Challenges Future TES Face With Position/Location And Implementing Geometric Pairing

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ABSTRACT

As the Army develops its next generation Tactical Engagement Simulations (TES) and replaces its existing laser based systems, many new technologies will be employed to meet the requirements. Future TES programs for the U.S. Army will provide a Live, precision, combined arms Force-On-Force (FOF) and Force-On-Target (FOT) training and testing capability using electronic bullets and RF communications for geometric pairing. The Army's Future TES must exploit recent advances in data processing, navigation, networking, interoperability, position location, weapons' orientation and M&S technologies to significantly advance the state-of-the-art of RTCA and automated data collection.

One of many challenges to be encountered by the Army's Future TES programs is that of obtaining highly accurate Position/Location in the use and implementation of Geometric Pairing (Geopairing). An accurate position/location tracking system for Combat Training Centers (CTCs) and other training ranges is a long-standing need of the United States Army. Such a system should be able to locate participants in training exercises, identify all players individually, and track them inside of buildings and on the battlefield with very low latency and to a high degree of accuracy. A system meeting all these requirements has yet to be developed and deployed. Technologies to meet the needs are only now being refined and beginning to appear in commercially available products. The Army is using GPS-based systems in sites around the world, but these do not address the need for tracking indoors and the high precision position location required for use in Geopairing. Geopairing is the capability where the fire event adjudication is resolved through knowledge of the positions and orientations of the shooter, the potential target(s), and the pointing vector of the weapon. In order to properly pair shooters with targets, each party's location must be known with high precision, thus a critical piece for Geopairing.

This paper seeks to define potential issues/problems with Position/Location and the implementation of Geopairing and how they relate to the Army's Future TES programs. This paper will also seek to suggest possible solutions to those challenges and how they could be implemented in helping Future TES programs address the issues of accurate Position/Location and Geopairing.

KEYWORDS: Future TES, GPS, Geometric Pairing, FOF, FOT, Position/Location, TES, AAR, RTCA

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His other experiences include working for the US Army's Research Development and Engineering Command (RDECOM) in the development of Dismounted Soldier Virtual simulations and in the application of

Massively Multi-Player games for Army training. Prior to this Mr. Grosse worked on US Marine Corps programs developing instrumentation systems for Urban Operations and 29 Palms Marine Corps Base.

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INTRODUCTION

Future TES programs will provide a Live, precision, combined arms Force-on-Force (FOF) and Force-on-Target (FOT) training and testing capability, embedded to the maximum extent practical, that capitalizes on the "train-assess-train" model using leap-ahead technology for use in FOF and FOT training and testing environments. Future TES will exploit recent advances in data processing and storage, communications, navigation, networking, interoperability, and modeling and simulation technologies to significantly advance the state-of-the-art of Real-Time Casualty Assessment (RTCA) and automated data collection. Future TES will be an affordable solution; both in terms of acquisition costs, and even more importantly, operations and maintenance costs. Additionally, Future TES will provide these capabilities:

- Electronic warfare (EW) and Information Operations Warfare (IOW)
- Engineer warfare and countermines
- Nuclear, biological, and chemical (NBC)
- Ground-to-ground engagements (includes directly and indirectly fired munitions/ Non-Line of Sight (NLOS) and Beyond-Line of Sight (BLOS))
- Ground-to-air engagements
- Air-to-air and air-to-ground engagements, to include Close Air Support (CAS)
- Smart fire-and-forget engagements
- Directed energy weapons (including High Powered Microwave (HPM) and Laser).
- Countermeasures (CM) and Counter-countermeasures (CCM).
- Non-lethal munitions.
- Precision gunnery.

Future TES must also be an integral part of a mobile, affordable, high fidelity, Live tactical engagement simulation and field instrumentation system; able to collect and report RTCA and other required data in support of its operational test mission. In addition to the capabilities listed above: Future TES must have the capability to collect, report, and store all manners of test data (to include RTCA, digital and voice communications, data bus, video, display, and environmental data) for near real-time monitoring and control of a test event. Future TES must be able transfer data to other federate modeling and simulation systems as may be needed. In addition, Future TES must be capable of providing data for post-test analysis and evaluation of systems under test. Additionally, the system must provide near real-time status and performance data on other instrumentation devices and subsystems to ensure the integrity of the simulations and data collection activities, as well to affect timely troubleshooting and repair.

- The interfaces to allow it to readily interoperate with other Live, Virtual, and/or Constructive simulation/instrumentation systems as may be needed to support an operational test.
- The capability to support operational tests in simple and complex environments, to include Military Operations in Urban Terrain (MOUT), dense foliage, smoke, fog, etc.; at whatever location the test may be assigned.

Defining the Missions

Future TES will support the conduct of combined arms FOF and FOT training exercises and testing events. Those training exercises support training of all Army Tactical Missions (ATMs) and cross all Battlefield Operating Spaces (BOSs). The system will be designed to support the training of both analog and modernized/digital units. Live training is performed in conjunction with Constructive and Virtual training in a Live, Virtual, and Constructive Training Environment (LVC TE), see Figure 1.

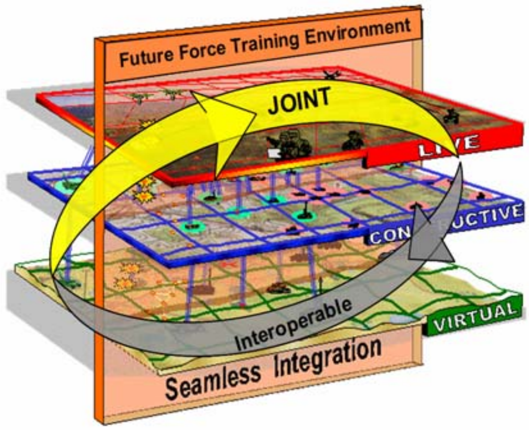


Figure 1. Seamless Integration of the Live, Virtual and Constructive Training Environment

Future TES builds on the proven TES training model to meet critical shortfalls in the training of war fighting capabilities and mission readiness, allowing commanders to most effectively use training time. Future TES will be used primarily during brigade (BDE) and below Live combined arms FOF and FOT training exercises and test events to simulate the effects of actual weapons systems, munitions, Counter Measure (CM), and Counter-Counter Measure (CCM) and stimulate weapon and battlefield sensors while providing the means to objectively assess all weapons effects experienced during Live training and testing in a comprehensive LVC Training Environment. Future TES will provide realistic weapons effects cues to soldiers and crews (including firing, hit, and kill signatures) and will stimulate player reaction to firing. With a wider variety of mission requirements, fewer units, and less forward deployed force structure, units must maintain a higher state of readiness and have deployable training and mission rehearsal capabilities. The system has the potential to provide an alternative to some Live fire training exercises that will result in a reduced need for Live ammunition. Future TES will provide these capabilities as new systems are developed as part of the Future Force.

Future TES and Live Training Transformation (LT2)

The LT2 System of Systems (SoS) product line provides the means to transform the Army's Live training ranges, training instrumentation and tactical engagement systems and will continue to transform in parallel, as the Army itself is transformed. The LT2 concept is grounded in Army doctrine (FM 7.0, Training the Force) and its training systems fully supports the preparing, conducting and recovering from training as highlighted in the execute phase of the Training Management Cycle. Planning, executing, and assessing coupled with continual feed back remain a cornerstone of how the Army trains. To be truly responsive, and meet our contingencies, Army forces must be deployable and capable of rapidly concentrating combat power in an operational area with minimal additional training (Train, Alert, Deploy sequence). The LT2 training systems are integrated across the training domains and supports the training execution process at all echelons from a joint level exercise to crew/squad drills and prepares the Force to execute its wartime mission.

The use of the LT2 product line system of systems allows the horizontal integration by the material developer to provide the training enablers for the Live environment and the links to the Virtual and Constructive environments. Additionally, the LT2 product line approach allows the material developer to look across the training domains (HS/deployed, institution or maneuver CTC) and provide the capabilities of the training systems to support training of the solider on demand, anywhere, or place. The architecture for the LT2 effort is the Common Training Instrumentation Architecture (CTIA). CTIA provides the foundation by which the LT2 product line common components are developed and then employed by the LT2 applications. CTIA provides the framework (protocols, standards, interfaces, etc.) and gateways to interface with Virtual and Constructive environments. In summary, the LT2 product line includes the common components and standard interfaces that tie in the Virtual and Constructive simulation systems, tactical C^4ISR systems, Joint interfaces, the Army Training Information Architecture (ATIA), and Targetry systems that require interoperability.

LT2 Instrumentation Systems (ISs) will have a special dependency on Future TES. The intent is the horizontal integration of Future TES across the Live training environment. The horizontal integration of the LT2 instrumentation systems provides the information/data backbone to collect and store exercise data, and to pass training feedback information within the training systems and across all the domains. The end state is a SoS that employs a common interface component that provides interoperability across the Live training environment. Future TES, as the LT2 TES component, provides the means for instrumentation systems to collect training engagement data for exercise control and AAR purposes. For a DoD Architecture Framework System View for Future TES (the OneTESS SV is used as an example), see Figure 2.

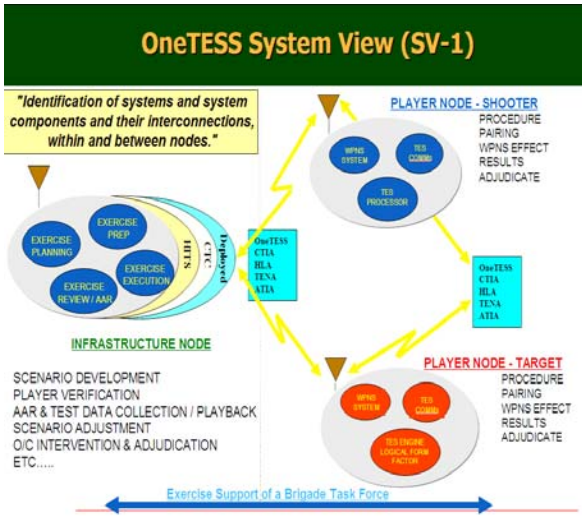


Figure 2. OneTESS System View

BACKGROUND

Current test and training instrumentation suffer from critical obsolescence issues, system-level deficiencies, lack of commonality and interoperability (especially with operational systems), and severe performance limitations. Additionally, these technologies do not capture data with adequate fidelity, are highly proprietary, and do not have the flexibility to be easily reconfigured, or modified to accommodate changes related to specific test or training events. These shortcomings not only diminish the quality of assessment data used to evaluate weapon and training performance, but they also adversely affect the future supportability of training and operational tests of a more demanding and complex Future Force.

Another critical problem is the communications element of instrumentation systems – radios, infrastructure, network architectures, and frequency. Data acquisition requirements will overwhelm current instrumentation systems as new data intensive, network centric Future Force systems undergo testing and training. Even now, data requirements exceed the capacity of any single instrumentation system. These systems lack sufficient data throughput, are not scalable, use an inflexible, inefficient, hub and spoke (centralized) architecture, and rely heavily on fixed tower infrastructures. Fixed tower infrastructures are not amenable to most home station or deployed training environments. Additionally, the radio portion of current player units is different at each test and training range across the country and overseas. No commonality exists within test and training domains and no commonality exists between these two domains. The lack of available spectrum is another critical problem. The Mobile Automated Instrumentation Suite (MAIS) program, for example, has been forced to an interim solution by having to operate in a different frequency band because of severe interference from high definition television (HDTV) signals. Until the development of the software defined radio (SDR) under the Joint Tactical Radio Program (JTRS) is completed, all legacy and near term instrumentation systems will have the same fundamental problems – fixed, proprietary designs that do not use open standards or interfaces and that are not forward compatible for plug and play components replaced through market driven development cycles. Scalability is another problem that is tied to the current hub and spoke network architecture at test and training sites. Testing of Future Force systems will involve thousands of entities from ground sensors, unmanned ground and air vehicles, dismounted soldiers, and vehicles – all interconnected via a wireless network. In the training domain, an acquisition program, such as the Future TES program, has a requirement to support 20,000 players, which means that network scalability becomes critical especially when considering real time casualty assessment (RTCA) and geometric pairing.

On the Internet and in wireless networks, Quality of Service (QoS) is the idea that transmission rates, error rates (packet losses), and other characteristics can be measured, improved, and, to some extent, guaranteed in advance. QoS is of particular concern for the continuous transmission of high-bandwidth data, such as video, voice, and test telemetry. Transmitting this kind of content dependably is difficult in wireless networks using ordinary "best effort" protocols. Mobile ad hoc networks (MANET) are a class of protocols that are specially designed for QoS over wireless networks where the communications systems are mobile and links between them are unstable. Several MANET protocols are being developed for the Army’s transformation to the Future Force, but none of them are addressing unique test and training applications such as geometric pairing or real-time casualty assessment. The Future Combat System (FCS), unmanned ground and air vehicles (UGV/UAV), and unattended ground sensors will be linked together using MANET protocols. There is significant risk that the test and training community will be unable to perform their missions unless geometric pairing and RTCA applications are thoroughly understood in the context of MANET and QoS.

Legacy instrumentation systems such as the Precision Lightweight GPS Receiver (PLGR) and the Multiple Integrated Laser System (MILES) have many significant issues that need to be addressed in the next generation of instrumentation systems. Reductions need to be made in cost, size, and weight, while at the same time, increasing accuracy.

Geometric Pairing – What is it?

Geometric Pairing (GP) is where fire event adjudication is resolved through knowledge of the positions and orientations of the shooter and the potential targets. The following information is required for a computational platform to generate a geometric pairing solution:

- Shooter and target position/location
- Weapons pointing vector (azimuth and elevation)
- Environmental characteristics (wind velocity, detailed terrain, etc.)
- Terrain Representation
- Time of firing event
- Weapon and munition characteristics

What is the Problem?

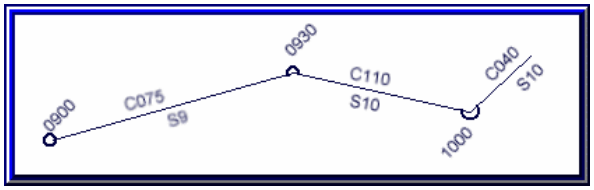
A critical aspect of the geometric pairing problem is maintaining constant position and location data availability of the player in all environments, especially where Global Positioning System (GPS) satellite signals become attenuated, distorted, or blocked. In order to properly pair shooters with targets, each party's location must be known with high precision. Indirect fire involving detonating rounds usually requires less resolution, but addressing one of the most difficult cases of position and location during Geometric Pairing is the goal of this paper.

The GP concept is specific to the test and training domains and with it comes very stringent performance requirements that cannot be solved by integrating or modifying commercial products. In some instances, larger weapon system's, because of their abundant power and carrying capacity, are more amenable to a solution. However, dismounted soldier line-of-sight (LOS) training constitutes over 75% of the Army's legacy training system – the Multiple Integrated Laser Engagement System (MILES). Dismounted soldier LOS training imposes the most difficult requirements of all training platforms. Dismounted soldiers are already at or near their tactical equipment weight capacity and adding any additional training equipment weight must be strictly minimized. Weight in this case is not simply the physical weight of the training device, but also the weight related to battery capacity required to maintain sufficient training exercise duration. Future TES requires that the player unit, a small, portable PC with all the sensors and software necessary to conduct GP, must weigh equal to, or less than, 2 pounds. The player unit must also be capable of conducting training exercises for a minimum duration of 72 hours without the need to change batteries. Accuracy is another key performance requirement and based on the Operational Test Command's (OTC) tests with their prototype GP system, a position and location accuracy of > 1m RMS is required. Accuracy of > 1m in itself is not a difficult requirement, but becomes so when considering other dismounted soldier requirements such as:

- Weight
- Power consumption
- Price
- GPS signal availability

Another factor concerning accuracy that must be considered is that GPS receiver augmentation systems such as the Federal Aviation Administration's (FAA) Wide Area Augmentation System (WAAS), while enabling 1 m accuracy, is not available outside the U.S.. Differential GPS (DGPS) augmentation requires proximity to their beacons and is not available outside of the U.S. and Europe. Therefore, the > 1m requirement must be achieved autonomously of these augmentation systems in order to conduct training exercises at homestation and during deployments. Less than 1 meter accuracy without augmentation is what can be considered the low end of the survey grade class of GPS receivers. Survey grade GPS receivers are portable to the extent that they are carried into field and run off of battery power, but are typically too large, heavy, and expensive ($2,500 to $6,000) to be considered for integration into the Future TES player unit.

GPS signal availability and quality are crucial to successful GP. Training exercises are routinely conducted in environments in which GPS capability is not sufficient to conduct GP. In order to compensate for degraded or unavailable position and location capability, dead reckoning navigation is a potential solution. Taking the last known GPS position and location, dead reckoning would commence provided that certain data is available such as heading, velocity, time, and distance traveled. Dead reckoning position and location relative to the last GPS coordinate is shown in the example below:



Dead reckoning navigation requires multiple sensor types that are integrated physically and in software. The software takes each respective sensor output, and through error models and filtering algorithms, called Extended Kalman Filters (EKF), calculates an approximate position and location from the last known GPS coordinate. There are various sensors that can be used for dead reckoning; however, each has their own distinct strength and weakness (error sources) that must be complemented with another sensor type with dissimilar error sources. Sensors used for dead reckoning include magnetometers (compass), pedometers, barometric altimeters, and Inertial Measurement Units (IMUs). There are also dead reckoning techniques that use the soldier's radio and communications network such as Radio Frequency Time-of-Arrival (RF TOA), and network assisted GPS.

The following table shows the various sensor types with their respective advantages and disadvantages:

Sensor Type	Advantages	Disadvantages
Magnetometer	Provides absolute angular measurement	Susceptible to magnetic interference; requires calibration
Pedometer	Error not time dependent	Error proportional to distance traveled
IMU	Provides angular rate and linear acceleration	Errors increase over time; substantial trade off required between cost and performance
Barometric altimeter	Provides absolute vertical measurement	Provides vertical measurement only
RF TOA	Uses existing soldier radio and network	Requires a network of 3+ radios and a dispersed geometry
Network assisted GPS	Extends the environment in which GPS receivers can function	Requires that 4+ receivers be networked together with a minimum of 1 GPS receiver with good satellite signal acquisition

The difficulty that arises with dead reckoning is having the proper individual sensors and in having the proper combination of integrated sensors (e.g.; magnetometer plus IMU) that offers 1m accuracy, yet is low cost (less than the current $2,000 price of MILES) and light weight enough for dismounted soldiers. To highlight the difficulty, research demonstrating the performance comparison of a survey-grade GPS receiver integrated with military-grade IMUs (can be found in Zhang et al. (2005)). Their results showed that by using these expensive ($5,000+), power consuming (5+W) IMUs integrated with a survey-grade GPS receiver, that accuracies of 1m could be sustained during GPS signal drop-outs of up to 20 seconds. Clearly, integration of only an IMU and a GPS receiver is not sufficient to maintain position and location robustness during extended GPS outages. Also, it is not feasible for the Future TES program to use survey-grade GPS receivers and military-grade IMUs because of their high cost, large size, and high power consumption. To explore this problem further, let's look at the specifications for both the IMU and the GPS receiver that were used in the research project.

Zhang et al. used a Honeywell HG1700 IMU and a Novatel OEM4 GPS receiver. Their specifications and prices are as follows:

	Accuracy	Wt.	Power	Price
Novatel OEM4 GPS	1.5m, unassisted 0.8 m, WAAS 0.45m, DGPS	80g	2.3W	$2,500
HG1700 IMU	2°/hour bias drift	907g	8W	$5,000
	TOTAL	**987g**	**10.3W**	**$7,500**

Both devices combined weigh almost 1,000 grams, consume an excess of 10 Watts of power, and cost $7,500 – an unsuitable solution. To illustrate the difficulty with fulfilling Future TES requirements using state-of-the-art commercial devices, let's select components that are low cost, light weight, and consume little power. One of the smallest, low power and high performance GPS receivers is the u-Blox AG model TIM-LA and in IMUs, CloudCap's Crista is the world's smallest and lowest power. The following table summarizes their individual specifications and price and a combined total:

	Accuracy	Wt.	Power	Price
u-Blox TIM-LA GPS	2.5m, unassisted 2.0 m, DGPS	3g	150mW	$100
Crista CloudCap IMU	500°/hour bias drift	19g	550mW	$1,500
	TOTAL	**22g**	**700mW**	**$1,600**

The combined weight, power consumption and cost for both the u-Blox GPS receiver and the CloudCap Crista IMU are quite suitable but their accuracies are not sufficient for GP as was demonstrated by research conducted by Brown, 2004 using an integrated navigation system consisting of a Novatel OEM4 GPS receiver and CloudCap's Crista IMU. Brown's test results showed that position error grows very rapidly during GPS signal drop-outs – exceeding 10 meters of position accuracy in 20 seconds, as shown in Figure 3.

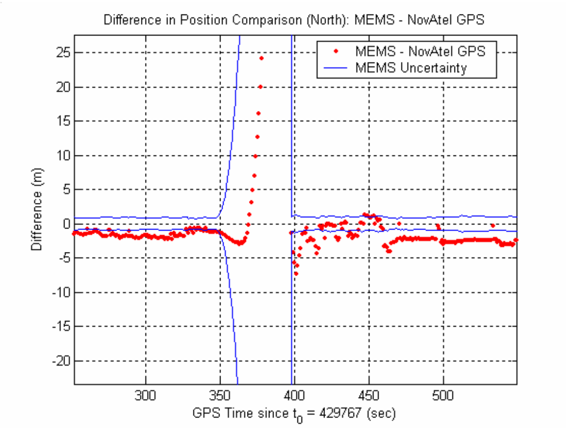


Figure 3. Position error growth during a GPS drop-out using the Crista IMU

These results demonstrate the intrinsic problem – unacceptable trade offs using existing, albeit, state-of-the-art commercial technology.

To solve the problem of having to make unacceptable trade offs, GPS receiver, IMU, and dead reckoning sensor technology must be developed that are accurate enough for GP but yet operate at low power, are light weight, and low in price.

DISCUSSION

As was demonstrated by Zhang and Brown, position accuracies during GPS signal drop-outs are very much impacted by the accuracy of the IMU – up to a 10X improvement between an IMU rated at 500 degrees of bias drift per hour such as the Crista and an IMU rated at 2 degrees of bias drift per hour such as the Honeywell HG1700.

To address the need for an accurate yet low power, low cost, and light weight IMU, RDECOM-STTC has funded the development of an innovative device that has potential to fulfill all of these requirements. This IMU, based on Ferromagnetic fluid, is unique in that measures all six degrees-of-freedom for both linear and angular motion simultaneously which reduces its size and lowers power consumption as compared to MEMS-based IMUs. Conventional IMUs require orthogonally mounted discrete gyroscopes and accelerometers for each measurement axis (x, y, and z) and expensive clean room manufacturing facilities. This Ferromagnetic fluid-based IMU has undergone three generations of prototype development to date and demonstrated promising performance thus far.

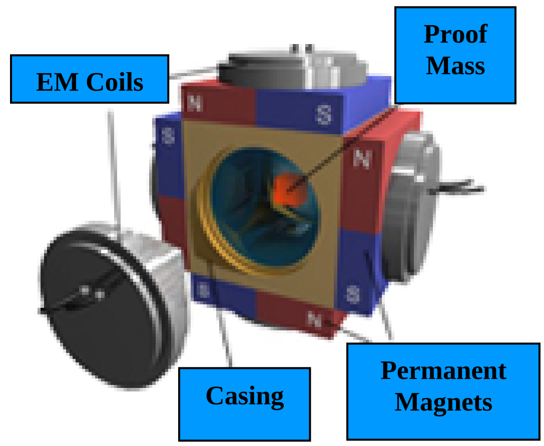


Figure 4. Ferromagnetic fluid-based IMU

The Ferromagnetic IMU concept consists of a cubic-shaped casing and at each of the 6 cubic faces are electromagnetic coils of two types: a power coil and a measurement coil. The power coils generate electromagnetic lines of flux inside the casing and the sensing coil passively detects disturbances in the flux lines caused by linear and angular movement of a proof mass that is situated at the center of the sensor. The power coil, controlled by software in the microprocessor, maintains physical equilibrium between the outside faces of the proof mass and the interior cavity inside the sensor casing. Ferromagnetic fluid completely surrounds the proof mass inside the casing. Ferromagnetic fluid consists of spherical Magnetite (Fe_3O_4), nano-sized particles that have diameters between 6 and 10nm. Prior to immersion in a carrier fluid (usually a synthetic hydrocarbon), the particles are immersed in a surfactant that is allowed to be adsorbed into the particle surface. The surfactant not only prevents oxidation but also prevents agglomeration of particles that would distort the effect of electromagnetic flux. These particles, when exposed to an electromagnetic field, rotate at very high velocities and their moments (M_d, Figure 5) align along the flux lines.

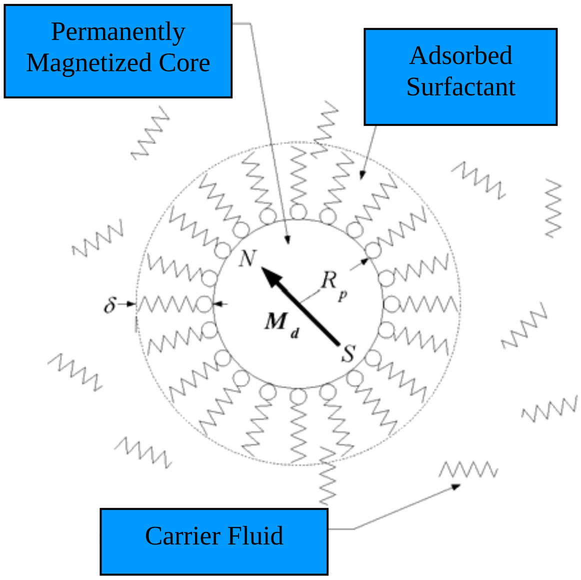
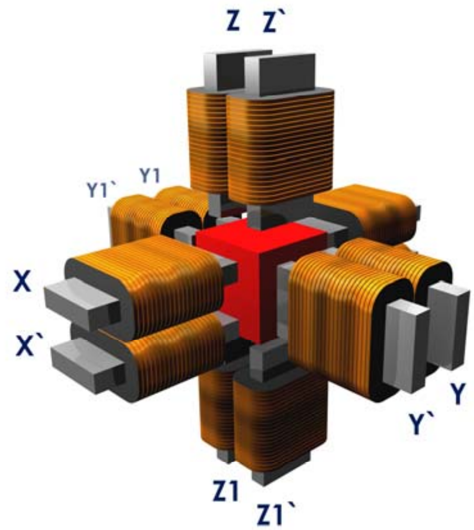
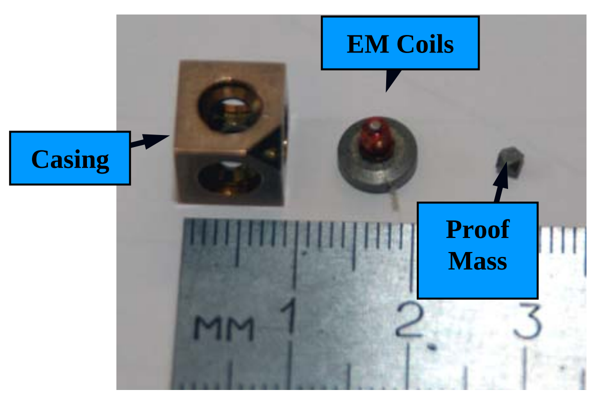


Figure 5. Ferromagnetic fluid

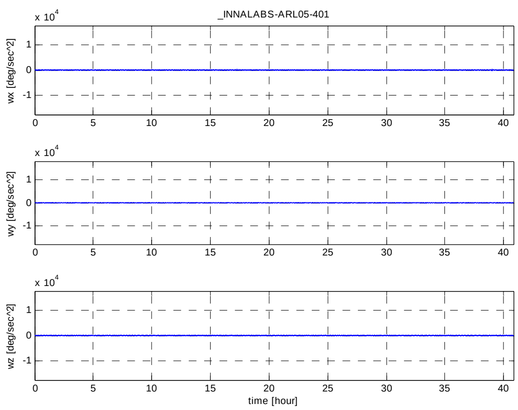
Figure 6. Ferrofluid moves according to the magnetic flux lines as shown

Variation in electromagnetic field strengths causes instantaneous changes in Ferro fluid viscosity. Viscosity gradients impart forces in the direction from highest to lowest which are used to maintain proof mass equilibrium by exerting force against the proof mass that is controlled by the amount of electromagnetic energy emanating from the power coils. The control software constantly monitors changes in internal displacement and makes real-time corrections, particularly for the effects of the Earth's gravity. The sensor also has filtering algorithms that takes raw sensor output measurements and based on precise error models (e.g.; hydro thermodynamics, temperature, etc.), performs appropriate corrections to the data.





Pennsylvania State University's Applied Research Laboratory and Navigation Facility was selected to conduct independent testing of the IMU prototypes. The most recent tests they conducted on the third generation IMU showed excellent performance as a linear accelerometer but was limited to demonstrating a respectable capability to measure angular acceleration, not angular rate.



ALTERNATIVE APPROACH

An alternative approach to the position tracking fidelity issue is to develop algorithms that can be used as part of the geopairing determination that will enhance the accuracy of the pairing. This would require developing a cone of uncertainty that potential targets would fall into. Many factors can be added to the determination with this approach such as distance from the shooter to each target, distance from the measured firing path, likelihood that the shooter would select each entity as a target (i.e. an M16 shooting at a tank), etc. Each of these factors can have a weighting factor applied to them to influence who was the actual target. The algorithm would apply each of these factors in its determination of the target.

CONCLUSION

Future TES has the requirement to simulate the actual accuracy of the weapon system being fired. The most important variables that go into the geopairing calculation of "who shot who" are the accuracy of the device measuring the orientation of the weapon and accuracy of the position location of both the shooter and target.

Currently, the most viable and affordable approach to track the position location of the entities on the live training battlefield is differential GPS. This approach will not meet the requirement for sub-meter accuracy that Future TES requires nor will it meet the requirement for units to be able to roll off of a transport and train. Differential GPS requires a survey team to mark the DGPS' location and close to a day to acquire the satellite information for an accurate differential signal.

Other solutions that have been pursued are costly and are not at the technology readiness level to be used by Future TES. Additionally these technologies may have issues operationally when placed on military equipment.

Future TES Programs need to continue pushing the envelope of technology in this area so that new and more accurate position location solutions will be available as the Army continues its development of Future TES Systems.

ACKNOWLEDGEMENTS

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