The Potential of Radarsat Imagery for Population Estimation: Riyadh Case

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Abstract. A spaceborne synthetic aperture radar (SAR) image acquired by the Canadian Radarsat-1 system and covering the city of Riyadh was used to investigate the potential of satellite radars for population estimation. Eight districts with population known apriori were utilized for the purpose. A PCI version 10 software was used to delineate district boundaries and to measure their areas in kilometers. A mathematical relationship was then established between area of district in square kilometers and population in thousands using information from four of these districts. The derived equation was then used to compute the population of the remaining districts. Errors in estimated population figures were then computed and averaged. The results showed that high resolution SAR imagery acquired from spaceborne platforms could be used to derive information about population to an accuracy of ±17%. Although this figure is large compared with those obtained from aerial photography (±6% - ±10%), it still points to the fact that when it is impossible or uneconomical to use aerial photography, radar imagery provides rough information about population. This is a worthwhile conclusion in circumstances such as relief operations and studying effects of natural disasters where preliminary information is urgently needed for the sake of taking further remedial actions.

Introduction

Electro-optical sensors, as popular as have become, are physically limited by changing atmospheric conditions (e.g. cloud cover, dust and fog). In many regions of the world, one cannot reliably acquire a surface image from an electro-optical sensor when it is most needed. Given these considerations, there are several advantages of using synthetic aperture radar (SAR):

(i) because of their day-night and all weather capability, radar systems represent the best approach to collecting interpretable data for a given region at a specific time;

(ii) unlike those from electro-optical systems, signals returned by radar are sensitive to the physical structure and moisture content of the surface being sensed and may offer avenues for obtaining important results for research and applications that are not otherwise available; and

(iii) depending on how the data is processed (e.g. as images or as interferograms), SAR data provides earth scientists with unique means for extracting information that is otherwise not possible to get with electro-optical systems.

For these reasons, the secondary role of radar imaging systems relative to electro-optical systems could be reversed in the future for certain applications. It is important, therefore, to recognize that radar systems have already demonstrated their usefulness in earth sciences and that still further development of these systems is possible.

Radar and Population Estimation Studies

Indeed, for almost 40 years, side looking radar has been used worldwide for mapping earth resources. The larger radar coverage has been acquired in cloud-invested areas of the world situated round the equatorial belt where photographic coverage is hindered by adverse weather conditions almost all the year round.

Many investigators believed that the limitations of applicability, geometric accuracy and thematic content of side-looking radar are imposed by system deficiencies and/or lack of general understanding of the system operation and complexities of the various levels of microwave energy/matter interactions. With the advent of microelectronics, these limitations started to be overcome albeit at a slower rate compared to other non-conventional remote sensing systems, e.g. multi-spectral scanner images, return beam vidicon camera photographs, push-broom scanner images, etc. Today, radar images obtained from aircraft or from space platforms offer higher resolutions that would allow images produced by them to be utilized for various mapping applications, e.g. land use (Kessler and Jano, 1985), vegetation (Morain, 1976), cartography (Ali, 1993; Leberl, 1990; Van Roessel and de Godey, 1974), agriculture and forestry (Sabins, 1987), etc.

There has been, however, little research on the application of radar imagery for population studies. For many years, population estimation has been carried out successfully using photographic image interpretation techniques. The lack of interest in using side-looking radar imagery for population estimation may be attributed to two main factors. First, understanding radar imagery is difficult in that it is non-optically-generated and does not present ground reactions of optical wavelengths but of microwave rays, which are not the component of primary human experience. This means that the normal experiences and procedures derived from photographic interpretation and listed as important in aerial photographic interpretation (e.g. using image characteristics of size, shape, shadow, tone, pattern, texture listed as important in aerial photographic interpretation) will often have limited application to the interpretation of SAR images. Secondly, optical radar images (i.e. those obtained by optical processing of radar records) show apparent similarities with panchromatic aerial photographs. Unfortunately, this fact often confuses interpretation more than it helps. Radar image interpretation for the purpose of mapping earth resources, therefore, seems to require very skilled interpreters who must have fundamental experience in both the physics of the system and the science of the particular discipline to be performed. This has led the authors to initiate this experiment. The present article reports the results of a pilot study concerned with the potential of the Canadian satellite radar system Radarsat-1 imagery for population estimation. Although it is not guaranteed that the results of this study will necessarily open up a new field of application, it may invoke researchers to further explore the potential of SAR imagery for population estimation.

The Radarsat System

Radarsat-1 is an advanced earth observation satellite project developed by the Canadian Space Agency (CSA). It was launched by NASA in 1995 from Vandenburg Air Force Base to monitor environmental changes and to support resource sustainability. Some potential applications of Radarsat-1 data include sea-ice monitoring, acquisition of daily ice charts, extensive cartography and some other non-cartographic applications. Under the auspices of CSA, Canada had been responsible for the design and integration of the overall system, for its control and operation in orbit, and for the operation of the data reception and processing stations located in Prince Albert, Saskatchewan and Gatineau, Quebec. Radarsat is equipped with an advanced C-band SAR wavelength (5.6 cm wavelength), right-looking and steerable antenna and multi-mode imaging capabilities.

Radarsat-2 program is a partnership between the Canadian Space Agency (CSA) and MacDonald Dettwiler (MDA). It is planned to be launched in February 2007. Earth-observation (EO) satellite program "Radarsat-2" was initiated to provide users around the world with an enhanced range of high-quality earth information SAR products.

Radarsat is placed in a near-polar, sun-synchronous orbit 798 km above the earth. It has a down-dusk orbit and is rarely in eclipse or darkness. The orbit characteristics are shown in Table 1, and Fig. 1 shows a view of Radarsat-1 platform with the SAR system onboard.

Table 1. Radarsat orbit characteristics (Radarsat International)

Parameter	Radarsat-1	Radarsat-2
Altitude	798 km	
Inclination	98.6°	
Period	100.7 minutes	
Repeat Cycle	24 days	
Coverage	7-day and 3-day sub-cycles	

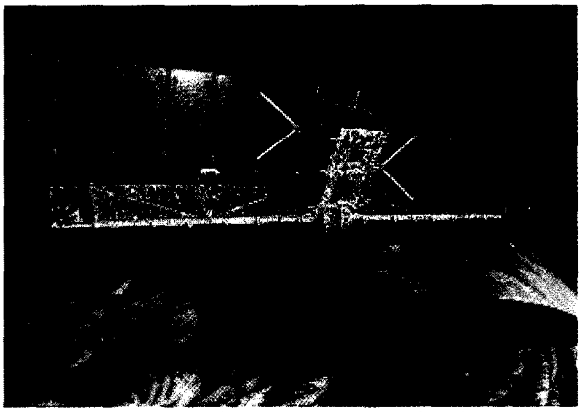

Fig. 1. Radarsat-1 satellite (Radarsat International).

Radarsat products consist of SAR images or signal data stored in magnetic, optical or electronic media. The products are characterized by the beam mode and position used by the satellite and the level of processing that has been applied to the data. A summary of the various Radarsat products are given in Table 2.

Table 2. List of Radarsat products (Radarsat International)

Processing Level	Product Type Radarsat Mnemonics	Product Type RSI Terminology	Product Level
RAW (Signal Data)	RAW	RAW Signal Data	Level 0
Georeferenced Data	SLC	Single Look Complex	
(Satellite Path Oriented)	SGF	Path Image	
	SGX	Path Image Plus	Level 1
	SCN	ScanSAR Narrow	
	SCW	Scan SAR Wide	
Geocoded Data	SSG	Map Image	Level 2
(Map Oriented)	SPG	Precision Map Image	

Radar Backscatter and Residential Areas

At depression angles of between 30° and 60°, the radar backscatter coefficient is mainly characterized by surface roughness. In this respect, the separability of different surface roughness types known with the terms micro-, meso- and macro-relief, which correlate with certain different land use classes, can be observed on high resolution radar imagery such as that produced by the Radarsat system. The back-scattering characteristics of incident SAR pulses have been thoroughly discussed by (Ali, 1986). It would be apparent that if a series of smooth surfaces combine to form a corner cube reflector, e.g. a combination of buildings or walls or a complex structure such as a bridge or a pylon, then a strong return signal will be produced. Towns, villages and city districts in particular exhibit many such reflections at SAR wavelengths. This fact prompted the idea of the present work whose results are reported in this paper.

The Purpose of the Study

Residential areas can be considered as good examples of high concentration corner-cube reflectors. This means that they backscatter a high percentage of the microwave energy incident on them back to the antenna of the radar system. In the city of Riyadh (Saudi Arabia), more than 90% of residential buildings are two-storey cement-brick houses with only less than 10% of the total area categorized as residential towers or villas. This would allow one to assume reasonably-even spatial distribution of residential buildings. This may point to the existence of some sort of mathematical relation between the area of the residential district and its population. This study attempts to derive such a relation.

Test Area and Materials Used for Population Estimation

The whole city of Riyadh is subdivided into 10 regions. The boundaries of these regions follow major road patterns of the city. Examination of the Radarsat test image of Riyadh under magnification or zooming up revealed that most major roads are clearly visible on the images. This can be seen in Fig. 2. Hence, the boundaries of the regions could easily be traced at their full lengths. Figure 2 was produced using F2 mode of SAR operation. The resolution is in the order of 8 m and the image was acquired during Radarsat flight at time 02:47:26, date 1999/11/26 and media number W0619501.

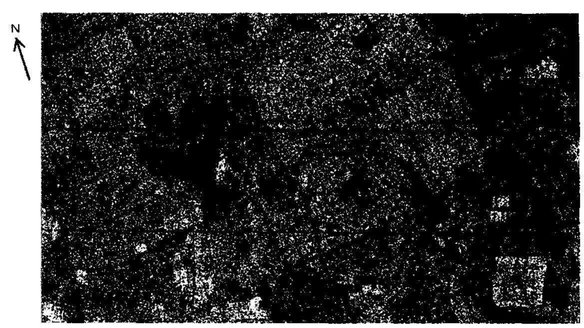

Fig. 2. Radarsat-1 image of the test area (scale 1:200,000).

Collateral information included an enlargement print, a recently-completed (2005) digital map of the city produced by the Naming and Numbering

Administration of the Riyadh Mayorship and a number of hard-copy 1/50,000 maps of the city.

The 2005 collateral information was used to separate urban expansions not included in the 1999 radar image. The 1995 census was used to forecast the population in 1999 using the famous compound interest mathematical model:

$$P' = P\left((1+\frac{r}{100}\right)^n$$

where P' = the population at present (date of image acquisition),

P = initial population (1995),

r = rate of annual population increase, and

n = number of years elapsed (n= 4 in this case).

Procedure of the Test, Results and Discussion

Seven regions of Riyadh, whose census population was known, were made available by the Riyadh District Development Authority. The boundaries of these districts were correctly identified and traced on the image. The areas of these districts were measured on the image using version 10 of PCI software with an accuracy of ± 0.2%. Table 3 shows the census population of the four districts and their areas in square kilometers as measured on the image.

Table 3. Population as derived from the 1995 local census versus area in kilometers as measured on radarsat SAR image.

District	Area (km^2)	Census Population (in thousands)
Olaya	13.3788	20.684
Rabwa	10.1787	14.211
Mursalat	19.3119	31.245
Al-Shifa	12.2917	13.788

The PCI Geomatica software version 10 used in this experiment is a Canadian commercial image processing package, and was developed to process digital images for earth science applications. The software was kindly supplied to the authors by the Research Center of the College of Engineering of King Saud University in Riyadh.

Every possible effort was made to separate residential from non-residential areas on the image. The procedures for radar image interpretation as mentioned by (Ali, 1986) were followed in this respect. A vector layer was generated using the PCI software version 10, the traced boundaries of the districts were saved as polygons. The areas of districts were attached automatically to the attribute table.

Figure 3 represents a scatter diagram of the two variable parameters, i.e. area of district in square kilometers and population; and the respective regression line for a least squares fit. The mathematics of the figure shows that the equation of this regression line is as follows:

$$P = 2002 \times A - 7638.2 \qquad (1)$$

where P = population in thousands; and

A = area of the district in square kilometres.

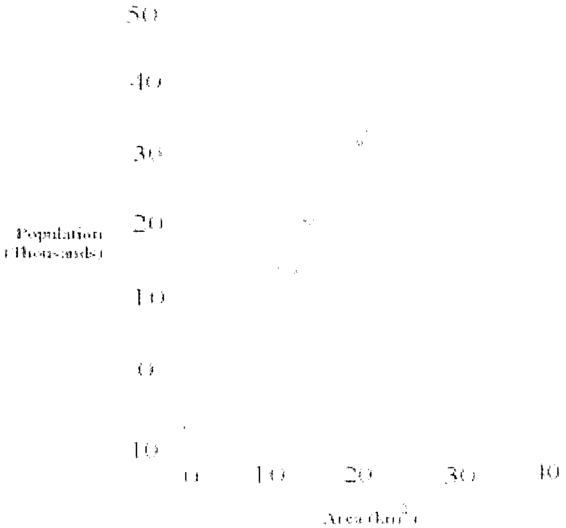

Fig. 3. Scatter diagram of the test.

Equation (1) was then used to compute the population of the remaining four districts whose local census population was also available. The areas of the four districts were also measured on the image using the PCI software and converted to square kilometers. The results are shown in Table 4.

Table 4. Computed population of the four test districts

District	Area (km^2)	Census Population (thousands)	Computed Population (thousands)	Error %
Sulimania	10.9744	16.114	14.3325	-18.5 %
Om-Alhmam	16.9991	20.519	26.34399	+28.6 %
Al-Naseem	23.3183	42.326	39.045	-7.8 %
Almuruj	9.92424	10.60	12.230	+11.1 %

The almost 17% absolute error obtained in this study can be compared with the 8% value obtained by (Elhassan, 1990) and the 7.2% figure quoted by (Ali, 1993) over the city of Riyadh using conventional aerial photographs and a mirror stereoscope. The disparities between the results obtained in this experiment and those obtained by these two investigators are obvious and may be attributed to the following factors:

(i) The very low resolution of radar systems compared to aerial photographs. This did not allow the famous techniques of dot grid and residential unit count, normally used with aerial photos, to be applied with radar imagery.

(ii) In this experiment, it was assumed that residential areas in Riyadh are homogeneous. This is not absolutely true. Some districts of the city have areas within them that have concentration of population in buildings with more than two storeys. This means an increase in population without an increase in area. So, the use of area as an indicator of population is less reliable in such cases. Also, it was sometimes rather difficult to separate residential buildings from non-residential buildings. So, it was probable that reflections from some non-residential buildings were treated as coming from residential areas thus resulting in an increase in area without actual increase in population. This may also explain the overestimation figures of Table 4.

Of course the regression relationship of Eq. (1) has some limitations and cannot be considered as a general mathematical model relating district area and population. However, the relationship may perform satisfactorily in areas where residential districts are uniform with low building densities and covered with high resolution radar imagery.

The 17% average error obtained in this experiment (although a relatively large error value) may be acceptable in cases where only rough information about population is needed very urgently, e.g. for the purpose of regional or national relief supplies in developing countries where direct population enumeration and/or the use of aerial photographs are both costly and time-consuming operations.

The 17% relative error figure obtained in this experiment can be compared with the +20.5% value reported by (Ali, 1997) over the same area using a 25-meter resolution optically processed SAR image from the Russian spacecraft Almaz acquired in 1991. The image interpretation was carried out with a 5× enlargement image using a pocket stereoscope and an 8× magnification glass. Residential areas were measured using a Sokkia digital planimeter and converted into square kilometers. The almost 20% improvement is clearly attributed to the improved resolution of the Radarsat image and the method with which the test image was processed. Both results, however, are noticeably much inferior to those obtained by (Ali, 1993) and (Elhassan, 1990) using aerial photography.

Significance of the Test in Tropical Environment

Table 5 shows some of the anticipated merits of side-looking radar. Two major advantages of the system is its capability to penetrate cloud, vegetation cover and thin rain, and the possibility of covering large areas quickly and at specific times. These two characteristics have offered SAR the term "all-weather system". The expression is particularly important in tropical regions of the world. Most of these regions are cloud-invested almost all the year round with semi-permanent vegetation cover. This hinders satisfactory acquisition of aerial photography. That pertains particularly to those parts of the world situated round the equatorial belt such as South East Asia, equatorial Africa and the Amazon Basin in Latin America. In such countries, persistent cloud cover is often a deterrent to resource surveys, such as forest mapping, inventorying land use and cover, geological surveys, population estimation, etc. with aerial photography. In such situations, side-looking radar may provide a suitable source of data for resource survey projects. Indeed, a number of small scale (1/100,000 and smaller) topographic mapping and land use projects had already been accomplished with side-looking radar. For details on this, reference is made to (Leberl, 1990). Some disadvantages of radar relate to system complexity, initial and running costs and lack of general understanding of system theory.

Table 5. Some of the merits of side-looking radar over other systems

- It can penetrate clouds and serve as all-weather sensor.
- It can produce synoptic views of large areas, typically for resource mapping at scale 1/50,000 – 1/400,000.
- It permits imaging at shallow look angles which results in different views to those of aerial photos.
- Coverage can be acquired quickly at specific times.
- It can penetrate vegetation.
- It provides its own illumination.
- Resolution independent of flying height with resolution cells being up to 1×1 m.
- Polarization effects can be utilized.
- Overlapping images can be obtained thus facilitating stereoviewing.
- It can operate with several wavebands allowing the use of multispectral radar imagery.

Furthermore, in many tropical countries of the world, financial resources allotted for mapping are usually scarce. Taking into account the fact that radar coverage costs under 5 U.S. dollars per km^2 (as opposed to perhaps 200-300 U.S. dollars/km^2 for aerial photography), radar seems to be an attractive resource survey system in many tropical cloud-bound areas of the world.

As far as the present experiment is concerned, the case may arise in which information on population in a cloud-prone tropical region is very urgently needed. In this case, ground survey methods cannot be used because they take long to complete. Also, aerial photography may be unsuitable because of the limitations mentioned before. So, if crude information about population is sufficient, side-looking radar, supplemented with limited ground survey, may be used for population studies with advantage and cost-effectiveness.

Conclusions

The present paper reported the results of a test initiated in order to estimate the population of a number of districts in the city of Riyadh in Saudi Arabia using Radarsat synthetic aperture radar (SAR) imagery. Eight districts of the city whose population is known apriori were used for this purpose. Because they act as good microwave corner-cube reflectors, residential areas are clearly identifiable on radar imagery. Assuming architectural homogeneity, the areas of four of the test districts were measured on the image using the Geomatica PCI software and converted into square kilometers. A least squares linear fit was then carried out on the data and a relationship between population and district area was established. This is used to compute the population of the remaining districts. The computed population was then compared with the known one and relative percentage errors were derived. An absolute average error value of almost 17% was obtained. Although this figure is large compared with those obtained by other investigators using aerial photographs of Riyadh, it still points to the fact that when direct enumeration is impossible and when the use of aerial photographs is limited by the shortage of finance, time and experienced photointerpretors, radar imagery could provide rough information about population provided that the limitations of the present experiment be taken into account.

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تقديرعدد السكان من صور رادارسات: حالة الرياض

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ملخص البحث. استعملت صورة رادارية من القمر الصناعي الكندي (رادارسات) تغطي مدينة الرياض لدراسة إمكانية الاستفادة من مثل هذه الصور في تقدير عدد السكان. لهذا الغرض. أمكن الاستفادة من عدد سكان ثمانية أحياء أجري لها تعداد سكاني عام ١٩٩٥م. استعملت حزمة البرنامج PCI الإصدار ١٠ من الشركة الكندية (جيوماتيكا) لتحديد حدود هذه الأحياء وقياس مساحاتها بالكيلومترات المربعة. من خلال جزء من هذه المعلومات أمكن استنباط علاقة رياضية بين عدد السكان بالآلاف ومساحة الحي بالكيلومتر المربع. استعملت هذه العلاقة الرياضية في حساب عدد سكان أربعة أحياء أخرى، ومن ثمَّ حُسبت نسبة الخطأ في تقدير سكان هذه الأحياء والخطأ المتوسط. وقد أثبتت النتائج أن صور الرادار الفضائي (رادارسات) يمكن أن تُستعمل في عمليات تقدير السكان بنسبة خطأ ±١٧٪. وبالرغم من أن هذا الخطأ كبيرٌ نسبيًّا بالمقارنة مع النتائج التي نحصل عليها من الصور الجوية (±٦٪-١٠٪)، إلا أن هذه النتائج توضح أنه في حالة استحالة أو صعوبة استعمال الصور الجوية يمكن أن تكون الصور الرادارية بديلاً مناسبًا لإعطاء أرقام تقريبية لعدد السكان. وقد تكون هذه المعلومات التقريبية ذات فائدة كبيرة في الحالات العاجلة مثل عمليات الإغاثة وتحديد تأثير الكوارث الطبيعية حيث لا بد من وجود معلومات أولية تُبنى عليها معالجات أو عمليات لاحقة.