed all satellites in view to estimate current position. The unit also uses Wi-Fi to provide faster acquisition and even coarse position estimates indoors. The unit was specified to provide position to within about 5 meters.

Central Man Worn Computer - The central man worn computer was a very small FIT-PC2 unit. This unit was the primary controller for the remote clients UWB unit and also provided the data bridge between the remote client’s smart phone running GDIS-Unity and the long haul telemetry network. A stand-alone version of the GDIS SimBridge client was running on the man worn computer which included the message and data interfaces for the Bluetooth and UWB extensions.

Telemetry - The telemetry system is based off the CommServer unit and provided a long haul Ethernet radio function for the remote client and the GDIS-Unity master server. The effective data rate of the telemetry system is approximately 1.4 mbits/second, and uses standard Ethernet packet data protocols. The effective range of the units (client to RF master server) is about three miles in free space.

After Action Review - The PC behind the RF master server ran the GDIS-Unity multiplayer server which broadcast real-time data and logged all multiplayer messages from the virtual and live training networks (including the remote client). These logs where then used after the action for review of the training exercise over the distributed network.

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.

PRELIMINARY DATA

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 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. For the test, many of these 5 GHz emitters were turned off but many of them were also still operating due to inaccessible controllers. As such, the UWB system component was forced to operate in a less than ideal (but not necessarily atypical) RF environment.

Figure 10 illustrates the general floor plan for the live/virtual bridge and Soldier tracking test. The two main rooms were filled with items while the outdoor area was essentially a parking lot with a number of trees in the surrounding area. 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 and indoor and 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 resolution capability of the system and evaluate random error components.

The raw data for the stand still test (Figure 9) indicated good stability of the UWB system over the 20 second window. From the stability test, the error distributions appear very close to normally distributed with standard deviations of 0.02m and 0.018 meters for X and Y respectively. For the "star pattern" test (Figure 10), the subject was asked to move from the center of the field directly toward each of the surveyed responders and then return to the center before moving to the next one. The star pattern test looked good with the exception of a few off axis points particularly when the subject got close to large static objects (very large screen television and metal racks of network equipment). In some cases, these static clutter objects in the room prevented a direct line from the center of the field to the surveyed responder causing the subject to deviate from a straight line path or not reach the goal.

The raw data from the out-the-doorway test (Figure 11) similarly looked good with the exception of a few bad tracks. The transition from indoor to outdoor was seamless and there was no "gap" in coverage, position estimates, or time. Some deviation was noted once outside however from the straight-line path which was likely due to survey errors associated with the sloping terrain. More analysis is needed to quantify the error sources associated with this curvature in the estimated position results. When outside, the GPS system indicated relatively good results but still not to the accuracy level of the UWB systems or INU systems (over short time scales).

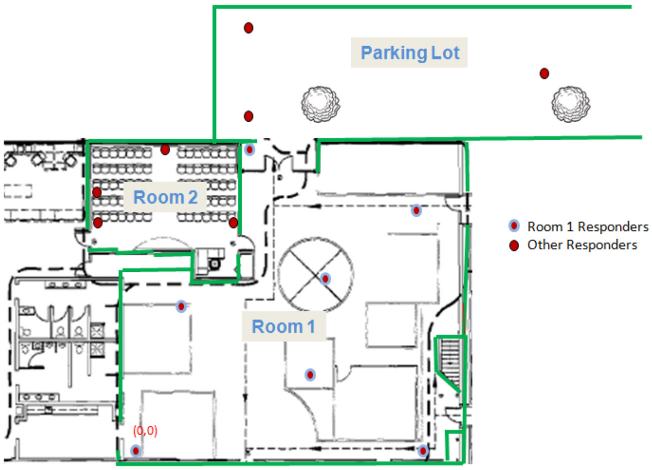

Figure 8. Floor Plan Illustrating Indoor and Outdoor Areas along with UWB Responders Survey

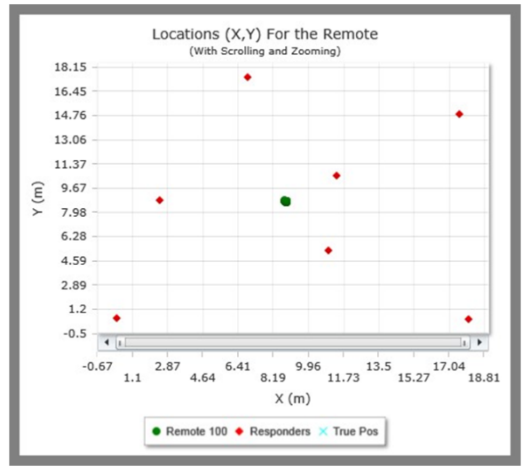

Figure 9. Stand Still Test (Room 1 - Indoor) - UWB Position Source

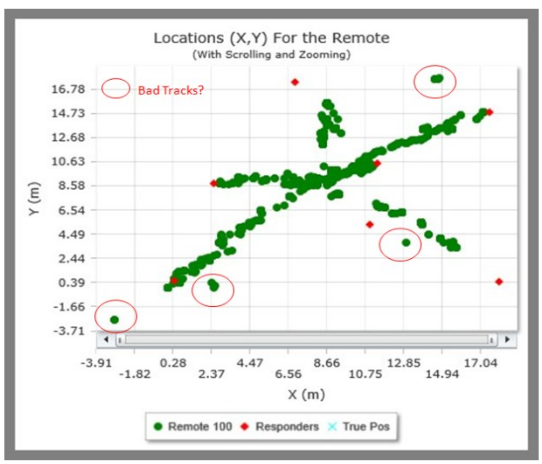

Figure 10. Star Pattern Position Results (Room 1 Indoors) - UWB Position Source

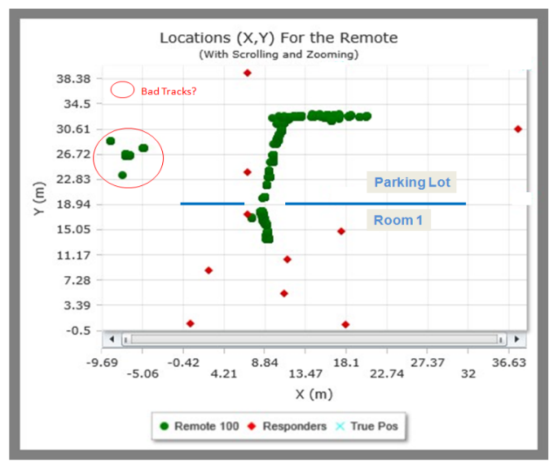

Figure 11. Out the Doorway Test (Room 1 to Outside Area) - UWB Position Source

Figure 12 is a screen capture from GDIS-Unity during the live trials in the indoor/outdoor transition region between Room 1 and the parking lot areas. This was correlated visually to the live test area zone in Figure 13. 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.

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. The primary subsystems used to achieve the live/virtual real time bridge are also described. Since this is the first integration of these subsystems, further study is needed to truly optimize the system components for (a) improved accuracy and (b) improved update rate; however the initial results 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 first phase of this research and additional experimentation and higher levels of system integration will be accomplished in later phases.

Figure 12. Live/virtual Bridge Real-Time Rendering (Virtual)

Figure 13. Live/virtual Bridge Real-Time Rendering (Live)

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 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. Where coverage areas contained significant static clutter, this stability reduced to about 0.3 meters. The Q&A implementation of the P410 limited update rate.
- Additional processing is likely needed on the raw data to locate and remove potential outliers and provide some smoothing of data.
- A highly accurate survey is needed for test facilities to establish ground truth for the tracking systems as visual confirmation. 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). This survey should include more "tie points" that correlate to visual landmarks in both the live and virtual databases.
- The Android phone compass provided reasonable subject avatar orientation during the trials for visual confirmation of body orientation and direction of travel.
- 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. The VIKENG system position estimates using inverse kinematics were clearly better than those derived from the Android phone acceleration and gyro sensors.
- Subjects clearly navigated the live environment with ease and the system instrumentation did not cause any significant hindrance to primary locomotion modes. More work is needed to optimize the system mount configuration for all natural locomotion modes.
- The AAR system demonstrated good correlation with the live event data and played back well on the distributed network.

REFERENCES

Bancroft, S. (1985). An Algebraic Solution of the GPS Equations. IEEE Transactions on Aerospace and Electronic Systems, vol. AES-21, No. 7, pp. 56-59.

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.

Dean, Jr, F. S., Garrity, P. & Stapelton, C. B. (2004). Mixed Reality: A Tool for Integrating Live, Virtual & Constructive Domains to Support Training Transformation. In *The Interservice/Industry, Simulation & Education Conference (I/ITSEC).* (Vol. 2004, No. 1). National Training Systems Association.

Dudek, G. & Jenkin, M. (2010). Computational Principles of Mobile Robotics. Cambridge University Press. ISBN 0-521-56876-5.

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.

Penrose, R. (1955). A generalized inverse for matrices. Proceedings of the Cambridge Philosophical Society (Vol. 51, No. 3, pp. 406-413)

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. (2010). Virtual Locomotion Concepts and Metrics Study. In *The Interservice/Industry Training, Simulation & Education Conference (I/ITSEC)* (Vol. 2010, No. 1). National Training Systems Association.

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.

Roetenberg, D., Luinge, H., & Slycke, P. (2009). Xsens MVN: Full 6DOF Human Motion Tracking Using Miniature Inertial Sensors. *Xsens Motion Technologies BV, Tech. Rep.*

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.

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

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.