Impact of High Resolution Terrain Data on C2 Decision Making

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ABSTRACT

New surveying and surveillance technologies and data processing techniques are allowing Command & Control (C2) decision makers access to significantly higher resolution terrain databases. Selecting the most appropriate trade-off between data resolution and speed of analysis is critical to successful C2 decisions. This paper uses LIDAR as an example to illustrate the impact of trade-offs within C2 planning systems. We conclude that planning systems must highlight realistic limitations on data quality. They must also provide an environment for decision making that allows a scalable approach to spatial analysis. This paper also highlights the importance of higher resolution data sets in enabling new areas of analysis.

INTRODUCTION

Decision making is planning the most appropriate course of action based on an assessment of available data sources. Within the realm of military Command & Control (C2) planning, an important element of the decision making process is based upon geographical terrain data and associated features. This paper examines LIDAR technologies to illustrate the potential impact of higher resolution terrain data capture on functional applications within C2 planning systems.

ISSUES WITH DATA QUALITY

It is often considered that spatial data "quality" is a critical issue in C2 planning. But what exactly constitutes spatial data quality ?

Defining Data Quality

According to our analysis, data quality consists of four distinct elements;

- Resolution - The spatial frequency of data, or density of measurement points
- Accuracy - The uncertainties within the data as a function of space (and time). A measure of accuracy within a data set is termed *relative*, whereas the accuracy of the data set when compared to reality is termed *absolute*

- Timeliness - A function of the time that has elapsed since data collection indicating its age and refresh rate
- Usability - The ease of data interpretation, understanding and integration with C2 systems. This contains many elements including the completeness of the data set and the processing required to exploit it.

It is important that new technologies and techniques for data collection, processing and analysis continually drive towards increased data quality. This will give C2 decision makers access to the best possible range of data sets. However, each of the four elements of data quality above can, for the case of terrain data, always be improved and can hence never be considered "perfect". It is important here to underline the fact that C2 decisions need to be taken regardless of the data available. This drives us to two immediate conclusions;

1. *It is essential to support C2 decision makers in extracting the maximum value from data sets that are currently available.*

We must remember to place an equal importance on exploiting existing data sets as well as pursuing better quality data. This exploitation can be witnessed by the use of appropriate C2 planning systems that expose the decision maker to the realistic limitations imposed by the quality of the data available. Such systems should offer the decision maker access to a scalable range of increasingly detailed data sets where available. We will discuss this further below.

2. *C2 decision makers themselves, in conjunction with C2 application developers, must be able to accurately assess their data requirements.*

If there are no "perfect" data sets, both C2 system designers and users must have an understanding of the required data quality limits. In all cases, data must be "fit-for-purpose", weighing up the two conflicting factors of;

- High resolution and accuracy, to maintain very high levels of fidelity for analysis
- Timeliness and usability, to limit data collection and processing times to acceptable parameters and to have sufficient data completeness

Without clear guidelines on data requirements, we risk collecting data sets and integrating them with C2 software tools for no tangible purpose. Potentially much worse, without an understanding of data quality limits and an appropriate software development strategy, we risk developing systems that generate results that appear to be of much greater fidelity than they are in reality.

The Current State of Data Quality

Many military spatial applications use Digital Terrain Elevation Data (DTED) Level 1 (or where available, Level 2) produced by the National Imagery and Mapping Agency (NIMA) as their source of geographical data. DTED Level 1 has an almost global coverage, while DTED Level 2 is only available for limited geographic areas.

Table 1 below shows the resolutions and accuracies that can be expected from these data sets. With DTED data each height value corresponds to an arc segment of the Earth's surface at the bare earth level. This can introduce significant geodetic problems when manipulating these data sets within certain software applications. This is discussed in more detail below.

	DTED Level 0	DTED Level 1	DTED Level 2
Resolution	Approx. 1000m	93m	30m
Accuracy (x,y)	N/A	≤ 50m	≤ 23m
Accuracy (z)	N/A	≤ 30m absolute (≤ 20m relative)	≤ 18m absolute (≤ 12-15m relative)

Table 1 : Approximate resolution and accuracy parameters for DTED terrain data. These figures are definitions of maximum accuracy limits. Note that accuracy is lowest at high latitudes and steep terrain gradients, so for most geographic areas accuracies can be considered much lower than these limits. Accuracy for DTED Level 0 is not specifically assigned but usually taken from DTED Level 1.

In 2000, a joint NASA and NIMA space shuttle mission collected a new higher quality data set referred to as the Shuttle Radar Topography Mission (SRTM). The processing is on-going, but should lead to a resolution of approximately 16m with absolute accuracies of ≤ 20m (x,y) and ≤ 16m (z), roughly equivalent to DTED Level 2 but with a much greater coverage area.

It is important to stress that all of these quoted accuracy limits are the maximums defined by the DTED data standards. DTED standards cover all geographic areas, including high latitudes and mountainous terrain, where accuracies are much poorer. For most mid-latitude areas, accuracies of the order of a few metres can be expected.

However, all of these data sets, with resolutions and accuracies of the order of metres, limit any analysis to "shape of the Earth" problems. In other words, they are only suitable for defining an approximate representation of the Earth's surface. As such, they can be used for large area problems such as cresting analysis, but give little or no information about detailed features such as foliage cover or buildings.

In conclusion, current terrain analyses can only give C2 decision makers "best guesses". Although these analyses can greatly improve operational readiness and efficiency, the requirement for recce teams (manned or unmanned) remains. This is the only reliable method for gathering detailed information about small terrain features, which with modern emphasis on urban and guerrilla warfare, are of increasing importance. As such, we must examine the possibilities of obtaining much more detailed terrain data to be able to include such features in C2 planning.

New High Resolution Technologies

We have seen that currently available data sets reach resolutions and accuracies of the order of metres. Here we examine LIDAR, a technology capable of higher resolution data capture and use this example to discuss the effectiveness of supplying C2 decision makers with information on detailed terrain features.

LIDAR (LIght Detection And Ranging)

It is possible to determine a distance to a target extremely accurately by using an infrared laser (LIDAR). A short flash of radiation is emitted and the time taken for the first fraction of the signal reflected back from the target (first return) is measured. If the exact location of the LIDAR is known, and the direction it is pointing, it is possible to deduce the exact location of the leading surface of the target.

We can use this concept by coupling a high repetition rate solid state LIDAR with high precision differential GPS (for location) and an Inertial Navigation System (for direction). This LIDAR system can then be mounted on an airborne platform (such as a helicopter) and pointed at the ground to carry out extensive 3D terrain mapping at very high accuracy and resolution. For airborne systems, the exact resolution and accuracy of measurements depend upon the altitude and speed of flight of the platform, the LIDAR repetition rate and the laser beam diameter (spot size).

Until recently there have been two types of airborne LIDAR systems; high altitude, high strength lasers and eye-safe lasers that can be used up to an operating height of only 60m. The former tend to give limited performance regarding resolution and accuracy, whereas the latter are operationally difficult to manage, requiring access to very low level airspace. We have developed a helicopter-mounted system with an operating height range of 60-500m. Our improvements in laser engineering and GPS / INS technology result in a high level of performance. At 150m operating height, for example, our system can deliver a resolution of 30 points per square metre at an absolute 3D accuracy (x,y,z) of ±5 cm. Figure 1 shows an example.

It must be noted that LIDAR actually creates a Digital Surface Model (DSM) which contains elevation data for the Earth's surface including all objects on the ground, such as buildings and trees. This is because the first return of the LIDAR pulse corresponds to the first surface it encounters. Hence data filtering is required to retrieve the bare earth elevation model equivalent to DTED data.

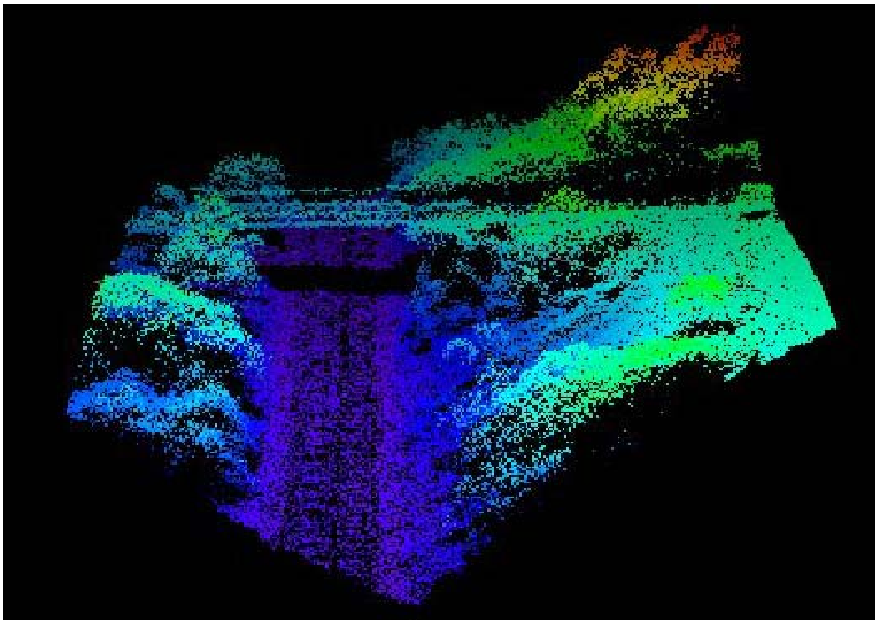

Figure 1 : High resolution 3D image of a railway cutting taken by QinetiQ Survey & Surveillance using the QinetiQ Airborne Topographic Lidar System (ATLAS) mounted on a Twin Squirrel helicopter

Alternatively, it is possible to retrieve some information on overlapping features (such as foliage over ground level) by examining multiple reflectance returns. This involves measuring secondary LIDAR returns and requires the reflected pulse detector to remain active for longer. In addition, the intensity information obtained from the different LIDAR returns can assist in classification of features. This results in slightly decreased resolution for equivalent measurement conditions relative to "first return only" systems.

IMPACT ON C2 APPLICATIONS

As we have previously stressed, the purpose of all terrain data collection is to enable faster, more accurate C2 decisions. New high resolution data sets shift the focus of attention from large area "shape of the Earth" problems to small area detailed analysis. However, we have concluded above that C2 application developers must consider a number of trade-offs to deliver maximum performance of their systems. This section looks at some specific trade-offs related to high resolution data.

Resolution vs. Processing Speed

The increasing resolution of terrain data sets is placing an ever greater burden on C2 applications with respect to data storage and processing. In addition, many of these technologies give more information than just spatial location, such as surface roughness, feature extraction and characterisation.

It is clear that high resolution data sets allow a much greater depth of analysis. On the other hand, data manipulation becomes increasingly unwieldy and time consuming, slowing down the C2 decision making cycle. Data compression techniques allow increasingly more effective storage and manipulation of large data sets to fully exploit their potential benefits but do not yet solve this issue.

In summary, existing DTED Level 1 gives almost global coverage. To build high resolution data sets to the same scope would place extraordinary demands on data storage and processing. A compromise is required.

Accuracy vs. Completeness

Because we currently do not have access to a global high resolution data set, this becomes a fundamental trade-off. If we base our C2 system on a low resolution, wide coverage data set, we are unable to exploit any higher resolution data that may be available. If we use a higher resolution data set with limited coverage, we have the problem of "filling in" the missing areas for which no data is available. Currently for DTED data, it is possible to use Level 2 data sets, reverting to Level 1 to provide total coverage where necessary. This leads to variations in resolution and accuracy within the C2 application that are dependent on the geographic area studied. These variations need to be considered in any analysis. As coverage must be considered the first and highest priority in any C2 system, we envisage that the concept of "filling in" needs to be extended to incorporate higher resolution data sets. This is discussed further below.

Visualisation vs. Analysis : The Projection Problem

It is important at this point to distinguish between two different uses of terrain data. Simply converting data sets into 2D or 3D images for visualisation of an environment is a fairly straightforward process. Beyond the processing requirements discussed above, the move to higher resolution data sets will not introduce any significant changes. However, if we wish to perform calculations based on terrain data (such as line-of-sight calculations) there will be further impact.

Most algorithms used for spatial computation are based upon a "flat Earth" representation of geographical information. In other words, they assume a projection system (such as those currently used for paper maps). Existing DTED data is geocentric, with each data point corresponding to a point in 3D space referenced relative to the centre of the Earth. This is equivalent to representing an arc segment of the Earth's surface (mathematically represented as an ellipsoid surface).

Currently, to perform spatial calculations requires sophisticated data processing to re-project DTED data into a suitable "flat Earth" model. New (non-geocentric) high resolution data sources, such as LIDAR, do not in themselves require this processing. However, in the vast majority of cases we will wish to compare this data with a map, which will be shown in a specific projection. Therefore, in order to overlay the results of all analyses, even higher resolution data sets (or the results produced from their analysis) must be projected into a suitable projection system.

In conclusion, projection is always required and this in itself necessitates a strong knowledge of spatial data management techniques. This is especially the case when dealing with new data sets as we can no longer rely on tried and tested processing as applied to DTED data sets.

Large Area vs. Small Area Analysis I : The Geodetic Problem

Current spatial analyses, limited by current resolution constraints, can only be applied to large area problems. When dealing with terrain data over large areas, and particularly where high levels of accuracy are required, it is essential to have a detailed understanding of geodetic principles (i.e. how geographic locations can be related to each other). Examination of a spatial problem requires all terrain data to be contained within a common "flat Earth" co-ordinate system (see above).

Problems arise from the fact that the surface of the Earth is curved. Mathematically, the best description of the Earth's surface of geopotential (or geoid, considered equivalent to mean sea level) is elliptical. However, the real geoid is not precisely an ellipse. It follows that straight lines in map projections actually relate to curved arcs that can not easily be described mathematically. This means that any map projection system requires adjustment to take this difference into consideration to prevent significant errors in spatial calculations.

Higher resolution data sets will enable self-contained analyses of small areas to be carried out, and relative accuracy limits can be used. For such problems, geodetic effects can be considered negligible. However, if we wish to relate this analysis to a map, we must now consider geodetic effects to allow the correct geo-referencing of our data. We must also work to absolute accuracy limits.

In summary, geodetic problems must be considered for all but the smallest self-contained analyses. This again underlines the need for detailed understanding of spatial data management, but geodetic effects can be considered within processing techniques and projection systems.

Large Area vs. Small Area Analysis II : The Timeliness Problem

We have already highlighted that current analyses are limited to large area "shape of the Earth" problems. For such problems, it is fairly safe to assume that the terrain data will not change significantly over time. However, once data sets are high enough resolution to pick out buildings, trees, etc., the timeliness element of data quality begins to have a much greater impact.

In essence, the greater the age of high resolution data, the more systematic errors it will contain. This implies that there is a requirement for a greater data refresh rate for higher resolution data sets. The consequence is a massively increased burden on data collection and processing, not only from the greater resolution but also for the requirement for more frequent measurements. The use of high resolution data in C2 planning is well beyond the current limits for speed of analysis if we attempt to use it in the same manner as DTED data. This promotes a different approach to exploiting terrain data that will be much more focussed.

It can be envisaged that the ultimate aim to improve the timeliness of data will require a more rapid feed of ISTAR information into C2 planning tools. One of the main barriers to this is the requirement for processing of spatial data to consider projection and geodetic effects.

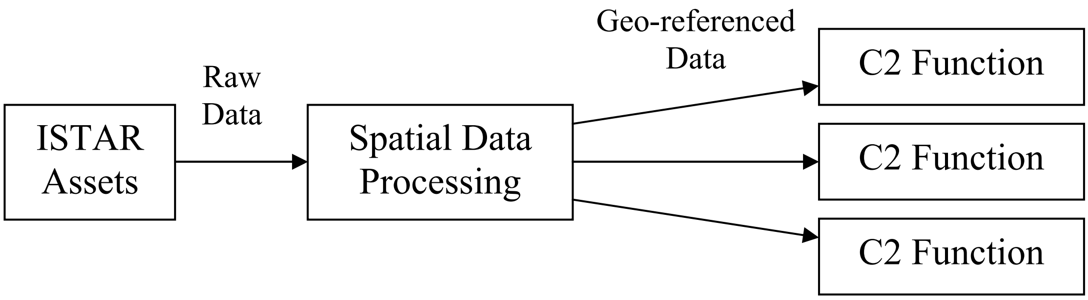

Figure 2 : The data feed for C2 applications showing the requirement for spatial data processing. This feed must be speeded up if we are to satisfy timeliness requirements for exploiting high resolution data within C2 applications.

Scalability – A Realistic Solution

The analysis we have outlined above shows that it is not currently feasible to use new high resolution data sets in the same manner as DTED data is used in existing C2 planning applications. This is due to the lack of sufficient capacity for data storage, insufficient data refresh rate and requirement for significant amounts of data processing. However, it is clear that data capture technologies such as LIDAR have a vast potential to improve C2 planning processes. In order to fully exploit both existing and future data sets, an adaptable approach to application development is required, allowing a scalable method for C2 spatial analysis.

We propose that C2 planning should start with large area analysis based on DTED data sets. This will allow computational analysis of terrain features. For such analyses the coverage of the data set is a key requirement above and beyond accuracy. Spatial data processing can be carried out to take into consideration geodetic effects to allow the required “flat Earth” projection of terrain data. Algorithms for spatial analysis can be adapted to compensate for the curvature of the Earth.

C2 decision makers require the opportunity to explore and investigate their C2 plans in a simplistic, easily visualised environment of the relevant geographic areas. C2 decision makers should not be concerned with the intricacies of spatial data management, hence all of the data processing need not be exposed to the user. These “broad brush” analyses of large terrain features will answer many C2 issues, as they do currently. In addition, they should highlight areas of specific interest for more detailed study.

When specific areas are identified for detailed analysis, high resolution data sets must be accessed on an “as needed” basis. Storage requirements may present problems at this point in time, but are unlikely to present any significant obstacles to exploiting high resolution data sets in 5-10 years time.

It may be possible that all C2 applications hold full data sets locally. If not, there are two possible alternative solutions; either data is called up from a central data repository as needed, or data sets are only collected and delivered when requested. Both of these options raise issues regarding the need for fast data transfer, security and reliability of data links, etc., which are not addressed in this paper. It is the opinion of the authors that the most likely solution is for low resolution data to be held locally. The most high resolution and time-sensitive data will be obtained through closer links between C2 planning applications and ISTAR assets, including the necessary spatial data processing stages. This will allow C2 planners direct access to the most accurate, up-to-date data, within their own planning systems.

This leads to the concept of “Geospatial Decision Support”, where flexible IT applications can lead C2 decision makers through a hierarchical planning process. Through a stepwise refinement of the scope of the problem, the most appropriate data set can be selected at each stage. Large area, low resolution, full coverage analyses can lead C2 decision makers, where possible, to drill down into more detailed high resolution studies. Data processing and algorithm development is carried out during application development to remove this skill requirement from the C2 decision maker. Further work is required to tighten links to ISTAR assets and information flows, but such a step would be entirely coherent with our flexible and scalable approach to C2 planning.

CONCLUSIONS

We have discussed one example of high resolution data capture (LIDAR) that can give data sets of over 1000 times greater resolution than the DTED data currently used. However, the massive burden this places on data storage, refreshing, and processing currently rules out using such data sets as a direct replacement for DTED data. If we wish to exploit the enormous potential of high resolution data sets, C2 planning systems must adopt a scalable approach to spatial analysis, first performing large area analyses to home in on smaller areas of specific interest. The C2 decision maker can then call up high resolution data as and when required. It is highly likely that such data sets will be supplemented by ISTAR assets on an “as needed” basis to overcome problems associated with the timeliness of data on detailed terrain features.

We believe that our concept of scalable C2 Geospatial Decision Support puts in place a C2 planning approach that is both flexible and scalable enough to support the introduction of new high resolution data sets. It also puts in place an appropriate methodology for the design and development of such C2 applications. With increasing emphasis on urban and guerrilla warfare, the full exploitation of existing terrain data and the introduction of new high resolution data for extensive analysis are critical to maximising operational efficiency and speed of response.