Positioning, Navigation and Timing: The Foundation of Command and Control

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Abstract:

A major tenet of Network Centric Warfare is "Information Dominance." The accuracy and availability of position information directly affects operational effectiveness. The traditional role of positioning was for "own ship" pilotage. That is, "can I get from Point A to Point B?" The evolving role of positioning is as a shared resource to establish near-perfect Situation Awareness (SA) to enhance Command and Control (C2).

C2 systems such as the Army Battle Command Systems (ABCS) rely on digitized position reports from all platforms on the battlefield. The predominate source of that position data is the NAVSTAR Global Positioning System (GPS). GPS provides a common consistent coordinate reference. GPS accuracy does not degrade with time or distance traveled as self-contained navigation units, e.g. Inertial Navigation Units (INU) or Doppler Radar Navigation Sets. In addition, GPS receivers are significantly less expensive to integrate, operate and maintain than INU's or Doppler's.

GPS has vulnerabilities to Electro-Magnetic Interference (EMI) and satellite signal blockage. Technology initiatives are concentrating on investigating sophisticated integration techniques for combining externally-aided and self-contained navigation systems.

This paper addresses the relationship of navigation systems to command and control systems and recent/new technology initiatives to improve the robustness of position information.

Introduction

A major tenet of the "Digitized Army" is "Information Dominance." The accuracy and availability of own force position information directly affects the future Army's operational effectiveness. The traditional role of position information was for "own ship" pilotage. That is, "can I find my way from Point A to Point B?" The evolving role of position information is as a shared resource to establish near-perfect Situation Awareness (SA) to enhance Command and Control (C2) effectiveness for force multiplication.

C2 systems such as the Army Battle Command Systems (ABCS) rely on accurate digitized position reports from all platforms on the battlefield. The predominate source of that position data is the NAVSTAR Global Positioning System (GPS). GPS provides a common and consistent coordinate reference. GPS accuracy does not degrade with time or distance traveled as does self-contained navigation units such as Inertial Navigation Units (INU) or Doppler Radar Navigation Sets. In addition and possibly more importantly, GPS receivers are significantly less expensive to integrate, operate and maintain than INU's or Doppler's.

A downside to GPS is its low signal power, making it vulnerable to EMI and signal blockage. The Air Force Scientific Advisory Board in November of 1993 and the Defense Science Board Task Force on GPS in November of 1995 found that GPS had several deficiencies. The most important being that it is vulnerable to jamming. The documents describing the jamming threat are the NAVSTAR Global Positioning System (GPS) System Threat Assessment Report (STAR), the National Air Intelligence Center (NAIC) 1574-0407-97 (7 April 1997) and the NAIC 1574-0407-99 (1 Jan 1999) which validated the GPS Star.

The Navigation Warfare program (Navwar) was initiated by DoD to address both the vulnerability to EMI and the Presidential Decision Directive (PDD) on US GPS Policy dated 1996. The PDD highlighted the need to improve GPS (both civilian and military) to strengthen and maintain our national security. It also called for the cessation of Selective Availability (i.e., the intentional degradation of GPS accuracy on the civilian signal) by 2006 (actually turned to zero in May 2000).

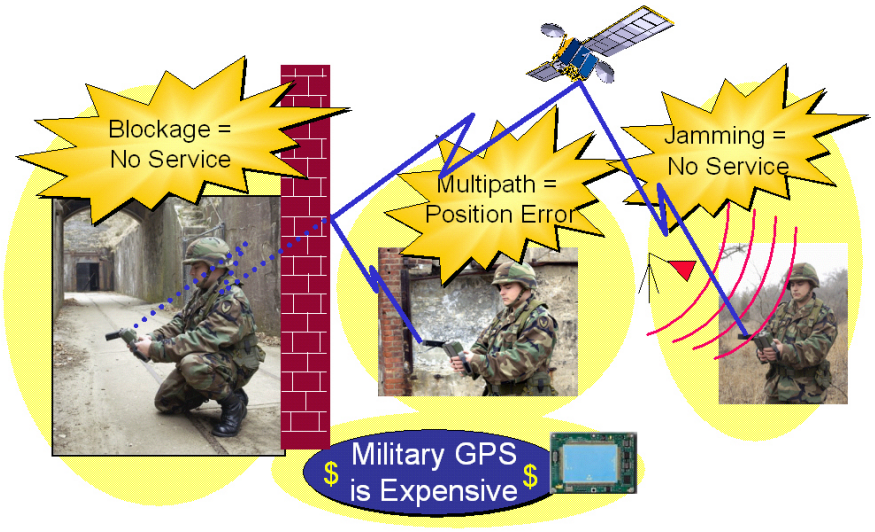

Figure 1 - GPS Limitations

The Navwar program objectives are:

1. The *Protection* of GPS capabilities for the US military and its allies.
2. The *Prevention* of the use of GPS by its adversaries.
3. Protection and Prevention must be accomplished while *Minimizing* the impact on the integrity of GPS for civilian use outside of an "Area of Responsibility."

Positioning, Navigation and Timing: In the Context of Operational Command and Control

As stated previously, C2 systems rely on frequent and automatically updated digitized position reports. Reports that are based on inaccurate or unavailable information can have devastating effects. One incident that was described in the Washington Post (1) indicated that a forward air controller during Operation Enduring Freedom called for a Joint Direct Attack Munition (JDAM) on what they mistakenly reported to be a target but was actually their own location. Ultimately a dead battery and training was cited as the reason for this tragedy.

The US Army Training and Doctrine Command (TRADOC) recognizes the importance of high quality positioning/navigation information as evidenced in the operational requirement documents (ORD) for the Future Combat System and the Land Warrior, and also in the TRADOC Pamphlet 525-66 on Force Operating Capabilities (FOC) (2). These requirements essentially describe a requirement for a very precise positioning system that operates in all environments and under all conditions. They further state these systems need to be fully interoperable with all Army Battle Command Systems (ABCS) that include Air Defense, Combat Service Support, Fire Support, Intelligence and Electronic Warfare, and Maneuver. These same documents acknowledge electronic threats to positioning systems and state a requirement to counter them.

Recent lessons learned from Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) have stated the need for affordable positioning equipment and have gone as far as to state that every soldier should be provided a system. A quote in an Inside the Army (3) article earlier this year stated that "…a majority of soldiers brought their own commercial GPS receivers", and the article expressed the concern of the DOD due to the vulnerability of commercial GPS receivers.

While less obvious in requirements documentation but arguably even more important is the accuracy and availability of synchronized time on the battlefield. Time is used in communications, sensor, and intelligence system is ubiquitous; it is used by virtually every unit on the battlefield, e.g. frequency hopping or cryptology.

FM 100-14 defines Situational Awareness as "The ability to have accurate and real-time information on friendly, enemy, neutral, and noncombatant locations; a common, relevant picture of the battlefield scaled to specific level of interest and special need." (4).

When individuals report their positions, a collective picture is "drawn". This is called the Common Operational Picture (COP). Friendly units and sensors further report enemy, neutral, and noncombatant locations by estimating them based on the known friendly locations (or by the use of laser ranging technology). These are converted into digital coordinates and "drawn" on the COP. Accurate and timely position information of these units is the key enabler to achieve these capabilities.

Joint Pub 1-02 defines command and control as "The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission." (5)

The commanders that have better situational awareness will make the better decisions. Having accurate position locations of friendly forces through frequently updated position reports lifts much of the "fog of war", and commanders are better able to issue directions to their units.

All this draws the conclusion that Positioning, Navigation and Timing information is, without a doubt, the foundation of Command and Control (C2) or a force multiplier. The US has identified that GPS is a critical element of the nation's transportation infrastructure. For the exact same reasons, GPS and the other positioning systems described in this paper need to be considered a critical element of battlefield's infrastructure (6) and require a very high level of protection.

Positioning, Navigation and Timing (PNT) Technology Initiatives

The remaining sections discuss recently completed and ongoing technology initiatives in the US Army Communication-Electronics Research, Development and Engineering Center (CERDEC) that address the protection of positioning, navigation and timing information through GPS signal robustness devices/techniques and the integration of aiding sensors.

Battlespace Tactical Navigation
STO: III.C4.1999.02

In 1998, the US Army CERDEC received approval for a Science and Technology Objective (STO) program titled Battlespace Tactical Navigation (BTN). BTN addresses several technical issues related to navigation and GPS. A primary Army technical challenge is the vulnerability of GPS to electro-magnetic interference (EMI) and jamming.

The Army has many more and different types of platforms with GPS receivers than any of the other services. (In fact the Army has 86% of DoD GPS receivers). This translates

to an enormous expense to upgrade individual user equipment suites. The Army also has a larger variety of missions that could necessitate different types of interference mitigation. It also operates in a higher EMI environment than the other services (especially during signal acquisition) due to its proximity to jammers and its longer mission duration.

BTN developed technology to improve the robustness of GPS reception in hostile ECM environments. One class of these technologies is anti-jam (A/J) antennas, to de described below.

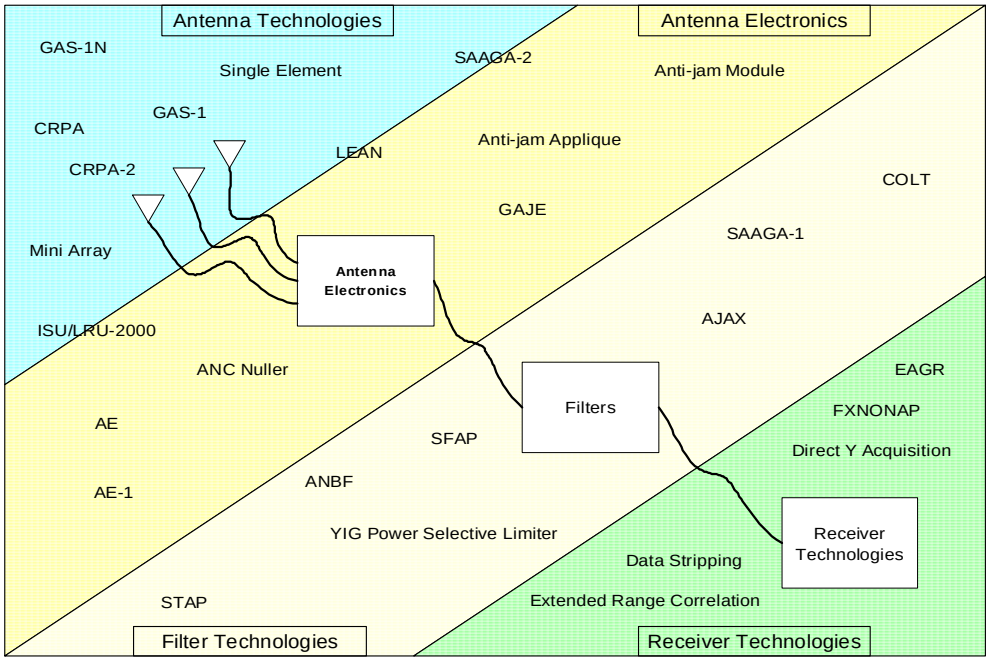

Figure 2 - GPS A/J Technologies

GPS A/J Devices

Anti-jam technologies are employed in different parts of the signal path. Figure 2 shows a representative sample of A/J technologies for GPS receivers. Some can work in series for improved performance. The colored bands depict different sections of the signal path. For example, one can employ a controlled radiation pattern antenna with electronics to "notch out" a direction in space where a wideband interference source is located. Sophisticated filters can be implemented after (or integrated with) the antenna electronics to attenuate narrowband jammers. Finally, advanced signal processing techniques can be employed in the receiver itself.

Anti-Jam Antenna Retrofit for the AN/PSN-11 Precise Lightweight GPS Receiver (PLGR)

BTN developed several of these technologies. Specifically several versions of an A/J antenna suitable for use with the hand-held Precise Lightweight GPS receiver (PLGR.)

Both Electro-Radiation, Inc. (ERI) and Toyon Research, Inc. developed retrofit null forming antennas for the PLGR.

Electro-Radiation Inc. (ERI): The ERI antenna was developed under an ACT II project executed by CERDEC and sponsored by the Space and Missile Defense Battlelab using a topic authored by CERDEC.

Figure 3 - ERI AJAR Antenna

This antenna has two elements forming a single null pointed off the end of the device. (See Fig 3) The LCD display indicates that jamming is being detected and then gives the operator an indication of the level. The operator rotates the PLGR to point the antenna in the direction that gives the minimum interference as shown on the LCD display. This also gives a line of bearing to the jammer. The GPS JPO has funded an effort to "productionize" the ERI antenna.

Figure 4 - Toyon AJ Tool Antenna

Toyon Research Corporation: The Toyon antenna is being developed under a Small Business and Innovative Research (SBIR) program. The Phase II SBIR started in Jan 2002 and is scheduled for completion in Jan 2004.

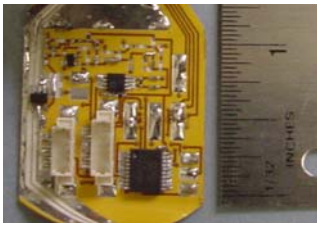

Figure 5 - Toyon Antenna Controller

The Toyon antenna consists of four spiral wound elements. Two are passive and two are active. (See Fig 4) There are electronically controllable impedance elements that enable the controller to automatically steer the null to minimize the impact of the jammer. (See Fig 5)

Advanced Pos/Nav and Tracking for the Future Force
STO IV.C4.2003.02

In FY 2003, a STO, managed jointly by CERDEC and the Simulation & Training Technology Center, entitled Advanced Pos/Nav and Tracking for the Future Force was initiated. The aim of the STO is to develop affordable, reliable and accurate sources of position, orientation and movement information for soldiers and other platforms to support

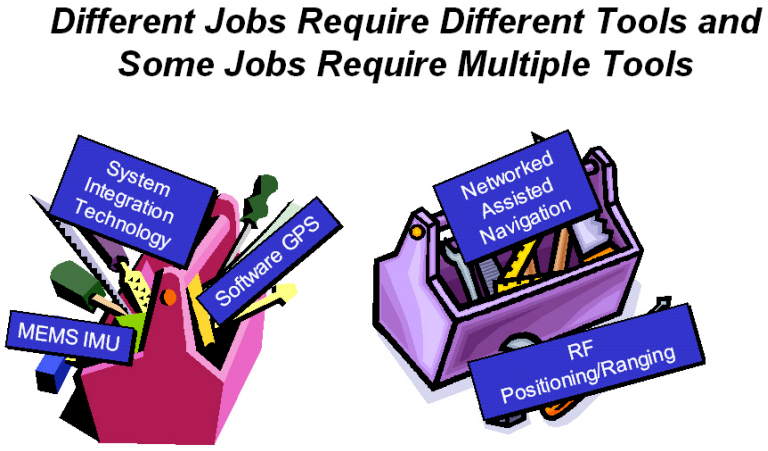

Figure 6 – The Navigation Toolkit

operations and training in urban and other complex environments.

It is clear that complex mission profiles, including urban and subterranean operations will require a suite of navigation sensors to insure position information for proper Situation Awareness and C2.

The technologies being explored in the Adv Pos/Nav STO include: Network Assisted Navigation, RF Ranging, Advanced Pedometry/Dead Reckoning and MEMS IMU integration.

Network Assisted Navigation extends the efforts begun in the commercial world for E-911 service on cell phones. This technology is based on the fact that there is information available via radio/network link that will help GPS or other navigation sensors operate in low or degraded signal environments that would otherwise preclude obtaining a navigation solution.

RF ranging uses time of flight information, similar to GPS ranging, but the "constellation" is the ensemble of users. Advanced algorithms can generate a relative location of, for example, a squad of soldiers in a building. If there are several members of the group that have absolute position, e.g., good GPS, then absolute position solutions can be obtained. The technical difficulty is overcoming wall penetration attenuation and mitigating multipath and reflections.

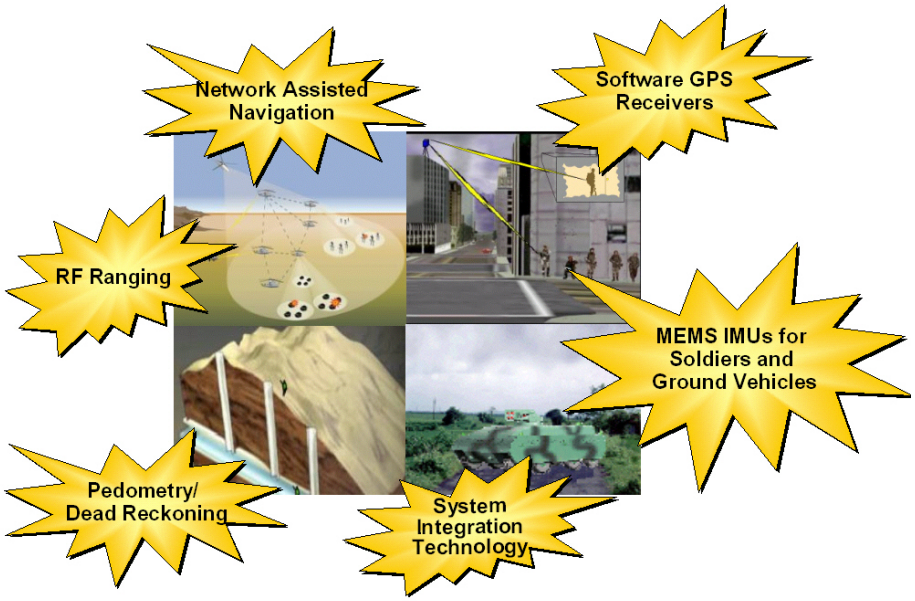

Figure 7 – Technologies being developed under the Advanced Pos/Nav and Tracking the Future Force Science and Technology Objective (STO)

Advanced Pedometry enhances the Point Research, Inc. Dead Reckoning module by adding improved motion classification algorithms to detect backwards or sideways walking and running.

The Micro-Machined Electromechanical Systems (MEMS) IMU integration effort hopes to leverage the commercial and military effort in MEMS to develop extremely small, robust but accurate gyroscopes and accelerometers. These sensors can be combined with the other technologies being developed by the STO to synergistically improve overall navigation performance.

Conclusion

This paper has discussed the evolving role for systems that provide position and time information from a role of navigation aid for individual consumption to a much greater role of enhancing Situation Awareness for remote commanders. This enhanced Situational Awareness capability has been shown to directly improve Command and Control capability to the point that it is identified as a force multiplier. The success of this position and time information evolution into greater utility has spawned many new concepts for its use. The new concepts generally place greater demands on the reliability, accuracy and timeliness of the position location and time information than current systems can provide.

The NAVSTAR GPS was identified as a national dual use asset, ubiquitous in both the civilian and military environments. It is interesting to note that the number of civilian GPS users far outnumber the military users with applications that span from the casual recreational user needs to paramilitary uses that impact real life or death situations. The Army, as the military's largest user of GPS receivers, has integrated GPS as the central component in deriving position and time information on individual platforms that report this information to Command and Control Systems on the battlefield. Due to the utility, practicality and performance of the GPS it is recognized today as an essential component of any navigation subsystem and will remain the central component in the foreseeable future. As remarkable as GPS is to be applied in so many applications, limitations in complex military environments dictate continued work in developing technology that enhance and augment GPS capability in these environments. Additionally, size, weight, power (SWAP) and cost enhancements to expand the utility of military GPS use must be addressed in future work.

This paper further discussed several technology efforts being managed at CERDEC in the Navigation, Position, and Timing Branch to address not only the limitations of the GPS (and augmented navigation systems in general) but also address the affordability and utility to a wider number of platforms such as the dismounted soldier. Currently today's various combinations of Army missions, platforms and need for position location and timing accuracy requirements stress the limits of the available technology applied to various Army positioning applications. Clearly, at present there is no single navigation suite of systems that could possibly be the optimal fit for the various Army applications. The technologies identified for investigation were carefully selected to enhance the Army's navigation capability operating in complex military environments as well as address the SWAP and cost of the technology. Solutions in these military complex environments certainly have application and capability to improve the overall navigation system when operated in less stressful environments as well. It is ironic that as the closer we get to satisfying today's Army requirements in position location and timing, tomorrows evolution of new concepts for future operational capabilities continually drives the need for enhanced capability from the Army's navigation systems while increasing the SWAP and cost constraints.

Position, Navigation, and Timing: The foundation of Command and Control
You bet – and More.

References:

(1) Washington Post, Sunday, March 24, 2002; Page A21, “'Friendly Fire' Deaths Traced to Dead Battery”, By Vernon Loeb, Washington Post Staff Writer

(2) Military Operations, Force Operating Capabilities (FOC), TRADOC PAM 525-66, Training and Doctrine Command, 30 January 2003

(3) Inside The Army, June 30, 2003, Pg. 1

(4) The Department of Defense Dictionary of Military and Associated Terms, Joint Pub 1-02 (JP 1-02), As Amended Through 17 December 2003

(5) Field Manual (FM) 100-14, Risk Management, April 1998

(6) Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System, Final Report, Volpe Laboratory, Department of Transportation, 10 September 2001