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Urban Change Detection in the Helsinki Metropolitan Region Using Radarsat-1 Fine Beam SAR Images

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Abstract—**This paper describes the potential of Radarsat-1 fine beam intensity SAR images in urban mapping and change detection. The main objective was to determine the possibility of building detection e.g. as a function of height, orientation, roof material and roof type in the Helsinki metropolitan region. Altogether 22235 buildings were used to estimate the effect of height, and then 14270 buildings were used to estimate the effect of orientation. Additionally, a smaller and more detailed set of buildings was selected from various environments e.g. from forested and dense urban areas. It was shown that height and orientation were the main factors affecting on the detectability of the buildings. The results indicate that approximately 39% of the buildings can be detected using the Radarsat-1 SAR; densely build up areas are clearly visible in Radarsat fine beam images, but in small-house areas buildings that are surrounded by forest are visible only in very rare cases.**

Index Terms—**Radarsat-1, SAR, building detection, map updating.**

I. Introduction

THE metropolitan region of the city of Helsinki is one of the fastest growing urban areas in the European union. Since the 1950's the migration from provinces to the metropolitan region has been enormous and population has doubled since then. Nowadays the metropolitan region, which includes the cities of Helsinki, Espoo, Vantaa and surrounding minor municipalities, has around 1.2 million inhabitants, which is nearly 25% of the whole population in Finland. New small-house neighborhoods, apartment and commercial buildings, and industrial areas are constantly built all over the metropolitan region [3].

Municipalities, who control the city planning, building supervision and building construction, have their own environmental and technical services, which are responsible of mapping activities. However, the municipal building information is not easily accessible to the private mapping companies and to the national mapping organization, thus topographical maps as well as guide and road maps are mainly done using large-scale aerial imagery. Globally considered, aerial imagery is fairly expensive, hence mapping organizations are constantly looking for new methods, firstly, to locate changed areas and, secondly, to update the map information.

Promising new mapping methods for urban mapping and map updating are digital aerial cameras, VHR optical satellite images and laser scanning. However, new SAR research concerning building detection and 3-D object reconstruction has also been conducted in recent years [1], [6]. Using shadow and layover effects typical to SAR imaging geometry, segmentation, shape-from-shading techniques and high-level image understanding, it is possible, for example to define 3-D outlines of the buildings [1], [6].

Despite the recent development in SAR based urban mapping, present satellite SAR systems still seem to be insufficient, for example, for defining outlines of the buildings. At the moment, Radarsat-1 satellite has approximately 8 meters spatial resolution, which is high enough to detect building in favorable conditions, but is not high enough to solidly detect building outlines. In order to see all details of buildings using SAR images, the target area should be viewed from at least 3 or 4 directions [1], which can not be achieved with sun-synchronous-orbiting earth observation satellite SAR systems, which can only have two views to the target, from ascending and descending orbits, due to the orbital dynamics.

This paper describes studies conducted at the Finnish Geodetic Institute, in order to determine the potential of Radarsat-1 fine beam SAR images, in detection of individual buildings for mapping and map updating purposes. Particular emphasis was on a determination of the visibility percentages for different types of buildings. The visibility percentage of buildings e.g. as a function height, roof material and roof type was studied. Additionally, the buildings were selected from various environments (e.g. surrounded by forests, in dense urban area). We also studied, how the orientations of the building walls regarding to the SAR look direction affect the visibility of the buildings.

The results presented in this paper summarize the possibility to detect a particular type of building in Helsinki metropolitan

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region using Radarsat-1 fine beam SAR images. Thus the results should be useful information for private mapping companies and national mapping organizations in order to consider the suitability of high resolution SAR images for their mapping and map updating requirements.

II. TEST AREA AND DATA

A. Test area

The test area covers the southern part of the city of Espoo, which is part of the metropolitan region and seamlessly the western neighbor of the city of Helsinki. The southern part of Espoo is characterized by very intense urban growth compared with other parts of Finland. A lot of apartment buildings and small houses have been built in recent years. On the other hand, entirely new neighborhoods are built, but then again, new buildings are also built in already planned area.

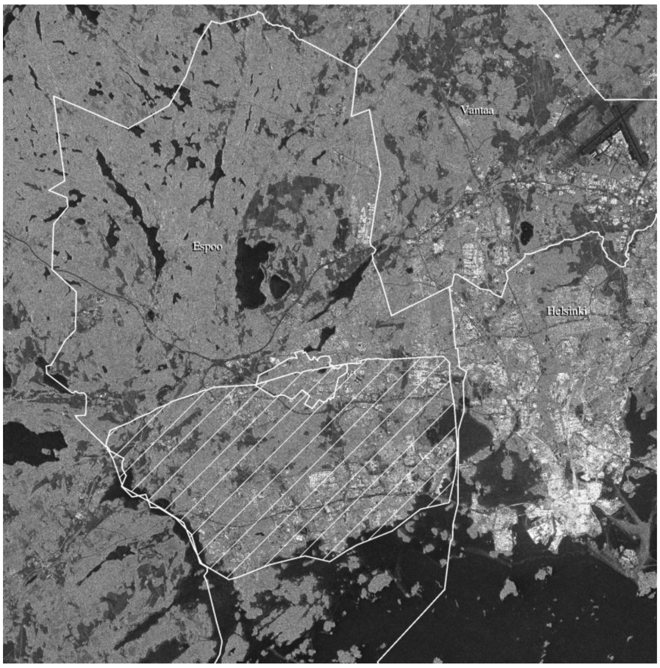

Fig. 1. The test area is located in Southern Espoo. (c) Canadian Space Agency 2001-2002, Distributed by Radarsat International/TSS/Novosat Ltd. Processed by Finnish Geodetic Institute.

Generally speaking, the properties affecting the SAR image intensity are, surface roughness compared to wavelength, surface geometry (land slope or orientation of the structures in the target etc.) and dielectric constant (soil moisture). As can be seen in Fig. 1, water bodies, which have very low backscattering, appear in black. On the other hand, agricultural fields have slightly higher backscattering than water, thus appearing in dark gray. Furthermore, brighter than agricultural fields are forested areas, therefore appearing in light gray. Finally, urban areas, that usually have the strongest backscattering, are shown in bright white areas in Fig. 1. Particularly, the center of Helsinki has in overall very strong backscattering.

The striped area in Figure 1 illustrates the test area. The western part of the test area seems to be forested, but is in fact quite densely build with small single-family houses. The eastern part of the test area, which is nearer to the city of Helsinki, is partly forested but there are also large urban areas with apartment, commercial and office buildings. Accordingly, the test area has practically all types of urban areas existing in Finland, and therefore is very suitable to be used in this study.

B. Satellite images

The project started in early 2001 when the first two Radarsat-1 SAR images were ordered, and by the summer 2002 altogether 7 SAR images were purchased. The list of the Radarsat-1 SAR images is presented in Table I.

TABLE I
THE LIST OF RADARSAT-1 SATELLITE IMAGES

Imaging mode	Acquision date
F5 descending	27 Feb 2001
F1 descending	2 Mar 2001
F3 ascending	13 Jun 2001
F2 descending	15 Jan 2002
F3 ascending	15 Jan 2002
F5 descending	11 Apr 2002
F5 descending	22 Jun 2002

The satellite images are acquired from ascending as well as descending orbits, with various beam modes in order to increase the chance to detect buildings. Basic facts about Radarsat-1 imaging modes can be found from internet [5]. Radarsat-1 images used in this study are so called path images processed by Tromsø Satellite Station.

All Radarsat satellite images were ortho-rectified using PCI's OrthoEngine, which uses a bundle-adjustment for calculating the image-to-ground coordinate transformation for each SAR image. The Bundle-adjustment is similar to the adjustment that is used for aerial image blocks. GCPs (ground control points) can be digitized from each of the images, but individual image specific GCPs can be used also. Image-to-image, so-called tie points should also be used in order to ensure as good as possible co-registration of separate images into each other. The ortho-rectification should be as accurate as possible since our objective was to detect buildings from SAR images acquired at different dates. In addition, digital elevation model was used in the ortho-rectification. The number of GCPs used in the ortho-rectification was 257, resulting RMS error of 8.41m in X-coordinate and 11.95m in Y-coordinate. The number of tie points was 21 (X-coordinate RMS error was 7.93m and Y-coordinate RMS error was 8.12m).

C. Test data

In order to collect data for the building detection tests, building maps were obtained from the National land survey's topographical database and from the FM-Kartta Ltd. Originally, the FM-Kartta building map has been extracted from the National land survey's topographic database, which on the other hand was produced using year 1999-2000 aerial images. In 2001 the FM-Kartta Ltd. updated the building database to agree with the 2001 situation and at the same time building height information was added into the building database using photogrammetric stereo plotter.

The first part of the test data consists of new buildings constructed in summer 2002. The new buildings were collected with the aid of the FM-Kartta building map, so that the purpose was to collect buildings, that were constructed after spring 2001, but which were erected before the last Radarsat-1 image acquisition. The new buildings were observed by ground surveys in summer 2002. Altogether 122 new buildings (small houses, apartment houses etc.) were found and mapped. The outlines of the new buildings were then inserted into a new GIS layer in order to overlay them with the Radarsat-1 images.

Following information for the new buildings was also collected during the ground surveys: height, number of floors, roof type, roof material, wall material, and the purpose of use. The 122 new buildings were collected from three different types of areas: 1) densely-built urban area, 2) apartment house area and 3) small-house area.

In order to evaluate the potential of Radarsat-1 images in the detection of new individual buildings, two operators, introduced by abbreviations YD and MK, conducted following four visual interpretations.

1. YD1 (using pixel-by-pixel average of 27 Feb 2001 descending and 13 Jun 2001ascending images)
2. YD2 (using 22.6.2002 descending image)
3. YD3 (using pixel-by-pixel average of all 7 images)
4. MK (using pixel-by-pixel average of all 7 images)

In the building visibility test, a simple rule was used: building in question must be distinctly separable from the background in the SAR imagery e.g. the interpreter must see that there actually is something distinguishable in the SAR images. The first test (YD1) corresponds to the situation before, and the second test (YD2) after the construction of the 122 new buildings. Tests 3 and 4 use an averaged Radarsat image, which have much less speckle than single Radarsat-1 image.

The second part of the test data consist buildings that were semi-automatically detected from Radarsat images. Detection process started, by firstly averaging all seven SAR images pixel-by-pixel in order to decrease the effect of speckle. Since man-made structures, such as buildings, should have high intensity values in SAR images due to the cardinal effect buildings acting as dihedral reflectors, an appropriate threshold value was manually discovered. Then all pixels, which had higher intensity than the selected threshold value (in this case the threshold pixel intensity was 10000), were registered as building pixels. Thus, it was possible to create an image mask that contains all detected buildings.

The automatically detected Radarsat building map was then compared to FM-Kartta's GIS building map in order to study what type buildings are visible in Radarsat-1 SAR images.

III. Results

A. Visibility of the new buildings

All test YD1, YD2, YD3 and MK were statistically analyzed by grouping buildings by their attributes. Table II represents results by groups of height, roof shape, roof material, wall material and the location of the building.

Table II
Result from the visual building detection

	Class	# of cases	YD1	YD2	YD3	MK
Height class	0-5 m	35	2.9 % (1)	28.6 % (10)	34.3 % (12)	42.9 % (15)
	5-10 m	56	5.4 % (3)	25.0 % (14)	21.4 % (12)	32.1 % (18)
	10-15 m	11	0.0 % (0)	18.2 % (2)	45.5 % (5)	72.7 % (8)
	15-20 m	15	26.7 % (4)	73.3 % (11)	80.0 % (12)	93.3 % (14)
	20-25 m	3	0.0 % (0)	33.3 % (1)	66.7 % (2)	100.0 % (3)
	25-30 m	2	100.0 % (2)	100.0 % (2)	100.0 % (2)	100.0 % (2)
	Total	*122*				
Roof shape	1 tail	20	5.0 % (1)	20.0 % (4)	55.0 % (11)	60.0 % (12)
	2 tails	74	8.1 % (6)	32.4 % (24)	27.0 % (20)	35.1 % (26)
	Flat	28	10.7 % (3)	42.9 % (12)	50.0 % (14)	78.6 % (22)
	Total	*122*				
Roof mat.	Tiles	24	12.5 % (3)	41.7 % (10)	50.0 % (12)	70.8 % (17)
	Steel metal	47	4.3 % (2)	29.8 % (14)	27.7 % (13)	36.2 % (17)
	Tar	39	12.8 % (5)	33.3 % (13)	43.6 % (17)	53.8 % (21)
	Vegetation	10	0.0 % (0)	30.0 % (3)	30.0 % (3)	30.0 % (3)
	Unknown	2	0.0 % (0)	0.0 % (0)	0.0 % (0)	100.0 % (2)
	Total	*122*				
Wall mat.	Cement	0	- (0)	- (0)	- (0)	- (0)
	Bricks	64	12.5 % (8)	48.4 % (31)	46.9 % (30)	60.9 % (39)
	Timber	23	0.0 % (0)	17.4 % (4)	30.4 % (7)	43.5 % (10)
	Metal	34	5.9 % (2)	14.7 % (5)	23.5 % (8)	29.4 % (10)
	Glass	1	0.0 % (0)	0.0 % (0)	0.0 % (0)	100.0 % (1)
	Total	*122*				
Area	Dense	72	13.9 % (10)	40.3 % (29)	52.8 % (38)	70.8 % (51)
	Apartment	15	0.0 % (0)	13.3 % (2)	13.3 % (2)	20.0 % (3)
	Small	35	0.0 % (0)	25.7 % (9)	14.3 % (5)	17.1 % (6)
	Total	*122*	*8.2% (10)*	*32.8% (40)*	*36.9% (45)*	*49.2% (60)*

Firstly, in the column YD1 in table II, the visual interpretation was done using Radarsat image acquired before the construction of the building, but there were still 10 buildings decided as visible by the operator, however, the reason might be that the construction has already been started already in summer 2001 since the actual starting date of construction is not known. Secondly, the YD2 test was done using summer 2002 SAR image, where all new buildings should already be existent, but only 32.8% of them were visually detected. It seems that only the highest buildings are visually detectable. And finally, the YD3 and MK tests, were done using averaged Radarsat image, and the highest overall visibility percentage of 49.2% was achieved in the MK test. There is great difference in the number of detected buildings in the YD3 and MK tests, which demonstrates that visual interpretation is not unambiguous, even though the interpretation rule was set as simple as possible.

As a conclusion, the detection of new buildings from single Radarsat-1 images or even from seven averaged images is not very reliable. According to the results in table II, it seems that out of all small houses only roughly 30% are visible in Radarsat-1 images. In the case of over 10 meters high buildings, in the MK test, the visibility percentage is 87.1%

(27/31 cases). It seems that the building height is the most important factor concerning the building visibility in Radarsat-1 fine beam intensity images and the material of the roof or the wall does not to have any significant influence.

B. Visibility of the semi-automatically detected buildings

In this case, the second part of the test data was used (i.e. the semi-automatically detected Radarsat buildings). The visibility of the Radarsat detected buildings was analyzed using FM-Kartta building map, which consists of polygons that define the outlines of the buildings. Then each building polygon in FM-Kartta map was tested whether there are any building pixels in the Radarsat building mask. The test was done using Arc/info. If building pixels were found inside the building polygon area, then the building in question was registered as 'visible' in Radarsat images.

Then all building polygons were categorized by their height, which was available in the FM-Kartta building map. Table III shows results of the visibility of the buildings grouped by different height categories.

TABLE III
BUILDING HEIGHT

Category	Number of cases	Percentage
0 – 5m	8486	30.2 % (2562)
5 – 10m	11772	39.7 % (4669)
10 – 15m	1232	70.9 % (874)
15 – 20m	386	87.6 % (338)
20 – 25m	227	86.3 % (196)
25 – 30m	95	86.3 % (82)
30 – 35m	20	100.0 % (20)
35m –	17	88.2 % (15)
Total	22235	39.4 % (8756)

The building database of the Southern Espoo consists of 22235 buildings, from which 39.4% were visible in the automatically detected Radarsat building map. The overall visibility percentage is nearly same as in the visual interpretation tests YD3 and MK in table II. It can also be noticed that in the category of buildings over 20 meters, the visibility percentage is nearly 90%, which coincides with the visual interpretations results in the same category of buildings. Thus, it appears that even though human interpretation uses also texture of the SAR image as well as intensity information, the visual building detection in this study did not prove to be any better than the semi-automatic building detection using only intensity information.

As mentioned in [4, page 735], the orientation of the buildings compared with the SAR look direction is also important concerning the building visibility in the SAR images. If the SAR look direction is perpendicular to orientation of the streets (less than 10º), buildings and walls cause high backscattering due to the cardinal effect [4]. In order to study the effect of the building orientation, a self-made C program was made to calculate orientation of the buildings. Only rectangular shaped buildings were included in this study because it is far too difficult to determine orientation for the very complex building blocks.

Although only the rectangular buildings were used, the test data are still quite considerable, since there were altogether 14270 buildings out of 22235 buildings that were digitized as rectangles by FM-Kartta. For all of these 14270 building orientation of the longest side was calculated. For square shaped buildings, the longest side is the first side appearing in the database. The orientation of the building is calculated as clockwise rotation from the map east.

Then these 14270 rectangular buildings were categorized by the orientation at 10° intervals. The visibility percentages for the orientation categories are represented in table IV. Similar categorization was done for all rectangular buildings, whose height is over 10 meters.

TABLE IV
BUILDING ORIENTATION

	All rectangular buildings		All rectangular buildings (>10m)	
Category	# of buildings	Percentage	# of buildings	Percentage
-90°– -80°	837	69.4 % (581)	104	96.2 % (100)
-80°– -70°	838	30.4 % (255)	66	72.7 % (48)
-70°– -60°	1388	17.7 % (1388)	134	40.3 % (54)
-60°– -50°	866	12.6 % (109)	23	39.1 % (9)
-50°– -40°	867	14.0 % (121)	79	40.5 % (32)
-40°– -30°	684	20.3 % (139)	46	15.2 % (7)
-30°– -20°	546	35.3 % (193)	26	50.0 % (13)
-20°– -10°	567	59.6 % (338)	37	94.6 % (35)
-10°– 0°	763	62.5 % (477)	65	90.8 % (59)
0°– 10°	837	66.1 % (553)	106	96.2 % (102)
10°– 20°	857	36.8 % (315)	56	73.2 % (41)
20°– 30°	1359	21.3 % (289)	147	42.2 % (62)
30°– 40°	759	13.7 % (104)	39	33.3 % (13)
40°– 50°	805	12.7 % (102)	66	36.4 % (24)
50°– 60°	569	17.8 % (101)	24	33.3 % (8)
60°– 70°	450	30.2 % (136)	16	68.8 % (11)
70°– 80°	537	60.9 % (327)	42	88.1 % (37)
80°– 90°	741	70.9 % (525)	88	97.7 % (86)
Total	14270	34.4 % (4911)	1164	63.7 % (741)

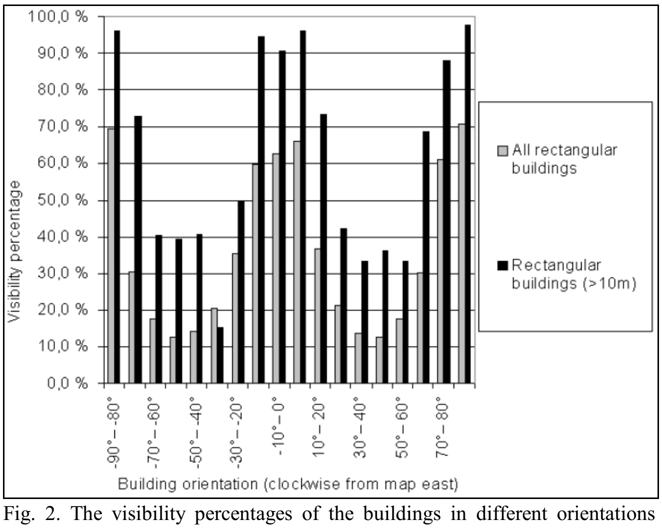

Fig. 2. The visibility percentages of the buildings in different orientations regarding to the SAR look direction.

From Fig. 2. it can be seen that buildings having a wall perpendicular compared with the SAR look direction are most probably detected. The use of descending and ascending orbits increases the range of visibility. It is evident, that if a building has even a one wall in orientation of ±20º compared with the map north, then than building is very likely visible in Radarsat-

1 fine beam image, which is averaged from ascending and descending orbit images. Explanation is that the inclination of the orbit of Radarsat-1 satellite is 98.6º, thus the angle between the SAR look directions of ascending and descending orbits is 17.2º. It should also be noticed, that even though using the ascending and descending orbit images, the buildings orientated in half-cardinal points of the compass have very low visibility percentages in Radarsat-1 fine beam intensity images.

The best visibility percentages of over 90% were achieved for the buildings that are over 10 meters high and are orientated perpendicular to SAR look direction. This 90% visibility percentage is easily explained, since high multi-storey buildings are located in non-vegetated urban areas and thus are easily seen from side-looking SAR antenna. Very low visibility percentages were achieved for small-houses orientated in half-cardinal points of the compass. The lowest visibility percentage according to the results presented in Table IV was for buildings orientated in 40°– 50° regarding to the map north. The majority of these rectangular buildings are small-houses located in the forested part of the test area, where the visibility percentages were low in the results presented in Table II also.

IV. Conclusion

The detection percentage of buildings was studied using Radarsat-1 fine beam SAR as a function of height, orientation, roof material and roof type. Both the height and orientation strongly affected the detectability of the individual buildings. The use of descending and ascending orbits increased the visibility percentage for different types of the buildings.

In summary, the buildings that are over 10 m and perpendicular to the SAR look direction have visibility percentages of over 90 %, whereas small houses oriented in half-cardinal points of the compass have visibility of around 10 %. On the average, approximately 39 % of the 22235 buildings were automatically detected using seven Radarsat-1 SAR images taken on the same area within the 18 months long acquisition period. The SAR look direction regarding to the walls has very significant effect on the visibility of the buildings in the SAR images, and should be taken into account when SAR images are considered to be used in the mapping or map updating applications.

In this study only Radarsat-1 SAR intensity images were used, since the satellite images were originally requested as so-called path image products. However, as demonstrated in many research projects using ERS-1/2 tandem pairs, a long-term interferometric coherence would also be suitable for mapping of urban areas. For instance, using 14 ERS-1/2 tandem pairs from the Helsinki metropolitan region, the interpretation accuracies for mixed and dense urban classes have been consequently 80% and 91% [2]. In order to use coherence information, we are considering acquiring Radarsat single look complex images from our test area. Besides the coherence information, the utilization of texture information in the SAR images and the use of more advanced segmentation and classification algorithms would also improve automatic building detection from SAR images.

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