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Remote Sensing, Geographic Information Systems, and Operational Research in Urban Operations

Fred Cameron
Operational Research Advisor to the Director General Land Combat Development
Fort Frontenac, PO Box 17000, Station Forces, Kingston, Ontario Canada K7K 7B4
(613) 541-5010 x 2470
Cameron.FWP2@forces.gc.ca

Abstract

In recent years there have been dramatic improvements in remote sensing technologies and geographic information systems to support the analysis of urban operations. Operational research tools like wargames and simulations have demonstrated deficiencies in several important aspects. Many tools from remote sensing and geographic information systems should permit improvement in the OR community's ability to support the military component in urban operations.

Introduction

The issue of urban operations for the military has considerable history – recently Western coalitions have had to contend with Kabul, Baghdad, Basra, Monrovia, Priština, and Sarajevo. During the Second World War, the Canadian Army had to deal with Hong Kong in 1941, Ortona in 1944, and a number of other urban operations in Northwest Europe in 1944-45.

Within the discipline of operational research we should be aware that one of the earliest applications of science on the battlefield was the collaboration between King Hieron II and Archimedes for the defence of the city of Syracuse against Marcellus and his Roman legions in 212 BC.

As we might anticipate from a military operation that was largely under the control of a mathematician, Archimedes' plans and devices defeated Marcellus and seemed about to save Syracuse. But when Archimedes' fellow citizens were celebrating at a religious festival, the Romans penetrated the walls through subterfuge and massacred much of the population.

Historical Context

Geographic analysis of urban terrain is not new in the operational research realm. As part of the development of the "American, Canadian, Australian, and British Urban Game" – ACABUG – Richard Ellefsen undertook a study of classification of urban terrain [Ellefsen, 1987]. He initiated this work while at the TRADOC Studies and Analysis Activity (now the TRADOC Analysis Centre – White Sands Missile Range, NM). The work was completed under a contract to support ABCA (the American, British, Canadian, and Australian Armies' Programme). For Ellefsen, this activity was an extension of an earlier study sponsored by ARPA (the predecessor to DARPA) in 1973.

Ellefsen's project included a number of aspects:

- A taxonomy and procedures for the classification of zones within urban terrain.
- An assessment of urban construction techniques – both in structures and in materials
- Use of available overhead imagery from a selection of 13 world cities, from a variety of regions, and cultural areas.
- Visits to 12 of the 13 cities to compare the results to 'ground truth'.

[Ellefsen, 1987] includes a tutorial on the history of urban construction covering both structures and materials. He asserts that choices in building design and construction are generally driven by local economics at the time, especially the price of land and of materials. With this knowledge it is much easier to assess what forms of buildings may be anticipated in an unfamiliar city.

Ellefsen's methods and findings have endured into current times and provide a worthy legacy for continuation and extensions. In particular, the approach and many of the results found in his earlier urban terrain zone classification have subsequently been used in the development of doctrine for operations in an urban environment [US Army, 2002] and [Joint Chiefs, 2002].

By way of illustration, the taxonomy used in [Ellefsen, 1987] is:

A – Attached
- A1 – Core area
- A2 – Apartments/hotels, core periphery
- A3 – Apartments/row houses
- A4 – Industrial/storage, full urban form
- A5 – Old commercial ribbons
- A9 – Old core, vestigial

Do – Detached, Open-set
- Do1 – Shopping centers
- Do2 – Apartments, <75% ground coverage
- Do3 – Houses, <75% ground coverage
- Do4 – Industrial/storage, truck related
- Do5 – New commercial ribbons
- Do6 – Administrative cultural

Dc – Detached, Close-set
- Dc1 – Urban redeveloped core area
- Dc2 – Apartments, >75% ground coverage
- Dc3 – Houses, >75% ground coverage
- Dc4 – Industrial/storage
- Dc5 – Outer city
- Dc7 – Engulfed agricultural village
- Dc8 – Shanty towns

Others
- ON – Open Space, not built upon
- OW – Open Space, wooded, not built upon
- Do31 – Leased garden areas with small structures

More modern classification efforts, e.g., the NATO DIGEST standard, resemble Ellefsen's effort, but are much more elaborate.

The cities were selected from a variety of regions and represented several cultures and climates:

- Helsinki, Finland,
- Braunschweig and Stuttgart, Germany
- Vienna, Austria
- Athens-Piraeus, Greece
- Beirut, Lebanon
- Tel Aviv-Yafo, Israel
- Tunis, Tunisia
- Kuala Lumpur, Malaysia
- Colombo, Sri Lanka
- San Jose, Costa Rica
- Panama City-Balboa, Panama
- Caracas, Venezuela

The study reported in [Ellefsen, 1987] must be commended in two respects. First, it included a variety of cities, though not by 'random sampling', to be sure. But acknowledging certain constraints, the approach was still able to identify differences across regions and cultures. Second, Ellefsen visited 12 of the 13 cities to develop a comparison between the classifications by overhead imagery with the 'ground truth' – a critical aspect of such a study.

[Ellefsen, 1987] focused largely on building structures to determine the classification zones within a city. He described the important issue of transportation corridors through urban areas, but mostly by describing the unique features of the corridors associated with each of the zones. Later material [US Army, 2002] includes a more rigorous framework for discussing street patterns and their potential effects on urban operations.

Military Doctrine

In recent years there has been a renewed interest from military organizations in urban operations, e.g., [ALLC, 2002], [US Army, 2002], and [Joint Chiefs, 2002]. One aspect that all sources reinforce is the need to better understand how cities operate. At the fundamental level, the military must develop an improved understanding of the nature of urban terrain.

Doctrine from the US Army, US Marine Corps, and Joint Forces in particular build on several Ellefsen terrain classification studies, including

[Ellefsen, 1987]. The technologies that are becoming available in remote sensing (RS) and geographic information systems (GIS) are reaching a point where they can make substantial contributions to improved understanding of urban terrain. These new capabilities go far beyond the tools that were available to Richard Ellefsen two decades ago.

Remote Sensing

Overhead imagery from airborne cameras has been used for terrain analysis for nearly a century. More recently, space borne sensors have added to the repertoire of data sources. There have been significant extensions to the spectral coverage of these in recent years, especially with the introduction of multi-spectral and hyper-spectral cameras. But two quickly developing airborne remote sensing technologies have recently been applied to the collection of elevation data from urban areas – LiDAR and IFSAR. These two technologies come together in a prototype collection platform flying under the US Army's Rapid Terrain Visualization (RTV) project (see [RTV, 2003]).

	LiDAR	**IFSAR**
Flight Altitude	2000 m above ground level	6000 m above ground level
Swath Width	540 m	Level III: 1600 m Level IV: 630 m
Flight Speed	140 knots	180 knots
Collection Rate	25 sq. km per hour	Level III: 50 sq. km per hour Level IV: 25 sq. km per hour
Processing Rate	3 hrs processing per 1 hr flight	Real-time onboard processing
Time	Day or night	Day or night
Weather	No clouds, minimal precipitation	No limitations
Source: Turner and Moscoco, 2002		

LiDAR, Light Detection and Ranging, is based on scanning a series of laser pulses across terrain below an over-flying aircraft. The direction of the outgoing pulse is known with considerable accuracy from differential GPS and inertial sensors. The returned energy can be processed to determine the distance to any intervening target. Multiple returns can be processed from an individual pulse. The distance to the first obstruction, e.g., the top of a tree canopy, and to the last obstruction, e.g., the ground, can provide additional information not usually available from other sensor systems. The LiDAR data can be processed into a dense 3D 'point cloud' of the terrain under the sensor. By taking the difference between the two 'point clouds', one from first pulses and the other from last pulses, some idea of tree coverage may be inferred. Note that this depiction presumes that any partial obstruction is from foliage, but it may not always be the case.

The second technology, Interferometeric Synthetic Aperture Radar or IFSAR, uses synthetic aperture techniques with a pair of receiver antennas mounted symmetrically about the vertical axis and the platform's centreline. The phase difference between the returned signals at the two antennas can be processed to determine the angle of the response relative to the vertical axis. The Doppler of returned signal can be processed to determine the angle of the response relative to the flight path. This provides the 3D angle of a returned signal. IFSAR techniques also provide a 'point cloud'.

As shown in the table above, LiDAR and IFSAR share some characteristics, e.g., both can be used in daylight and at night. IFSAR can provide Level III (10m) and Level IV (3m) resolution. In general LiDAR has greater resolution, to Level V Digital Terrain Elevation Data (1m resolution or better). The flight path for LiDAR is typically at a lower elevation than for IFSAR. Although IFSAR's resolution is poorer than for LiDAR, it is not as restricted in terms of weather conditions.

Due to demands from the civilian market for improving the performance characteristics of LiDAR and IFSAR, we can anticipate that the processing time for LiDAR and, potentially the resolution of IFSAR, will continue to progress.

These two sensor techniques provide a 3D dataset of elevations over an urban area. Meanwhile improvements in multi-spectral and hyper-spectral imagery permit the characterization of the textures of the rooftops and walls and, even, inferences of the land cover based from the spectral signatures.

Land Cover, Land Use, and Land Exploitation

In the civilian community, 'land cover' and 'land use' are familiar terms (see [Donnay, et al. 2001]). Overhead imagery is used first to determine 'land cover' – a characterization of what is on a specified area of the ground. Often each pixel of an overhead image is characterized individually for its 'land cover'. If adjacent pixels seem to have the same cover, they may all be designated the same – hence areas of vegetation, say, can be discerned from a group of green pixels.

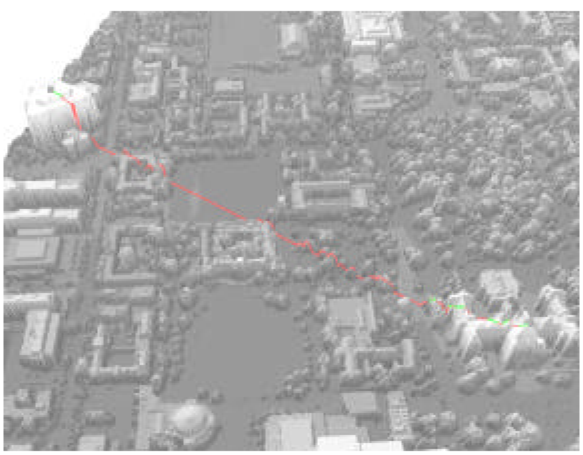

Figure 1: Line of Sight

Source: [Harrap and Lim, 2003]

'Land use' requires more analysis, and generally includes some inferences from the land cover in the vicinity. Thus the 'use' of a multi-story story feature of regular geometry with asphalt around it might be classified as a 'commercial building'. Another cluster of pixels with the same land cover, might be classified as 'apartment building'. Recently, many innovative techniques have been proposed for classifying both the land cover and land use for urban analysis for civilian purposes [Donnay, et al. 2001].

Classifying terrain data from urban areas for military purposes can exploit the innovations in the civilian realm. But for military operations, a further stage of classification seems appropriate – 'land exploitation'. This would identify how the urban terrain represented by some appropriate cluster of pixels could be exploited [Harrap and Lim, 2003].

The classification of 'land exploitation' may have to be conducted several times, with different objectives each time. [Pigeon, 2002] points out that in most military settings different components of a military force will bring with them different points of view as to what constitutes an exploitable feature. For example, 'planning for snipers positioning might require a spatial accuracy of 1 meter with a high level of textures' and 'blast damage assessment analysis should require a medium-high spatial accuracy, a low level or an absence of textures, and a high level of details for target attributes related to physical composition (e.g. wood, concrete, glass)'. The concerns of the communities will differ, the land-use characteristics of interest will be different, and impressions of what is exploitable will also be different.

This is without considering intelligence staffs that will want to deal with many of the same issues, but from an opponent's point of view. And an opponent's view of exploitable features might be drastically different from that of friendly forces.

[Donnay, et al. 2001] point out how semantics of the urban terrain may be used to determine land use. [Harrap and Lim, 2003] take the idea further in many respects. They point out how, in the context of military urban operations, semantics can inform both land use and land exploitation.

Geographic Information Systems

Commercial geographic information systems (GIS) are now in widespread use by military topographic teams. For example, the BOREALIS exercise conducted by the ABCA Armies Program in June 2002 demonstrated considerable interoperability of GIS software across a potential coalition. The exercise indicated that topographic teams from the five participating nations (the ABCA armies and New Zealand Army) had demonstrated considerable interoperability because they all used commercial products from the ESRI company.

Furthermore, commercial GIS have been extended with add-ons for military applications. As an illustration of current capabilities, Figure 1 shows the use of LiDAR data from central Toronto in ArcGIS with the 'Military Analyst' add-on. Along a potential line of sight running from the upper left to the lower right, locations that are visible are shown in green and locations that are obstructed are shown in red. The data is from central Toronto and was provided by the Optech Company.

Figure 2, based on the same data shows a viewing area (in green) from the top of the Ontario legislature building in the lower right.

Both illustrations were developed using the Military Analyst extensions to ArcView 8, an ESRI commercial product.

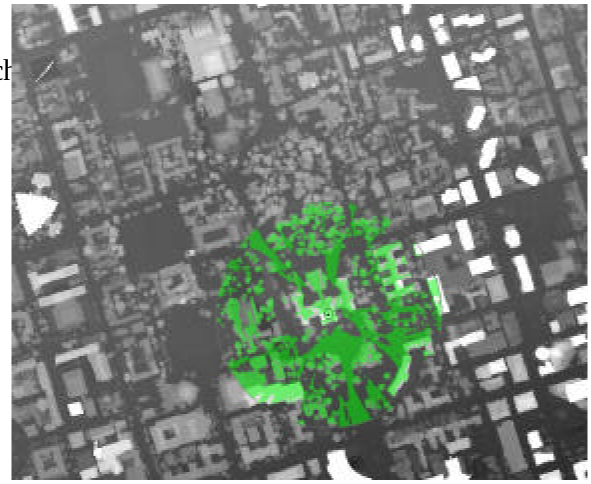

Figure 2: View Area in Green

Source: [Harrap and Lim, 2003]

Canadian Army Wargames and Simulations

The preceding issues are raised in the context of military formations and units. But the issues – and the consequent paraphernalia for dealing with them – must be shared with the military operational research community. Whatever a military component may have to deal with, its OR analysts will be required to study. Amongst the paraphernalia of military operational research, wargames and simulations are crucial.

For operational research studies, available Canadian wargame and simulation tools include Janus, JCATS, CAEn, and the OneSAF line of products. These accommodate urban features up to a point. CAEn, for example, has the capability to represent a few buildings and small forces, say company strength. It is unsuitable for representing larger forces or more extensive urban areas. The application of the others in an urban context remains largely unproven in Canadian studies.

Most of the more complicated models used in Canadian military operational research originate with American developers. The US Army and the US Marine Corps have had an initiative to assess their modelling and simulation ability to support the analysis of urban operations (see [MOUT-FACT, 2003]). Because of the close connection due to the sharing of models and simulations, the findings of the US review influence the Canadian assessment of our own modelling abilities.

The US review included four models, Combat XXI, IUSS, OneSAF, and AIMS. 'AMSAA [the US Army Materiel Studies and Analysis Activity] has recently published a series of white papers that assess the Army's current models and their ability to represent operations in an urban area. The white papers evaluate the areas of Search and Target Acquisition, Mobility, Direct Fire, Indirect Fire, Wide Area Surveillance and Tactical Communications in the Army's force-on-force simulations.' [Crino, 2002] indicates that the study revealed weaknesses in these models in the six aspects for urban operations. A significant effort has since been underway to determine priorities for improvements and to resolve deficiencies.

Through recent initiatives, such as SEDRIS, computer-based models will gain the ability to more easily incorporate digital terrain data from many sources. This will include urban terrain. So the domains of remote sensing, geographic information systems, and military modelling are gaining more means of sharing digital terrain at the same time that there is some urgency to improving the analytical tools.

The Canadian Army's operational research community has considerable interest in the AMSAA assessment of models, in innovations in studying urban terrain, and in protocols that permit the rapid sharing of digital urban terrain. There has been substantial collaboration between the US Army and the Canadian military operational research communities on model development, and this will continue to focus on modelling urban operations to improve the models of interest in the aspects where they are deficient for urban operations.

Conclusions

The capabilities of remote sensing systems have improved dramatically in recent years as contributors to the collection of data on urban terrain for military operations. This is evident in sensors like LiDAR and IFSAR. Other sensors not covered here, like multi-spectral and hyper-spectral cameras, are also showing promise.

Geographic information systems have reached a level of sophistication where they, too, have considerable capabilities for understanding urban terrain. Their use is widespread in a number of coalition armies. With various add-on packages, commercial GIS software can provide very sophisticated analyses having military significance.

Deficiencies in model and simulation support of operational research analysis for urban operations have become apparent. Many of the initiatives to deal with these deficiencies can benefit from the advances in remote sensing and geographic information systems.

Military personnel need to know more about urban areas and how the populations interact with their environment. As operational research methods to deal with urban environments improve, practitioners will have the ability to provide the necessary analysis to support their military colleagues.

References

[ALLC, 2002] Army Lessons Learned Centre "Training for Urban Operations", *Dispatches*, Vol 9, No 2, Land Force Doctrine and Training System, Kingston, Ontario, May 2002

[Crino, 2001] Scott T. Crino, 'Representation of Urban Operations in Military Models and Simulations' in Proceedings of the 2001 Winter Simulation Conference, Dec 2001

[Donnay, et al. 2001] J-P Donnay, MJ Barnsley, and PA Longley, *Remote Sensing and Urban Analysis*, Taylor and Francis, London and New York, 2001

[Ellefsen, 1987] Richard Ellefsen, *Urban Terrain Zone Characteristics*, Tech Memo 18-87, US Army Human Engineering Lab, Aberdeen, MD, 1987

[Harrap and Lim, 2003] Rob Harrap and Kevin Lim, 'Terrain Classification for Military Operations in Urban Areas', Queen's University, Kingston, 2003

[Joint Chiefs, 2002] Joint Chiefs of Staff, *Doctrine for Joint Urban Operations*, Joint Publication 3-06, 16 September 2002

[MOUT-FACT, 2003] Military Operations in Urban Environment Focus Area Collaborative Team Web Site https://www.moutfact.army.mil/

[Pigeon, 2002] Luc Pigeon, 'Concept of C4I data fusion command center for urban operations' in *Proceedings of the 7th International Command and Control Research and Technology Symposium*, Quebec, Sep 2002

[RTV, 2003] Rapid Terrain Visualization Website:

https://peoiewswebinfo.monmouth.army.mil/
JPSD/rtv.htm

[Turner and Moscoso, 2002] Jeffrey T. Turner and Christian P. Moscoso, '21st Century Terrain – Entering The Urban World', available at [RTV, 2003]

[US Army, 2002] Combined *Arms Operations in Urban Terrain*, FM 3-06.11 (supercedes FM 90-10-1), US Army, Washington, February 2000