MONITORING OF HEIGHT CHANGES IN URBAN AREAS FROM MULTI-TEMPORAL, MULTI-SCALE AND MULTI-PLATFORM REMOTELY SENSED DATA

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ABSTRACT:

This study aims to automatically determine changes in urban areas from multi-temporal, multi-scale, and multi-platform remotely sensed data as a base for estimating changes in population. The data sets used were a stereo pair of IKONOS panchromatic images and three stereo pairs of digitized airborne images taken at different epochs. The study is carried out jointly between universities in Brazil and Germany. The investigations have been made in the *Rio das Pedras* community, a poor inhabited area in the neighbourhood of Rio de Janeiro, where the likelihood of vertical growth of unplanned buildings exists and may be speeding up over time. In processing the data sets we made use of photogrammetric software packages developed by the Institute of Photogrammetry and GeoInformation (IPI), Leibniz Universität Hannover. We determined the vertical changes by comparing Digital Surface Models (DSM) derived from the IKONOS stereo pair and aerial imagery. The results are encouraging since they have clearly shown the differences in building heights between 1975 and 2007. The generalization of this methodology and its application to other areas will permit local government branches to take appropriate actions, and to establish policies for improving the quality of human life, in particular for people who do not possess a satisfactory status in basic living conditions.

1. INTRODUCTION

1.1 Statement of the Problem

The world population is increasing remarkably fast. This phenomenon has critical consequences in poor segments of population, living mainly in developing countries. Poor people generally live in areas located in the neighbourhood of urban centres. The high rate in population growth in these countries often leads to severe social problems. Public policies for counties and cities where this situation occurs call for a reliable detection of related areas as well as for an estimation of the growth rates. Since population growth is of course linked to the existence of living quarters, municipalities often request an estimation of the number of unplanned buildings in such poor areas over time, incl. potential changes in height.

For a number of reasons a ground survey to acquire the requested data is not always possible. Also, the determination of ground control point coordinates is at times difficult, because access to the area is sometimes dangerous and only possible with massive police support. Thus, remote sensing is seen as an attractive solution.

1.2 Goals of the Study

This study aims to automatically determine changes in urban areas from multi-temporal multi-scale, and multi-platform remotely sensed data as a base for estimating changes in population. It is based on the following data sets: a stereo pair of IKONOS panchromatic images, and a set of three stereo pairs of digitized-airborne imagery, taken at different epochs with different scales. For evaluation purposes a 1:2.000 DXF vector dataset was used. The investigation was carried out jointly between universities in Brazil and Germany. It is financially support by the Brazilian National Council for Scientific Research (CNPq), and the German Aerospace Center (DLR).

1.3 Project Area

The study area is the *Rio das Pedras* community, a poor inhabited area in the west of Rio de Janeiro. Figure 1 gives an overview of the region. It has a perimeter of approximately 4.6 km and an area of 0.5 km^2. The topography of the terrain is practically flat, with average heights close to sea level. The rapid human occupation of this region is remarkable. Figure 2 depicts the area in 1975. From this image one can see that the community did not exist at that time. However, this situation has changed significantly in the meantime. For example, in 2000 (figure 3), the aerial image shows a completely different situation, with a large settlement area. The 2000 Official Decennial Census of that area has estimated its population to be approximately 113,000.

Going along in time, in aerial photos from 2004 (figure 4), one sees that the community covers basically the same area as in 2000. Figure 5 shows an oblique view taken in 2006; many high buildings can be seen. Due to these observations, our research hypothesis arises: if there is no considerable horizontal change, any changes in population, if they occur, are due to an increase in building heights.

Figure 1. Overview of *the Rio das Pedras* area taken in 2006. (Courtesy of Mr. Gabriel de Paiva)

Figure 2. Aerial image of the *Rio das Pedras* area from 1975 showing no significant human occupation of the region.

In order to investigate this hypothesis, we studied reliable newspaper reports for social profiles and human density changes in the *Rio das Pedras* area. The results confirmed the expectation: the news reported many unplanned multi-floor building constructions (O GLOBO, 2007). Thus, there was no doubt about an increase in human population of the *Rio das Pedras* area.

The main topic of this investigation is the quantification of the vertical growth as function of time from the images using automatic techniques.

2.USED DATA

2.1 Images

This investigation used the following datasets: (a) a stereo pair of panchromatic IKONOS images taken in January 2007; (b) a set of three stereo pairs of aerial images, scanned with 30µm pixel size, taken at 3 different epochs. Table 1 summarizes the characteristics of the imagery with the ground sampling size (GSD).

Figure 3. Aerial image of the *Rio das Pedras* area from 2000

Figure 4. Aerial image of the *Rio das Pedras* area from 2004

Figure 5. Overview of the buildings in the *Rio das Pedras* area in 2006 (Courtesy of Mr. Gabriel de Paiva)

Year of flight	Image scale	Focal length [mm]	GSD [m]	Effective GSD [m]
1975	1: 8.000	152,98	0,24	0,51
2000	1: 8.000	301,387	0,24	0,45
2004	1: 18.000	151,98	0,54	1,13
2007	IKONOS	-	1,0	1,00

Table 1. Specification of imagery used in the study.

The image quality of the aerial imagery is limited – the digitized aerial images are somewhat blurred. For this reason the image quality was investigated by edge analysis. Across an edge a sudden change of object brightness causes a continuous change in the image. The first derivative of the grey value profile perpendicular to the edge leads to the point spread function. The width of the point-spread function includes information about the effective resolution. The images of the year 1975 exhibit a factor of 2.13 between nominal and effective ground resolution which means that instead of the nominal GSD of 0.24m, the information in the image corresponds to 0.51m GSD (see Table 1) – similar investigation were carried out for the other two aerial stereo pairs. Only for IKONOS there was no loss of information against the nominal resolution.

2.2 Ground Control Points

In the study area surveying of ground control points (GCP) was possible. Despite this fact we derived the orientations of the aerial images from GCP determined in the IKONOS images. As a result, all stereo pairs and the resulting DSM refer to the same datum and can thus be compared easily. The IKONOS stereo pair was oriented using a number of GCP. We employed GPS L1 receivers and the static surveying method, with post-processing of base-line vectors to determine the ground coordinates, the image coordinates were measured interactively. In the IKONOS images conjugate points, which were well visible in the aerial images, too, were then determined, again by interactive measurement, and the object point coordinates were computed. These points were subsequently used as GCP for the orientation of the three aerial stereo pairs. Some of them are depicted in Figure 6.

2.3 Vector Data

For evaluation of the results four cartographic DXF vector datasets at the scale of 1:2.000 were used in this study. These datasets came from the Official Urbanism Bureau of the City of Rio de Janeiro named *The Pereira Passos Institute*.

3.METHODOLOGY

3.1 Photogrammetric Software Packages

Processing of the images was based on the programme systems DPCOR and BLUH, developed by Karsten Jacobsen (IPI 2008, Jacobsen 2008) and the programme system LISA developed by Wilfried Linder (Linder 2006).

3.2 Data Processing

Generally speaking, our main goal is to extract Digital Surface Models (DSM) from every stereo pair. The following steps are necessary for achieving goal, using both, aerial and satellite images:

Figure 6. Overview of the ground control points in the *Rio das Pedras* area. Yellow pinpoints with the suffix "**RDP**" show ground control points of the area

(1) Computation of image orientation;
(2) Automatic image matching using a region growing least squares matching algorithm (Otto, Chau 1989; Heipke et al. 1996).
(3) DSM computation by forward intersection;
(4) DSM interpolation;
(5) Intersection of the DSM with horizontal planes at different heights. These heights were chosen to correspond to the different numbers of building floors.
(6) Comparisons between the areas at the same height extracted from DSM of different epochs;
(7) Computation of height changes in the area of interest

Obviously, the areas in which heights were computed must be identical for the different epochs. Figure 7 shows a view of the resulting common area of all DSM data sets used for comparisons. Note that the DSM area has some gaps, corresponding to the areas where image matching was not successful.

4.RESULTS

4.1 DSM Validation

Figure 7 shows the overlay of the vector data and the DSM from 2000. By visual analysis of the DSM with the cartographic data a change of the river and one road, that crosses the image, can be identified. Besides this visual check, we have compared DSM heights and ground heights from the vector dataset in open terrain. The results were quite similar, thus, we consider the DSM as accurate enough for our study.

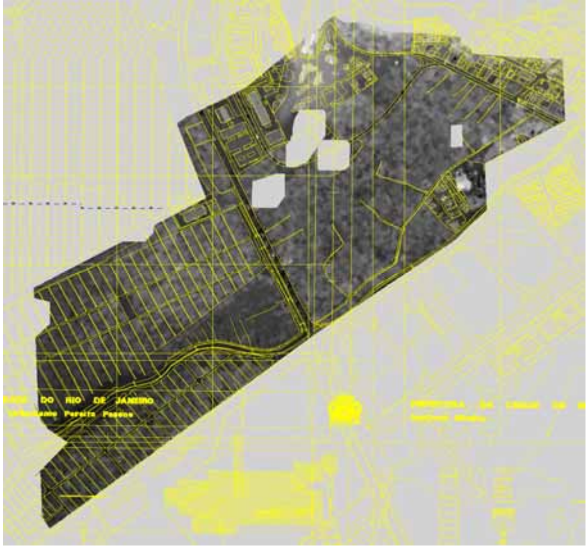

Figure 7. Overlay of the cartographic 1:2000 database with the extracted DSM from 2000. The larger white areas in the upper part are holes in the DSM due to incomplete image matching.

4.2 DSM Differences

Figures 8 to 10 show the results of consecutive differences between the DSM datsets. The colours correspond to height differences, see the legend at the lower right of th figures.

Whereas a clear incrase in height is visile between 1975 and 2000 and a lesser extend also between 2000 and 2004 (apart from the blue whole in the lower right, Figure 10 depicts an apparent decrease in height, visible by the blue colour (for a discussion of this result see sections 4.4. and 5).

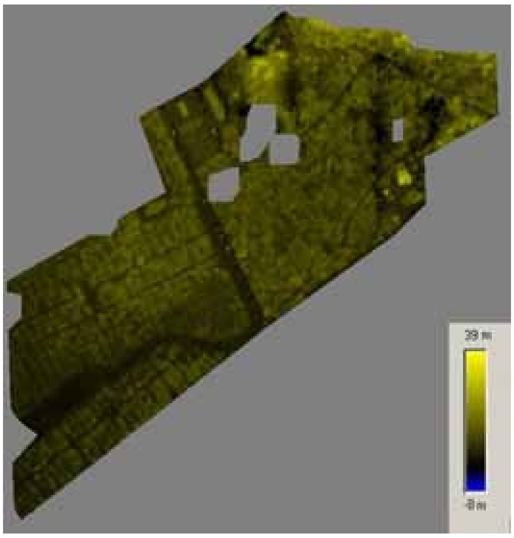

Figure 8. Difference DSM between 2000 and 1975

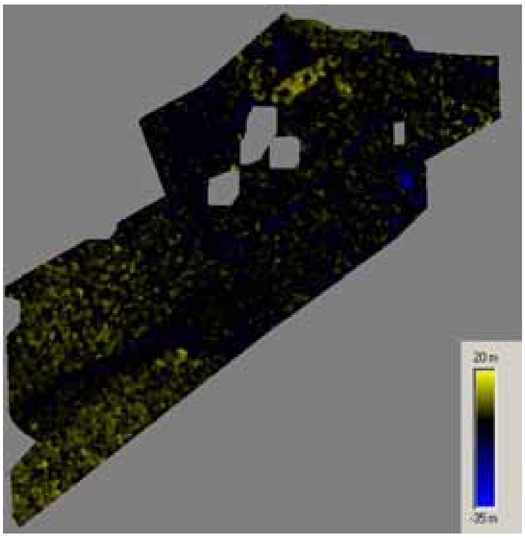

Figure 9. Difference DSM between 2004 and 2000

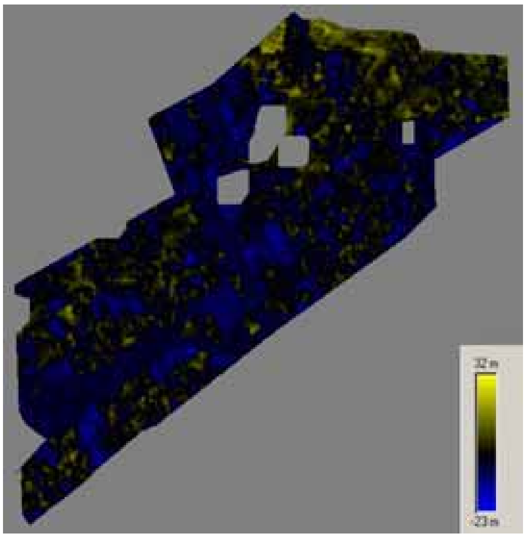

Figure 10. Difference DSM between 2007 (IKONOS) and 2004

4.3 Intersections of DSM with Horizontal Planes

Table 3 shows the results of intersecting the DSM with horizontal planes of different height (see left column). The values depicted in the columns represent, respectively, the number of floors of a building, the height above sea level, and the area, in m^2, computed from the intersection of each DSM with the horizontal planes. The heights of the parallel planes were selected so that each plane intersects the building at roughly half the height of each floor. Assuming that a single floor is typically 3 m high, we place the first plane at 1.5 m from the ground, and further planes every 3 meters above it. This guarantees that each plane intersects different floors in a building and, conversely, that each floor is intersected by a single horizontal plane.

Floors	Height Level (m)	Area of intersection to an horizontal plane (m^2)			
		1975	2000	2004	2007
1	1.5	37.981	513.343	514.532	408.677
2	4.5	16.972	370.311	408.190	335.706

Floors	Height Level (m)	Area of intersection to an horizontal plane (m^2)			
		1975	2000	2004	2007
3	7.5	5.969	188.563	250.156	222.500
4	10.5	3.100	78.757	115.767	137.816
5	13.5	1.459	28.166	39.167	63.012
6	16.5	217	10.373	16.957	29.803
7	19.5	0	4.361	7.270	18.019
8	22.5	0	1.430	3.032	11.369
9	25.5	0	511	1.133	7.615
10	28.5	0	40	68	4.911
11	31.5	0	11	3	3.254
12	34.5	0	3	1	1.913
13	37.5	0	0	0	443
14	40.5	0	0	0	0
Total area (m^2)		65.698	1.195.869	1.356.276	1.245.038

Table 3. Resulting areas [m^2] of the DSMs in the different height levels

4.4 Height Changes

Figure 11 shows the total area of the buildings at each floor level, and their variation along the time.

It can be seen that there is a significant increasing in area of the buildings from 1975 to 2000 for most floor levels. This fact could be also observed from 2000 to 2004. However, this is not the case for the period 2004 – 2007; on the contrary, the areas decrease. This would mean that building floors having been constructed between 2000 and 2004 have been removed in the following 3 years. We believe that such development is rather unlikely, and the numbers – as the blue colour in Figure 10 – can be explained by some missing buildings in the 2007 dataset, since matching from the IKONOS images turned out to be more difficult than those from the aerial images. Thus, population estimates for 2007 should be handled with care.

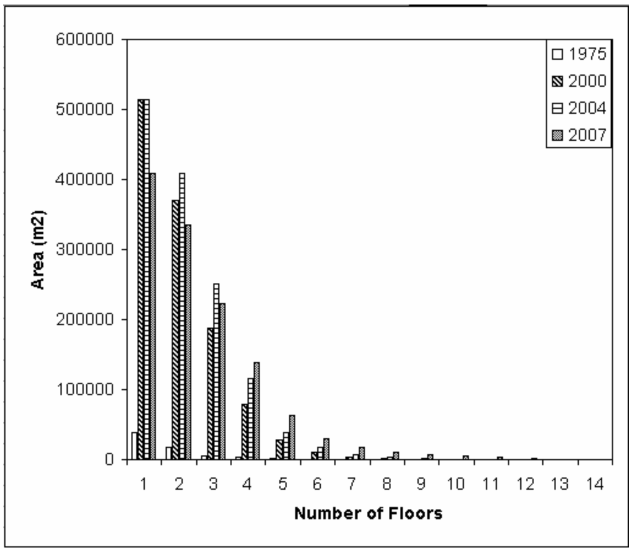

Figure 11. Building height changes as function of time

5. DISCUSSION

The main motivation of this work was to investigate the use of remote sensing data as ancillary information for population estimation. However, the work is limited to the estimation of inhabited areas. In fact, the inference of population from the area is not a trivial task. Nevertheless, we include in this section a simulation for population estimation.

According to the official decennial census, (Cezar, 2002), the population of the *Rio das Pedras* community was estimated to 31.071 inhabitants in 2000. Coincidently an image acquired in 2000 is part of our data set. This permits to estimate the population density at that epoch.

According to Table 3, the total inhabited area in 2000 was equal to 1.195.869 m^2. Hence, the average area a (m^2) per inhabitant, in 2000, is approximately equal to 38,5. If one assumes that this value does not significantly change in the time interval of our analysis, it is possible to estimate the population in the other epochs by just dividing the last row of Table 3 by a. These results are shown in Table 4.

These values indicate a significant population growth rate especially between 2000 and 2004. This value is thought to be realistic according to the social facts known about that area. The value for 2007 on the other hand seems to be wrong; a possible reason was discussed above.

The model conceived to produce such estimates involves a number of simplifying assumptions. Their impact on the accuracy of the estimates is hard to assess. As a matter of fact, the population estimate depends on a number of factors other than the inhabited area alone. A thorough analysis on this subject is beyond the scope of this work.

	Year			
	1975	2000	2004	2007
Absolute	1.706	31.071	35.228	32.339
Growing rate (%)	-	1.821,3	13,4	-8,2

Table 4. Population estimates of *Rio das Pedras* over the year

6.CONCLUSIONS

The estimation of the settlement population by means of digital surface models seems to be promising for areas where classical census methods are difficult or impossible. The height changes in such poor urban settlements from multi-temporal, multi-scale and multi-platform remotely sensed data leads to reliable results. Despite recognizing the need for additional investigations to derive a more precise check of our estimations, we have no doubts that this research has achieved its goal.

The generalization of this methodology and its application to other areas will permit local government branches to take appropriate actions and to establish policies for improving the quality of human life, in particular for people who do not possess a satisfactory status in basic living conditions. This methodology has also potential to lead to a more rational use of natural resources.

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