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ABSTRACT

Evolution of Ground Line of Sight Data Field Collection Techniques

by

L.A. Fatale, J.R. Ackeret, J.A. Messmore, and J.C. Walker

The U.S. Army Topographic Engineering Center (TEC) has been involved in the collection of ground Line of Sight (LOS) data to support Army studies since 1988. This ground truth data is used in conducting in-depth analyses of elevation model capabilities and limitations. This paper describes the evolution of field collection techniques for ground line of sight data to support various comparative analyses of field data for applications such as terrain visualization, line of sight fan chart generation, and tactical decision aids (TDAs). These field data collection procedures have evolved over a series of collection efforts since 1988. The latest available state of the art technologies have been employed such as total station theodolites, Global Positioning System (GPS) point positioning (differential and PPS Navigation mode), GPS controlled photogrammetry, and the most recent TEC system development, On-the-Fly (OTF) system (uses GPS rapid kinematic techniques). The first LOS field work, conducted at Fort Hood, Texas, was a part of a Tactical Terrain Data prototype evaluation. At that time, distance measuring equipment was the primary data acquisition tool since the GPS constellation was not fully operational and could not support the required near real time collection of location information. In 1993, additional LOS field work was conducted at Forts Bliss and Irwin. At that point, distance measuring equipment was still the primary collection tool, though GPS technology and capabilities played a greater role and its potential for further enhancing of our data collection capabilities was clear. Most recently, this year at Ft. Irwin and at Twenty Nine Palms Marine Corps Air Ground Combat Center (MCAGCC), GPS technology became the dominant technology employed in our ground data collection methodology and we were able to overcome some of the distance limitations of current laser distance measuring technology. In the near future, additional GPS technology will be employed to deal with the ever increasing demands on the field data that more accurate and higher resolution test elevation data sets require. These technologies include GPS controlled photogrammetry, GPS point positioning (differential GPS), and On-the-Fly (OTF) GPS.

EVOLUTION OF GROUND LINE OF SIGHT DATA FIELD COLLECTION TECHNIQUES

L.A. Fatale, J.R. Ackeret, J.A. Messmore, and J.C. Walker

U.S. Army Topographic Engineering Center

1. Introduction

Consideration of Line-of-Sight (LOS) conditions has always been an essential aspect of the battlefield. Knowledge of the surrounding terrain and its corresponding elevation has even more implications today in the modern Army. To date, the Defense Mapping Agency's (DMA) Digital Terrain Elevation Data (DTED) Level 1 database, an elevation matrix with 3 arc second or approximately 100-meter post spacing, has been used by most military and DOD users when elevation data was required for modeling, simulations or other applications. Recent advances in weapon systems and combat simulators has brought into question the adequacy of DTED Level 1 for terrain appreciation and threat prediction applications, especially LOS. Consequently, the need for higher resolution terrain data (e.g, ≤30 meter post spacing) and the ability of differing resolutions of DTED to accurately predict LOS conditions is of great interest to the Army's user community.

Due to the importance of elevation data, the U.S. Army Topographic Engineering Center (TEC) has dedicated considerable resources to understanding the capabilities and limitations of this key digital product. In order to determine the LOS predictive accuracies of various resolutions of elevation data, field collected LOS measurements are required. In the early eighties, as part of an Army prototype evaluation, there was a desire to collect field LOS measurements to better characterize elevation data predictive capabilities; however, no technology was available at that time for rapid and accurate measurement of the ground distances required. In the latter part of the decade, however, another Army prototype evaluation pointed to the need for characterization of elevation data predictive capabilities based upon ground measurements. At that time, electronic distance measuring equipment was employed for accurate distance measurements as well as early generation Global Positioning System (GPS) equipment for accurate, though slow, collection of position information. Our field techniques evolved through the early nineties, and along the way have employed the most advanced technologies available. As our field measurement capabilities have progressed and matured, more accurate and higher resolution elevation data have surfaced for evaluation.

2. Evolution of Techniques

The following sections provide a chronological description of ground LOS data field collection activities at test sites during the period from 1989 to the present.

2.1 Fort Hood (1989)

In 1989, scientists from TEC's Digital Concepts and Analysis Center (DCAC), Alexandria, VA collected ground truth LOS data for the first time. The field collection at Fort Hood, TX was in support of the Army's evaluation of Tactical Terrain Data (TTD), a joint service terrain analysis data set containing a corresponding DTED Level 2 elevation matrix (30 meter post spacing). To investigate TTD resolution issues, a LOS study using cartographically derived DTED Level 1 and Level 2 was carried out. The objective of this study was to evaluate the DTED resolution required to adequately represent terrain morphology in the study area for LOS applications. The study consisted of the identification of four representative observation points and generation of LOS prediction plots for DTED Level 1 and 2. The selected observation points were used as the origins for LOS prediction plots. To assure that the ground coordinates for the LOS prediction plots were accurate, each point was surveyed using differential Global Positioning System (GPS) techniques. This approach fixed the LOS origin locations to an accuracy of 0.05 meters relative to a 4th order fixed horizontal control monument at Fort Hood (MIDMARK 3, 1974). Once the prediction plots were generated, DCAC personnel revisited the origin points to compile field LOS plots which would later be compared to the DTED Levels 1 and 2 prediction plots.

2.1.1 Procedure

2.1.1.1 For initial orientation, the DTED prediction plots were registered to a 1:24,000 USGS TLM on which each specific origin point had been carefully mapped. A visual inspection of the site was conducted and all obvious errors in the prediction plots were annotated. This procedure helped to clarify the plots for later analysis.

2.1.1.2 The five person field team split into two crews. Three team members remained at the origin point and two traveled in a roving vehicle. At times, two members manned the origin point, but this arrangement did not prove time-efficient.

2.1.1.3 The first crew set up an analog theodolite at the origin point to obtain and maintain true lines of azimuth. A compass was used to determine the 0° point for the theodolite. The azimuths were at approximately 20-degree intervals, with intermediate rays focusing on special terrain conditions, in a 360° sweep around the site.

2.1.1.4 The second crew traveled along each azimuth remaining true to the heading via directional instructions radioed to them by the first crew. Whenever sight was lost or gained along each azimuth in relation to the origin point, a distance measurement was taken using a digital laser distance measuring instrument. LOS lost due to intervening vegetation was noted and differentiated from LOS lost because of terrain in order to obtain the most precise representation of reality.

In addition to the LOS measurements, photographs were taken and landmarks noted in a 360° panorama around all 4 points. This information, in conjunction with the annotated prediction plots (see section 2.1.1.1 above), proved valuable in terms of orientation during subsequent plotting of the data.

2.1.2 Data Compilation

The raw data collected in the field was plotted onto coinciding 1:4800 scale aerial photographs obtained at Fort Hood and covering the study area. These photographs were vital in assuring correct initial alignment and accuracy of the azimuths. Once this was accomplished, the field fans (those areas determined to be visible in the field and the masked regions contained within them) were reduced to 1:24,000 scale for comparison to the DTED-generated LOS prediction plots. LOS or the lack of it within the field fan was then compared to the computer generated plots and differences noted. The range of each azimuth was two kilometers or less.

2.1.3 Lessons Learned

The following actions were identified at the time as potential enhancements for subsequent work:

2.1.3.1 Use Real-Time GPS in Precise Positioning Service (PPS) Mode to Locate Origin Points in the Field. Attempts to use a "hand-held" real-time GPS system were unsuccessful due to lack of sufficient satellite coverage. The differential GPS technology employed was highly precise but proved time-consuming. Moreover, its degree of accuracy (.05m) was not required considering the horizontal positional accuracy and resolution of the elevation matrixes used for analysis.

2.1.3.2 Replace the Theodolite With a Digital Survey Instrument Capable of Determining Azimuths as Well as Distance, i.e., a Total Survey Station (TSS).

2.1.3.3 Increase the Sample Size to Approximately 10 Origin Points to Better Characterize the Terrain.

2.1.3.4 Locate Origin Points in Different Terrain Roughness Conditions (Smooth, Moderate, and Rough). This approach assesses the impact of terrain roughness on data performance for LOS applications. Furthermore, establish the origin points in areas of little or no vegetation to eliminate vegetation as a variable and strengthen the validity of the analyses.

2.2 Fort Irwin/Fort Bliss (1993)

DCAC initiated its second LOS field study during February/March 1993 in conjunction with TRADOC Analysis Command/White Sands Missle Range (TRAC/WSMR). The field work was conducted at Fort Irwin, CA and Fort Bliss, TX in support of a Model & Simulation Management Agency (MISMA) sponsored initiative entitled Combat Modeling and the Effects of Terrain (CMET). LOS prediction plots generated by several Army models (using a mixture of cartographic and photographic source data)[1] were compared to LOS field truth data. Model

[1] Photographically compiled elevation data was preferable but unavailable for the entire study area. The mixture of data that was eventually used was the best that could be obtained during the timeframe of the study.

scenarios were developed at TRAC-WSMR from which a list of approximately thirty prospective LOS origin points was produced for each study area and provided to the field team. The points were chosen to represent various terrain roughness conditions. A hand-held Global Positioning System (GPS) receiver in the Precise Positioning Service (PPS) mode was used to locate

the absolute position of points to within 10 to 15 meters. The corresponding geographic coordinates were then annotated on 1:24,000 United States Geological Society (USGS) Topographic Line Map's (TLM) which were used for plotting the points. After each point was located, a 3/4" x 40" metal reinforcing bar (rebar) was driven into the ground to mark the spot for future reference. The use of rebar (instead of wood) afforded a more permanent marker and is especially important if subsequent visits to the site become necessary.

At Ft. Irwin, the full complement of prospective origin points were identified of which four were chosen for further analysis. However, at Ft. Bliss, unexpected difficult terrain conditions prevented the field team from collecting data at most of the prospective sites. As a contingency, three alternative points were identified where conditions were more favorable for LOS collection.

2.2.1 Procedure

A five-member DCAC field team revisited the study areas in April 1993. The following steps were employed in the collection of the field LOS for all the points in the study:

2.2.1.1 For initial orientation, a compass was used to determine the four cardinal points. A field of view in degrees was then chosen based on tactical objectives of the modeling scenario. Field-of-view extent ranged from 120° to 200°.

2.2.1.2 At each study area, the field team split into two crews in a similar arrangement to the 1989 work.

2.2.1.3 The first crew set up a total surveying station (TSS) (combination theodolite and electronic distance measuring (EDM) system, effective range ≤ 2 kilometers) at the origin point to determine lines of azimuth and LOS distance readings along each azimuth. The TSS was registered to grid north using a compass and then "turned" to the appropriate angles of interest. Azimuths were collected at approximately 20° intervals, with intermediate azimuths focusing on special terrain conditions.

2.2.1.4 Climatic conditions such as heat shimmer, dust, and wind occasionally precluded use of the EDM. In these cases, GPS was used to determine range. The field team, using a pocket calculator, manually computed the difference between the Universal Transverse Mercator (UTM) coordinates of the origin point (OP) and the LOS point or "waypoint" (WP). Comparisons with the EDM at test locations proved this method accurate to within ≈10 meters.

The equation used for the GPS range computation is as follows:

$$\text{Distance} = \sqrt{(N_{OP} - N_{WP})^2 + (E_{OP} - E_{WP})^2}$$

where:

N_{OP} = Northing of Origin Point
N_{WP} = Northing of Waypoint
E_{OP} = Easting of Origin Point
E_{WP} = Easting of Waypoint

The most appropriate recording procedure continued on each azimuth for two to three kilometers (depending on terrain conditions) or until sight was permanently lost, whichever occurred first. Analysis was not performed beyond a maximum range of 3.2 kilometers or 2 miles. In addition to the LOS measurements, photographs highlighting terrain features and other landmarks were taken in a 360° panorama around all of the points.

2.2.2 Data Compilation

Raw data collected in the field was plotted onto 1:24,000 USGS TLM's. A coordinate scale protractor was overlaid onto the TLM at each origin point and aligned to grid north. Each appropriate azimuth coinciding with those collected in the field was annotated on the TLM. The azimuths were then plotted to indicate masked or unmasked conditions.

NOTE: Masked and unmasked areas of ≤20 meters in extent were not included in the LOS field collection. It was determined that these areas were small in comparison to the test data sets' resolution and plotting of this data was impractical at the 1:24,000 scale.

2.2.3 Lessons Learned

2.2.3.1 Increased Utility of GPS. Although distance measuring equipment was still the primary collection tool, GPS technology and capabilities played a greater role and its potential for further enhancing our data collection capabilities had become clear. At the same time, it was also recognized that a longer range TSS would eventually be needed to provide distance information along the entire azimuth and to meet the more stringent accuracy requirements of evolving higher resolution test data sets.

2.2.3.2 Importance of a Standardized Elevation Data Source. Analysis results in terms of model sensitivity vs. elevation data resolution were inconclusive due to uncertainty created by comparing LOS predictions generated by a mix of cartographic and photographic source data. It was acknowledged that only photographic source test elevation data should be used for future studies.

2.2.3.3 Importance of Communication Emphasized. In rougher terrain, driving along an azimuth to collect LOS information was often precluded thereby forcing the field team to travel on foot and use a team of people to relay information. In these situations, a portable radio (in contact with the mobile radio in the vehicle) would have been extremely useful.

2.2.3.4 Higher Density of LOS Azimuths at Each Origin Point is Required (i.e., every 10° vs. 20°) for Comparison With Computer Generated LOS.

2.3 Fort Irwin/29 Palms, CA (1994)

DCAC revisited Fort Irwin in March 1994 to collect follow-on LOS field data as part of a Phase 2 CMET study[2]. The Phase 2 study was intended to incorporate several enhancements to the original work such as: 1) increased number of locations for the field work to better represent rough, moderate, and smooth terrain roughness types, 2) utilization of an advisor from TRAC-WSMR to help select more tactically significant locations for the origin points, 3) comparison of several Army LOS algorithms to assess their impact on M&S weapon systems analysis, 4) increased use of GPS technology to fill the gap where traditional field collection procedures had failed or were inefficient, and 5) use of a photographically produced test elevation matrix with a resolution (post spacing) of ≤10 meters.

LOS field work was also conducted at nearby Twenty Nine Palms Marine Corps Air Ground Combat Center (MCAGCC), CA during April 1994 in support of an on-going Advanced Research Projects Agency (ARPA)/Marine Corps terrain fidelity initiative. The above mentioned CMET enhancements were incorporated in collection of the field data which will be used in the development of a high precision Marine Corps training model.

The joint DCAC/TRAC field team identified ten origin points at Fort Irwin and three at 29 Palms. A hand-held Global Positioning System (GPS) in the Precise Positioning Service (PPS) mode was used to locate the absolute position of points to within approximately 10 meters. Origin points were identified with rebar and corresponding geographic coordinates were annotated on 1:24,000 USGS TLM's.

2.3.1 Procedure

The procedure for this round of field work was similar to the previous work with the following enhancements:

2.3.1.1 The TSS/EDM used had an effective range of ≈2.5 kilometers (km). Longer range instruments were not available. Therefore, most measurements ≥ 2.5 km were collected via GPS.

2.3.1.2 The "hand-held" GPS was configured for a wide variety of tasks. In addition to location, the system was used to determine distance and azimuth (secondary to the EDM), including the "0°" azimuth, a necessary step during TSS set-up. GPS was also especially useful in monitoring the position of the roving team during movement between lines of azimuth. Furthermore, in addition to distance, coordinates for northing and

[2]Additional Phase 2 work was conducted at Yakima Training Center in June 1994 (see section 2.4)

easting and a value for ellipsoid height were recorded at each point where LOS was lost or gained. This information was collected to assure better precision in the alignment of the field data with the test data bases.

2.3.1.3 The field of view (FOV) extent at each point was reduced from ≈180° to ≤ 90°. However, azimuths within the new FOV's were collected at 5° to 10° intervals (instead of 20°), to provide a more rigorous portrayal of LOS conditions.

2.3.1.4 All masked and unmasked areas of 10 meters or greater were identified in the field collection. This was done to coincide with the resolution of the test data sets.

2.3.1.5 Both stationary and roving teams had one mobile and several portable radios at their disposal. This afforded the roving team greater flexibility in rough terrain and allowed a greater volume of data to be collected.

2.3.1.6 Target and Observer height were strictly monitored.

2.3.1.7 Formal standardized data collection worksheets were used for the first time.

2.3.2 Data Compilation

Raw data collected at Ft. Irwin was plotted onto USGS TLM's enlarged to 1:12,000 scale. Field data collected at 29 Palms was likewise plotted but at 1:6,000 scale. Final compilation was completed similarly to previous analyses.

2.3.3 Lessons Learned

2.3.3.1 **Data Resolution Pushes Need For Higher Accuracy Field Data Collection.** As the 1994 field work progressed, it became evident that increasingly higher resolution test data sets would be used for this and future similar studies. A 5 meter resolution data set was made available for part of the Ft. Irwin study area and plans were finalized to produce similar resolution data over the remainder. An even finer grid covered the smaller 29 Palms area.

Although GPS in the PPS mode can feasibly produce accuracies as good as 5 meters, this level of fidelity is not consistent. Sub-meter accuracies are attainable with more sophisticated systems but such an advanced system was not available during the field work. Therefore, at times during the Ft. Irwin work and throughout the 29 Palms collection, elevation data accuracy exceeded LOS field collection accuracy. It was recognized that a more precise survey of the Ft. Irwin and 29 Palms LOS origin points was required and that an enhanced level of GPS technology would be necessary for all future work.

2.4 Yakima Training Center, WA (1994)

DCAC continued work on the CMET Phase 2 study at Yakima Training Center, WA in June 1994. It was decided that a full range of GPS technology would be used at Yakima. Collection of aerial photography using GPS-controlled photogrammetry technology was used for production of a digital elevation model. A test DEM with 1 meter post spacing and sub-meter elevation accuracy was the catalyst for the requirement for rapid collection of sub-meter accuracy LOS data. Fortunately, TEC has under development a prototype On-the-Fly (OTF) system with decimeter accuracy that met time requirements for rapid point positioning in the field. This technology is based upon kinematic GPS surveying techniques, but with some advantages. While normal kinematic positioning systems require a period of static initialization in the event of loss of lock with the satellites, kinematic positioning systems which employ OTF technology are not adversely affected by signal losses (loss of satellite lock). OTF systems determine the integer number of carrier wavelengths between the GPS satellite and receiver (integer ambiguity) while the receiver is in motion. OTF positioning systems thereby offer sub-decimeter accuracies in real time or post processed.

2.4.1 Procedure

The procedure for the Yakima field work was similar to the previous work with the following enhancements:

2.4.1.1 The TSS/EDM used had an effective range of 3.5 kilometers (k). The range of this instrument was entirely adequate for the LOS work as the maximum distance for radials were 3.2 kilometers from the origin point.

2.4.1.2 The "hand-held" GPS was configured for PPS navigational mode and used only for general navigation from the 1:50,000 map sheets. The OTF system was used for origin point positioning, azimuth determination, and general navigation.

2.4.2 Data Reduction/Compilation

The OTF system collected point positioning data for the origin points and their respective azimuths. This data was post-processed at TEC and is currently being used for statistical analysis. The raw data collected at Yakima was plotted onto USGS TLM's enlarged to 1:12,000 scale. Final compilation was completed similarly to previous analyses.

2.4.3 Lessons Learned

2.4.3.1 The OTF system proved to be extremely useful for point positioning and azimuth determination; however, power and memory limitations of the receiver required a substantial amount of time to be expended driving to an alternate site where power was available for downloading. Much of this time loss could have been avoided by using a generator on site. In the future, it is recommended that LOS gain/loss along an azimuth be collected only with the TSS instrument (7 km ranging capability). Use of the OTF system along each azimuth makes sense in the case where LOS gain/loss is being derived from elevation data generated along the profile rather than from direct field LOS measurement with EDM equipment.

2.4.3.2 Based upon previous difficulties in visually following the data collection vehicles as they traversed azimuths about the origin, each vehicle was covered front and back with blaze orange. This greatly increased visibility of the vehicles which facilitated data collection.

3. CONCLUSIONS

Evolution of TEC's ground LOS collection capabilities has taken place on two fronts. On one front, we have improved upon methodologies used to physically collect the data such as use of hand-held radios to facilitate coordination, employing a highly visible color (blaze orange) on the vehicle to aid in data collection, and employing rebar rather than wood stakes to ensure the origin points can be relocated after having been run over by a 70-ton tank. On another front, in the technology area, a number of improvements have been made. GPS is now fully operational and is a must for rapid collection of highly accurate key position information. EDM equipment is available with 7km measuring capability that adequately fulfills our needs even in circumstances where atmospheric conditions reduce this capability.

As our ground collection capabilities have improved, candidate test data sets have also improved in terms of accuracy and resolution. Ground collection accuracies that were initially adequate for DTED Level 1 data sets (30 meter vertical accuracy and 100 meter resolution) are today inadequate for test data sets with vertical accuracies of less than 1 meter and resolutions of 5 meters. Fortunately, technology applicable to ground LOS collection efforts has kept pace with this development of higher accuracy and more dense elevation data sets.

Based upon our experiences to date, it is anticipated that future ground LOS data field collection studies will selectively employ both GPS and EDM technologies. Specifically, OTF positioning systems will target our need for highly accurate origin point and 0° azimuth determination while 7 km capable EDM equipment will be employed for turning azimuths about the origin and for measuring gain/loss distances along a given azimuth. In addition, "hand-held" GPS, configured for PPS navigational mode, will be used only for general navigation purposes.