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GIS/ISR - Fusion on the battlefield

Dr Carlo Kopp

Geographical Information Systems (GIS) are a byproduct of the digital age. First developed during the 1960s, GIS have found numerous civil niches but increasingly are penetrating into a range of military and security applications. The most recent step in this progressive evolution is the fusion of GIS with Intelligence Surveillance and Reconnaissance (ISR) products.

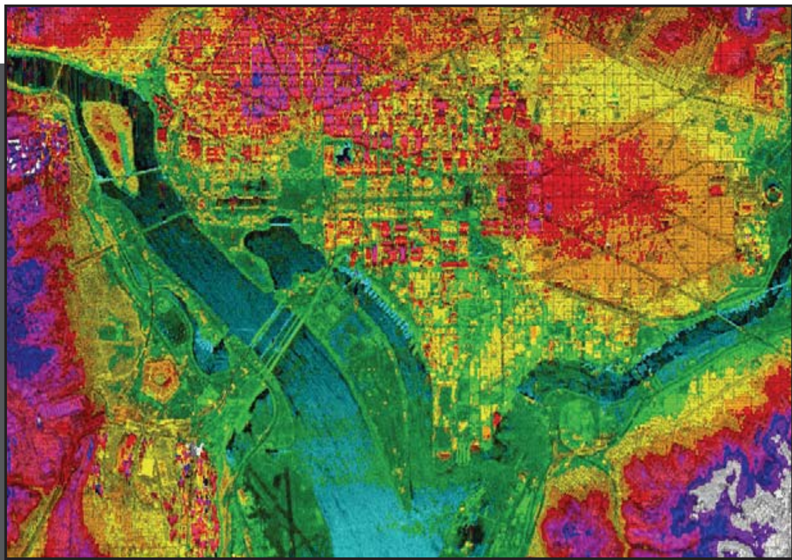
Consider a future scenario where the notional “Sword of Allah” Islamist militia takes control of a city in a Third World nation. It declares itself to be the new Taliban, ready to host terrorists. The decision is to defeat the militia to allow the legitimate regime to regain control. While precision air attacks bear the brunt of the action, special operations raids capture key terrorists, militia leaders and documentary material. Local ground forces occupy the city and round up militia members who survive the initial attacks.

During the operation, human intelligence and signals intelligence provide good indications of the disposition of the militia and its key assets. However, the region is so underdeveloped the best visual mapping data available is based on decade-old satellite imagery, 1990s Shuttle synthetic aperture radar elevation maps, and colonial-era planning maps for the city. Yet, performing the required air strikes and ground force raids requires significantly more complete, accurate and certainly current data. While legacy maps and aerial or satellite imagery could be digitised and entered into a GIS database, this material lacks currency.

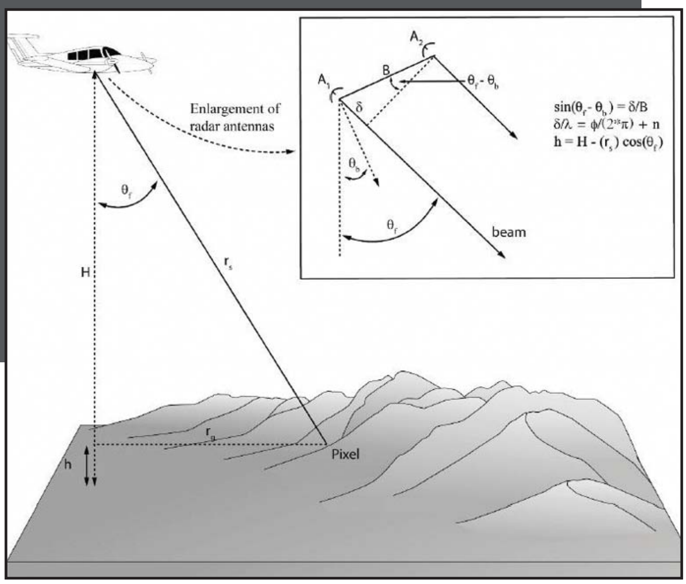
In this notional scenario, the JFACC (Joint Force Air Component Commander) is asked to generate ISR sorties to build up a current GIS database of the target area, while Intel staff input legacy datasets into the GIS database.

A large UAV is launched, equipped with an optical and infrared imaging suite, and it flies a meandering pattern over the city, gathering daylight visual and infrared images of the city and surrounding areas. These are transmitted in real-time to the UAV control station and a courier is dispatched with multiple hard disks containing the datasets. A repeat sortie is flown at night, imaging in two infrared bands to establish areas of habitation using two-colour infrared imaging and thermal profiling.

While this transpires, intelligence staff merge existing digital maps of the city with legacy hardcopy maps of streets, building plans for key sites and the sewerage and aqueduct maps. The hardcopy maps are first scanned, the bitmap images converted by software into vector datasets, and then mensurated against the GIS database. The latter uncovers major inaccuracies in the placement of streets and buildings in the legacy maps, but software tools designed to correlate map features correct these errors.



Interferometric SAR uses vertically displaced antennas to extract terrain elevation information. This allows such radars to produce 3D terrain maps.



Interferometric 3D Synthetic Aperture Radar (Uni of Washington image), lower Interferometric SAR (image of Washington, DC) produced in 1993 by the Jet Propulsion Laboratory(JPL) AIRSAR carried by the NASA Ames DC-8. Height is encoded in colour.

As the database is built up it is clear that elevation of terrain and buildings will be a major issue. The city was built on a steep hillside, and numerous sites and tall buildings provide commanding fields of view and fire covering key approaches to the city and all prospective landing zones for helicopter insertions. The JFACC requests a sortie by a fighter equipped with a three dimensional Interferometric Synthetic Aperture Radar system capable of mapping with pixel sizes of eight inches and generating accurate elevation data by virtue of a vertically displaced antenna pair. The aircraft arrives on station and flies two orbits around the city, each at a different altitude producing 8-inch resolution elevation maps of the area. Orbits are required to avoid radar shadows. The dataset is so large it is stored on an internal hard disk, which is extracted from the aircraft after it returns to it base.

Intelligence staff load the 3D SAR images and process the datasets with a software package, which first merges the various azimuthal images to eliminate shadowing where possible and then converts the 3D representation into a vector dataset. The vector dataset, a current representation of the shape and elevation of all features, is then loaded into the GIS database.

Further effort is required, with the infrared and optical high-resolution images loaded into the GIS database. The picture of the objective is becoming clearer day-by-day as the fusion of the datasets progresses.

With a first complete synthetically generated GIS database, intelligence and imagery analysts proceed to compare the GIS representation with the infrared and optical high-resolution images, and other intelligence sources. Markers are inserted into the GIS database indicating confirmed targets and possible targets and areas of civilian occupation that present collateral damage risks.

A team of operational planners then analyses the deployment of hostile forces and their tactical options. A specific software tool proves of great value, as it shows in a colour overlay on the map the field of view and fire from any designated datum point in the database. Key observation posts, occupied roofs and towers are used to identify blind spots in the defender's coverage.

As the operational plan for taking the city develops, it is clear that all Western approach routes are unusable due to the large number of well elevated stone buildings, which present good cover and field of fire for the defenders. The Eastern approach routes are concealed due to terrain elevation, hampered by wooden buildings of low height, which deny the defenders good visibility and cover.

Three weeks of data gathering, fusion and analysis have produced a good picture of the upcoming battleground, and the operational planners have pinpointed all weaknesses in the defensive deployment.

As the attack nears, UAVs equipped with Ground Moving Target Indicator (GMTI) radars are deployed to continuously monitor the movement of vehicles and troops in the city. Analysts use software to produce time histories of these movements, and discover that one hospital and three elementary schools are being used to stockpile munitions. They also discover that several small buildings are being used as access routes to the aqueduct and sewerage tunnels where the defenders have caches of weapons, food and prepared movement routes. The defenders do not know that infrastructure maps made in 1937 by the former colonial administration included all of the entry shafts used for inspection and maintenance.

The attack on the city is initiated. Special Forces penetrate unseen to their objectives and secure a valuable haul of prisoners and intelligence material. As they egress their targets, bombers arrive overhead and proceed to destroy key strong points with 285 lb smart bombs. Several key points in the sewerage and aqueduct systems are caved in with 2,000 lb bunker busting bombs, to deny the defenders concealed movement and access to munitions caches. After three hours of bombardment, government ground forces storm the city led by coalition force advisers, each carrying a handheld terminal providing GIS database access. The diehard militia fight to the last but their traditional advantages of concealed movement and prepared ambush sites are gone. Twenty hours later, resistance crumbles and the city falls.

This scenario may be hypothetical but the basic technology it presents is not. All of it exists and is being used in a range of applications, some in commercial remote sensing, and some in military applications. What remains hypothetical is the full integration of these technologies to produce a comprehensive spatial picture of a battlespace.

GIS System

The typical GIS system is a digital database of coordinate and object information, all referenced to a geographical coordinate system. To call a GIS system a 'digital map' is to do it a disservice, as typically mapping data comprises only a small fraction of the information held in such a system.

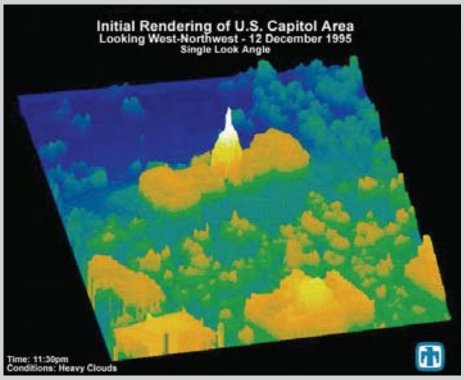
The most frequently seen GIS are used by urban planners and include combinations of mapping information, cadastra (property boundaries), surface structures and roads, subterranean services such as sewerage, water pipes, electricity and communications cabling, access tunnels and other features of interest. The reasons for such systems emerging are pragmatic - a backhoe operator must be told where he can or cannot dig. It is worth observing that in the era predating GIS, instances of cables and pipes being inadvertently cut during earthworks were much higher, with significant service outage and monetary costs resulting. Another area where GIS have proved valuable is in mobile telephone network planning, as they permit modelling the effects of terrain elevation and obstructions such as buildings on radio propagation.

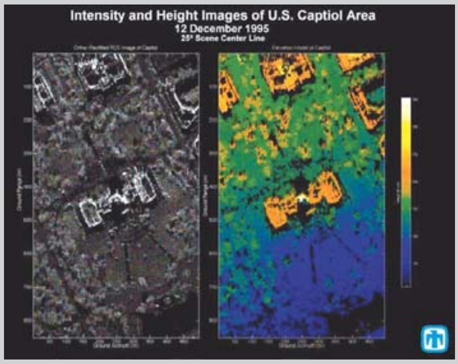
GIS are however not constrained to urban infrastructure planning applications. Suffice to say any application where data with a geographical spatial extent needs to be managed, analysed or handled is one where GIS tools have use and are increasingly used. There is a plethora of software tools now available for GIS applications, including Autodesk Mapguide, Cadcorp PostGIS, ESRI Arcview/ArcGIS, Clark Labs IDRISI, Intergraph Geomedia, MapInfo, Microsoft MapPoint, Caliper Maptitude, TransCAD and TransModeler, GRASS (Geographic Resources Analysis Support System) developed by the U.S. Army Corp of Engineering Research Laboratories, and MapServer developed by the University of Minnesota.

Military applications have emerged over the last decade, primarily as a byproduct of urban combat and the need for precision targeting in urban areas. The urban combat problem emerged millennia ago and has persisted. Urban areas qualify as 'complex terrain', as buildings, tunnels, basements and other structures provide opportunities for defenders to prepare ambushes, hide from attackers, play the 'human shield' game and conceal weapons caches. It is this detailed local knowledge, which has historically favoured insurgents and defenders in urban terrain whether the attacker is advancing on the ground, or orbiting overhead with a payload of smart bombs.

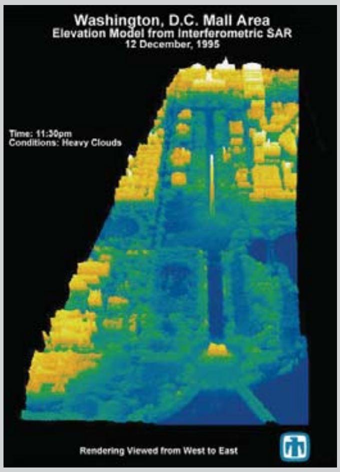
Whether fighting the Battle for Stalingrad, the Battle for Berlin, Hue during the Tet Offensive, Grozny, or the ongoing insurgency in Iraq, the recurring problem for an attacker is maintaining high situational awareness while knowing and understanding an opponent's options in urban terrain.

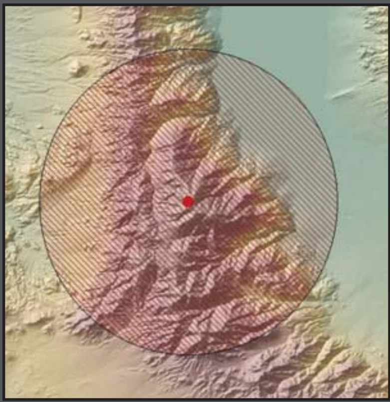
The related problem that emerged during this period is targeting for precision air strikes. Even a 500 lb smart bomb is a weapon with significant destructive footprint in a dense urban environment, and the long running history of insurgent and rogue nations in playing the human shield game created an enormous imperative to increase the quality of targeting. The 'CNN factor' being what it is, every

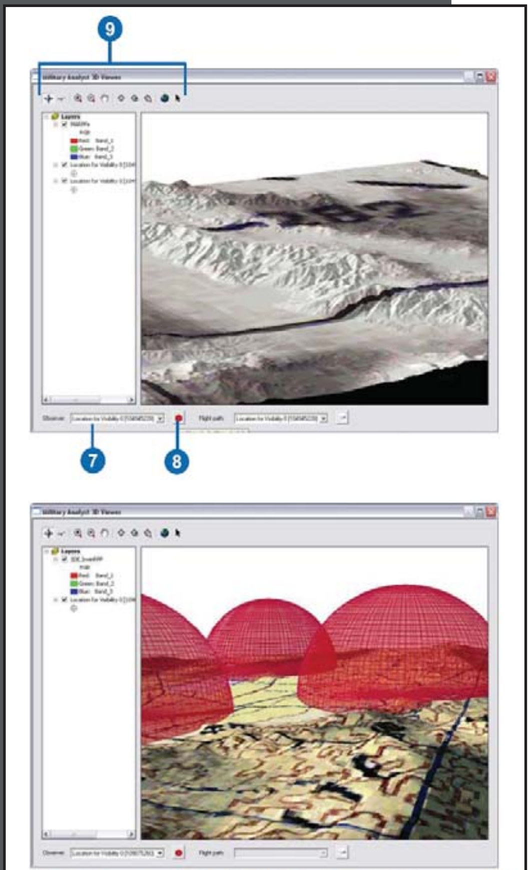




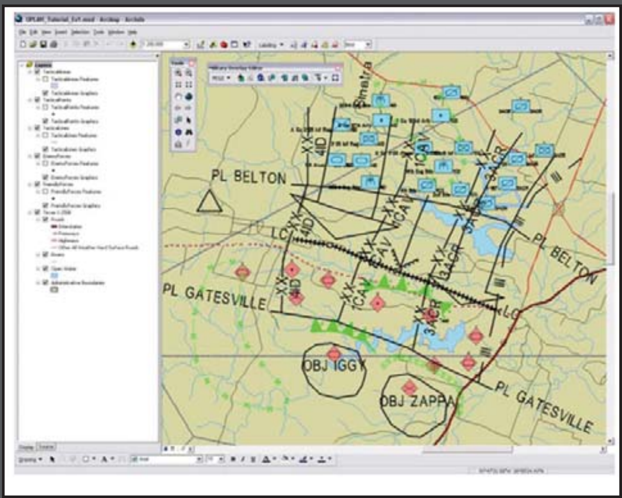
Sandia Labs Interferometric SAR imagery produced during the 1990s, and rendered in 3D with radar captured elevation data.







The 3D Viewer populated with JOG data from an RPF catalog and multiple threat domes from an RLOS observer shapefile



ESRI ArcGIS 9 Military Analyst and Military Overlay Editor screen shots.

bomb hitting anything other than a hostile will produce enormous propaganda value very rapidly.

Conventional maps, even local street directories and planning maps are often limited in detail, cumbersome to use and demand considerable expertise in reading. Rapidly accessing the data required to understand a tactical situation, especially an opponent's ingress and egress options, concealment options and the opportunities these present are a genuine problem. This is a problem initially faced by police forces in hostage situations, and more recently in counter-terrorism operations. Provision of real-time or near real-time access to GIS databases during military operations and planning activities thus presents a high value capability, both for ground troops and air assets engaged in operations.

The principal challenge is implementation since detailed GIS databases largely exist only for developed nations where there are imperatives to make the investment and the resources to do so. Far more problematic is the production of detailed GIS databases for Pyongyang, Tehran, Mogadishu and other problem sites. The reality is that most demand for urban combat and associated supporting capabilities arises in places that are typically underdeveloped and run by regimes that lack incentives and resources to even contemplate GIS database development. Indeed, if such databases exist they will more than often not be available and require espionage to acquire.

An idea that has recently emerged is the use of modern digital high-resolution ISR products to facilitate rapid production of GIS databases.

Fusion of GIS and ISR

At present, the process of technological evolution in the fusion of GIS and ISR is embryonic. The US military have a number of programs and research projects exploring this area but as yet there is no overarching effort to produce a fully integrated system. Its emergence in the longer term is however inevitable, as the pressures of the long running Global War On Terror make it so.

Last year, the US Marine Corps contracted the US National Geospatial-Intelligence Agency (NGA) to produce 'city map books' of Iraqi towns and cities, not unlike street directories printed in Arabic and English to aid troops in counter-insurgency tasks. NGA use an internal system, the Commercial Joint Mapping Toolkit based on an ESRI GIS product. A parallel NGA program is the Stereo Airfield Collection (SAC) effort, using synthetic stereo imaging and obstacle height-finding on commercial satellite imagery to map the proximity of airfields used or likely to be used by US forces – the aim being to establish clearances for instrument approaches, taxiing and risk assessment of possible MANPADS attacks.

A recent interview in the US C4ISR journal cites a senior NGA staffer stating: "Our ability to accurately place weapons on targets has exceeded our understanding of the functional and physical properties of the target. The result has been that we have used the right weapon against the wrong target. Geospatial intelligence holds great promise for reducing the ambiguity that plagues the task of divining those targets that really matter from all possible targets. Smaller weapons, driven by smaller collateral damage, force a greater understanding of the target you intend to strike. This will force us to better understand the situation on the ground. It requires bringing together all sources, including targeting pods, unmanned aerial vehicles and commercial imagery. In some cases on the ground, we're having some pretty good success with that now. In other cases, there's significant work to do. It's a mixed bag."The NGA's thinking is that in the longer term all sources of imagery and intelligence data will need to be fused with high quality elevation mapping data.

There are significant research projects underway. An example is the Advanced LIDAR Exploitation System (ALES) project sponsored by the US Army and the US Geological Survey contracted Visual Learning Systems to develop the LIDAR Analyst, which produces 3D GIS models from 3D LIDAR mapping data using an ArcGIS database.

Sandia National Laboratories have had a long running effort involving advanced SAR technology and Interferometric SAR for 3D mapping. Work produced by Sandia over a decade ago shows the potential of this technology.

Space precludes a survey of the full scope of current programs in the US but it is very clear that fusion of ISR data with GIS systems is a work in progress, with an enormous long-term payoff.