

# Monitoring of Buildings based on GeoEye-1, IKONOS and aerial image stereo pairs

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**Abstract.** Monitoring of buildings is a basic task for survey administrations. It is not just limited to identification of new or eliminated houses also the extension of building heights is important. Especially the identification of building height changes is very difficult by manual image interpretation. With least squares and semi global matching digital surface models (DSMs) in urban areas have been generated using stereo pairs from aerial images taken in May 2007, IKONOS taken in May 2008 and GeoEye-1 taken in September 2009. For the aerial images orientations from a bundle block adjustment were given, but there were no control points for the satellite images. In a first step the satellite DSMs were based just on the given rational polynomial coefficients (RPC) and compared with the DSM from aerial images. The direct sensor orientation of IKONOS required a shift in X and Y in the range of 7m and in the height 0.3m in relation to the orientations from aerial images, for GeoEye-1 the required shift in X and Y was below 1m and in the height 2.8m. The noise of the DSMs computed by least squares matching (LSM) is larger as based on semi global matching (SGM). Especially the building shape is more precise based on SGM and SGM has not as much problems with areas of low contrast and shadows. Nevertheless with DSMs of both methods differential height models could be generated, showing very clear height changes of buildings caused by new, eliminated and enlarged buildings. Height changes of one floor, in the range of 2.7m, became obvious. The relative accuracy of filtered height models without effects caused by viewing shadows and poor contrast areas is in the range of 0.5m up to 1m, an accuracy which required before large scale aerial images.

**Keywords.** Satellite imagery, aerial imagery, orientation, 3D-determination, matching, buildings

## 1. Introduction

For a suburb of Riyadh changes of buildings should be determined based on scanned aerial wide angle photos from May 24<sup>th</sup> 2007, an IKONOS stereo pair from May 24<sup>th</sup> 2008 and a GeoEye-1 stereo pair from September 15<sup>th</sup> 2009. The base to height relation is similar for all stereo pairs with 0.60 for the aerial images, 0.60 for the IKONOS stereo pair and 0.67 for the GeoEye-1 stereo pair. The height to base relation is important for the accuracy of height determination. The IKONOS stereo pair as well as the GeoEye-1 stereo pair have a roll angle of 11°, both viewing to West of orbit (figure 1). The wide angle aerial photos with a scale 1 : 45 000 have been scanned with 14µm pixel size corresponding to 63cm ground sampling distance (GSD), while the IKONOS images have 1m GSD and the GeoEye images 0.5m GSD. The manual inspection of building changes is time consuming and not very reliable. Especially the change of building heights by adding one or more floors is very difficult to be seen, so the building changes should be identified by differences of digital surface models (DSM) determined by automatic image matching for the different update periods.



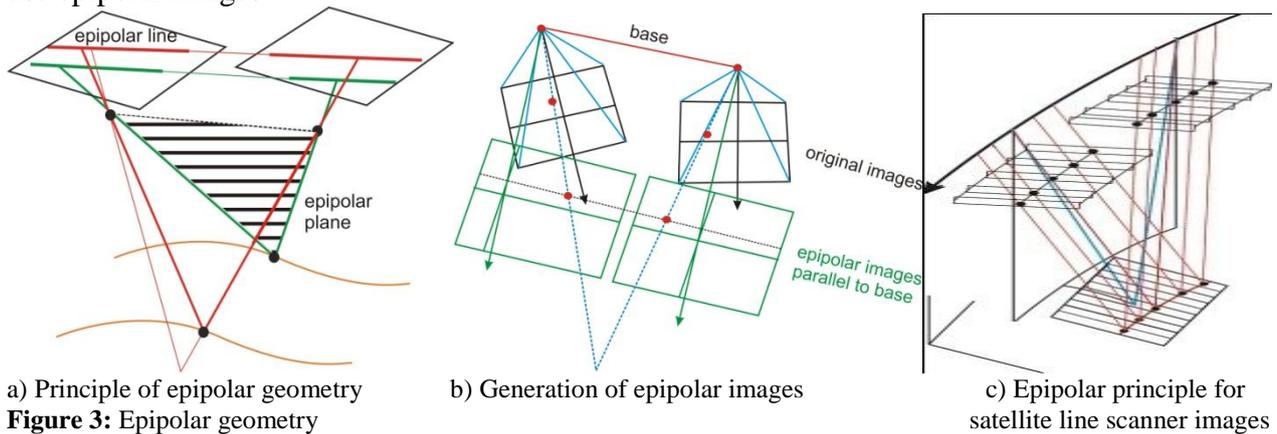
As obvious in figure 2, GeoEye-1 shows with 0.5m GSD more details as the other images, but a comparison of IKONOS with 1m GSD and the scanned aerial image with nominal 0.63m and effective 0.74m GSD shows slightly clearer details of the IKONOS image. As typical for scanned aerial images it has larger noise, lower contrast and as result of this, details are more blurred.

### 3. Image orientation and generation of epipolar images

The image orientation of optical satellite Geo images, being a projection of the original images, improved by radiometric and geometric system calibration, to a plane with constant object height in the national coordinate system, became standard with bias corrected RPC-solution (Grodecki 2001). The absolute geo-reference of the satellite images without use of ground control points (GCPs) has reached a standard deviation without the effect of terrain relief correction for X and Y of 4m for IKONOS and 2m for GeoEye-1, being accurate enough for several application. For aerial images bundle block adjustment with self calibration is standard.

For the Riyadh project areas at first no GCPs have been available, so at first the height models using IKONOS and GeoEye-1 images have been based on the absolute sensor orientation without bias correction. Of course this may lead to systematic errors of the height models, especially shifts in X, Y and Z. Later we got aerial images together with the results of bundle block adjustment. With the oriented aerial images object reference points, usable as GCPs, have been determined. Based on these well defined points root mean square errors of the object coordinates in the stereo models of 0.40m in X, 0.46m in Y and 1.15m in Z for IKONOS and 0.41m in X, 0.48m in Y and 1.13m in Z for GeoEye-1 have been reached. Nevertheless the height models not based on GCPs had to be shifted against the height model from aerial images by adjustment, requiring a shift of the IKONOS height model of -5.0m in X, 8.0m in Y and 0.3m in Z and for the GeoEye-1 height model 1.0m in X, 0.7m in Y and -2.8m in Z. By unknown reason the height model based on aerial images was slightly rotated, requiring a rotation by adjustment with the Hannover program DEMSHIFT.

Height models have been computed by means of least squares matching (LSM), pixel based matching with dynamic programming (DP) and semi global matching (SGM). DP and SGM have to use epipolar images.

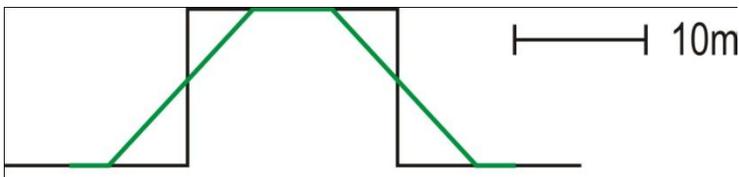


Epipolar lines in perspective image pairs (figure 3a) are the intersections of the epipolar plane, defined by an object point and both projection centres, with both images. A change of the object height corresponds to a shift of the corresponding image points only in the epipolar lines. In epipolar images (figure 3b) corresponding image points have the same y-coordinate. Satellite line scanner images have perspective geometry only in line direction. Any line has a different projection centre (figure 3c), so only quasi epipolar images can be generated by the definition that corresponding image points shall have the same y-image coordinate and a change of the object height causes only a

shift of the image point in x-image direction. Such epipolar images can be simply generated with Geo-images (or OR Standard or SPOT level 2A) just by an image rotation to the base direction of the stereo model. The influence of a roll angle and height differences against the reference height of a Geo-image under usual conditions does not exceed 0.1 pixels.

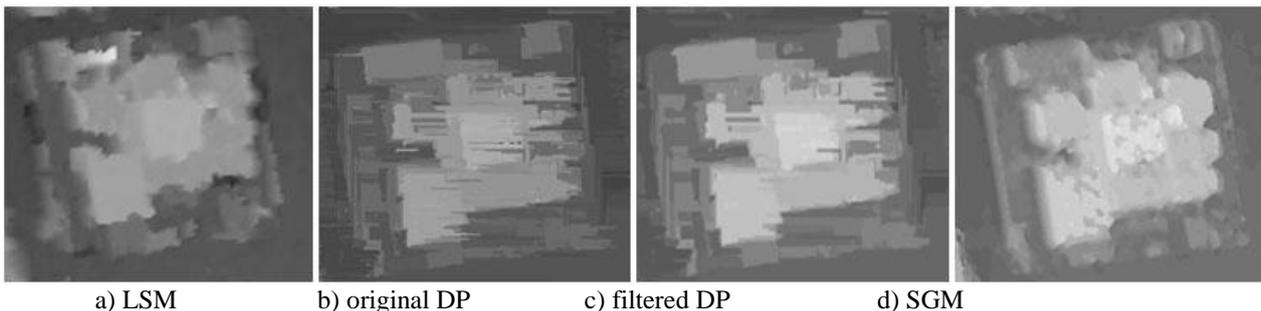
#### 4. Image matching

The classical image matching is area based – a sub-matrix of the left image will be matched with a sub-matrix of the right image. In the case of cross-correlation, the sub-area in object space is expected to be parallel to the image plane. The least squares matching improves this to a geometric fit of both image sub-areas by affine transformation, corresponding to any inclination of the ground area, but all area based matching methods expect a continuous change of the object height. This is not the case for buildings with sudden height changes in the object space. By least squares matching the height profiles are smoothed as shown by the simulated height profile in figure 4.



**Figure 4:** Black: Height profile of a typical building in Riyadh suburb  
Green: Simulated height profile determined by LSM with sub-matrix of 10x10 pixels

With a smaller sub-matrix as 10x10 pixels LSM by theory will describe the object more precise as in figure 4, but a smaller sub-matrix will cause more blunders and not so accurate results. Test showed that a sub-matrix of 10x10 pixels was leading to the best results of LSM. Feature based matching is able to determine the building shape under optimal conditions accurate, but by feature based matching usually not enough object points are determined for a satisfying height model. An alternative is the pixel based matching with additional cost function. The matching of individual pixels is not possible also the neighbourhood has to be respected, this is done by DP and SGM with a cost function, respecting all pixels in the corresponding epipolar lines in the case of DP and the pixels in several lines with different directions in the case of SGM (details in Alobeid et al. 2010). DP matches the neighbored epipolar lines independently, causing striping of height models. Based on an improved model and the use of several profiles SGM leads to sharp building shapes, not disturbed by striping.



**Figure 5:** Grey value coded height models of a building based on GeoEye-1 stereo pair of sub-area shown in figure 2

Figure 5 demonstrates the characteristics of the used methods for automatic image matching. The height model determined by LSM shows the building shape not sharp while DP generates sharp building structures, disturbed by striping. The striping of DP can be reduced by a median filter with a size of 1 pixel in epipolar line direction and a specified number of pixels across the epipolar line direction – in this case a filter matrix of 1x3 pixels has been used. There is no discussion about the best building shape determined by SGM; this is a general finding not only for this sample.

### 5. Building monitoring in suburb of Riyadh

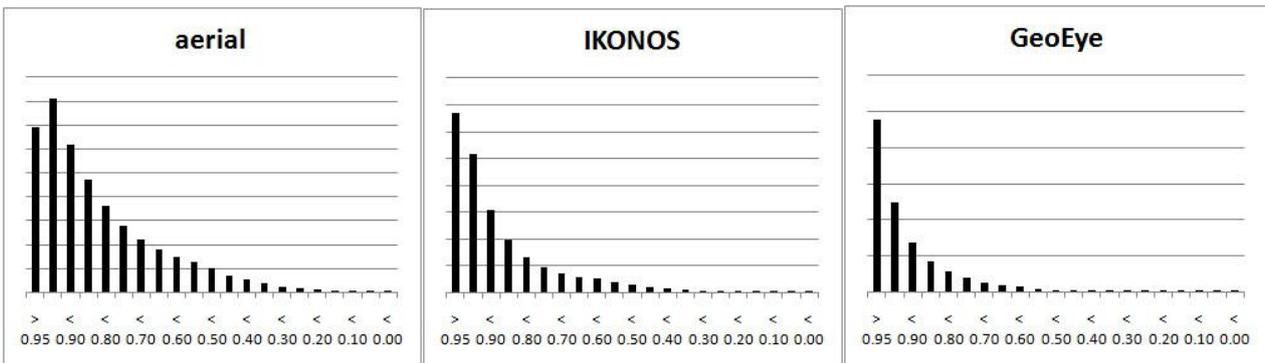
The city of Riyadh expands very fast, causing problems in updating the building data base. A manual update with stereo models is very time consuming and it is not easy to detect all new buildings. The visual detection of buildings where some floors have been added is nearly impossible. The totally automatic update of the building data base with the today technique is not accurate and reliable enough and would require high resolution aerial images. An operational solution is the determination of the height changes by a differential height model of two imaging periods. The differential height models indicate the location of height changes where the human operator has to measure the building vectors for updating the data base.

As mentioned before, SGM would be a nice tool for determining the digital surface models as base information of the differential height models, but SGM as well as DP failed with the scanned aerial photos. The scanned aerial photos are too noisy for the pixel based matching, so at least for this data set least squares matching was required for the generation of a DSM. Because of this problem for the building monitoring of all three periods LSM was used. Nevertheless the matching by DP and SGM did not cause any problems with the original digital images from IKONOS and GeoEye-1. The matching in the suburb of Riyadh is simplified by the fact of missing vegetation – no trees are disturbing the determination of the buildings.

**Table 1.** Standard deviation of building height determined by matching

	Least squares matching	Dynamic programming	Semiglobal matching
IKONOS	0.9m	1.1m	0.8m
GeoEye-1	0.7m	0.6m	0.5m

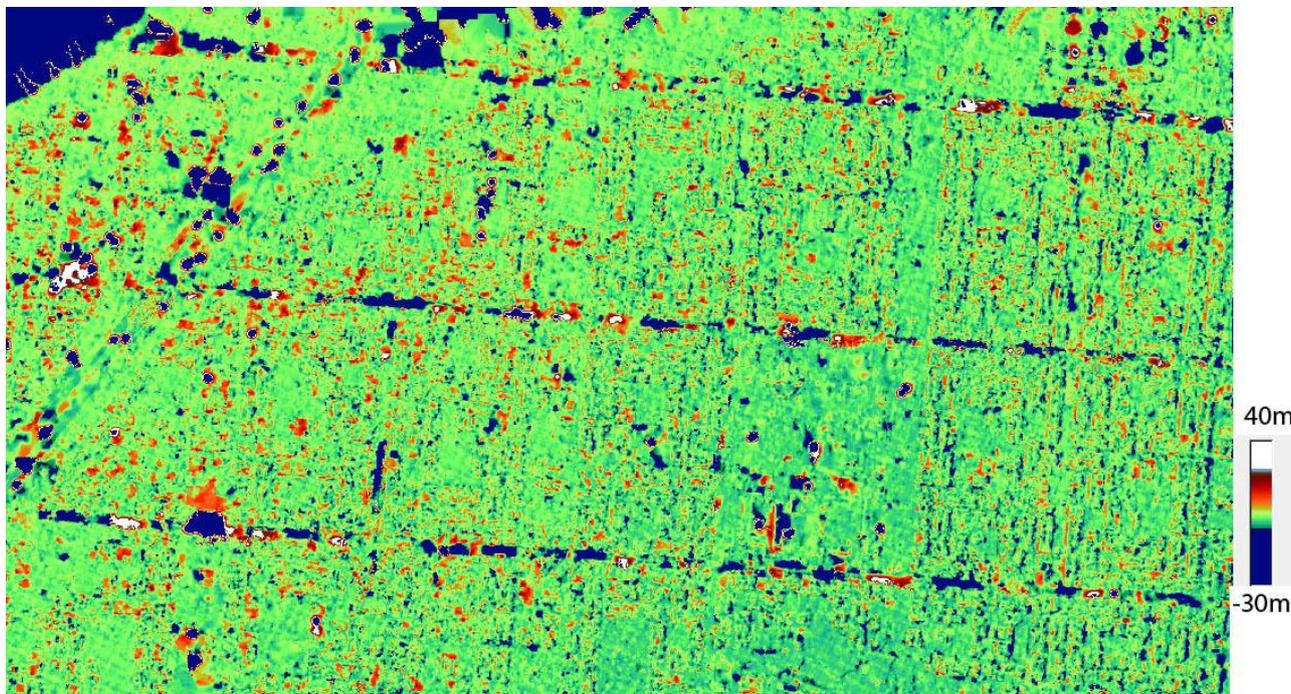
The standard deviation of building heights defined as height of building centre minus the ground height, has been determined for the three used methods of image matching (table 1). The buildings in the project area have flat roofs, simplifying the matching. The not sharp determination of the building shapes by LSM and the striping by DP have no influence to the centre of the buildings (see figure 3). Because of the height differences, orientation errors do not affect the building heights, pointing out the influence of the matching methods. SGM shows slightly better results as the other methods, LSM and DP are on a similar level. The better results of the matching with GeoEye-1 images are clear, but it does not correspond to the factor 2.0 for the relation of the ground resolution. An explanation may be the fact, that the building tops are not totally flat; some small objects as shelters for staircases in most cases are causing some noise for the building tops.



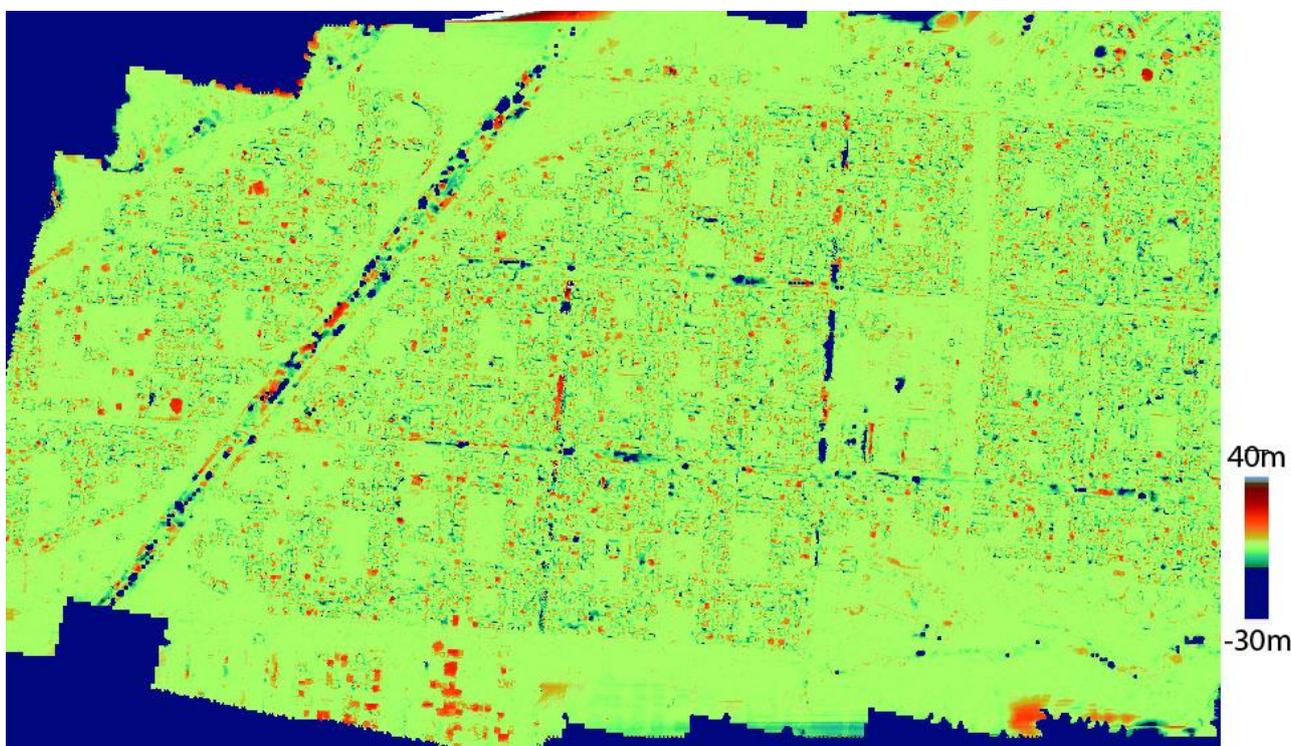
**Figure 6:** Frequency distribution of correlation coefficient for LSM (vertical: frequency, horizontal: groups of correlation coefficients)

The influence of the image quality to the least squares matching is obvious with the frequency distribution of the correlation coefficients (Figure 6). The correlation coefficient frequency of the aerial stereo pair has the maximum not in the first group of  $1.0 \geq c \geq 0.95$  as it is the case for IKONOS and GeoEye-1, in addition a higher percentage of smaller correlation coefficients exist. Only 54% of the correlation coefficients of the aerial stereo pair exceed the value 0.80, while this is 76%

for IKONOS and 85% for GeoEye-1. Corresponding to this, as threshold for accepting matched points of the aerial stereo pair, the low value of 0.55 was used, to reduce the not accepted points to 11% against a loss of 15% for the threshold of the correlation coefficient of 0.60 or even 46% for the threshold of 0.80.

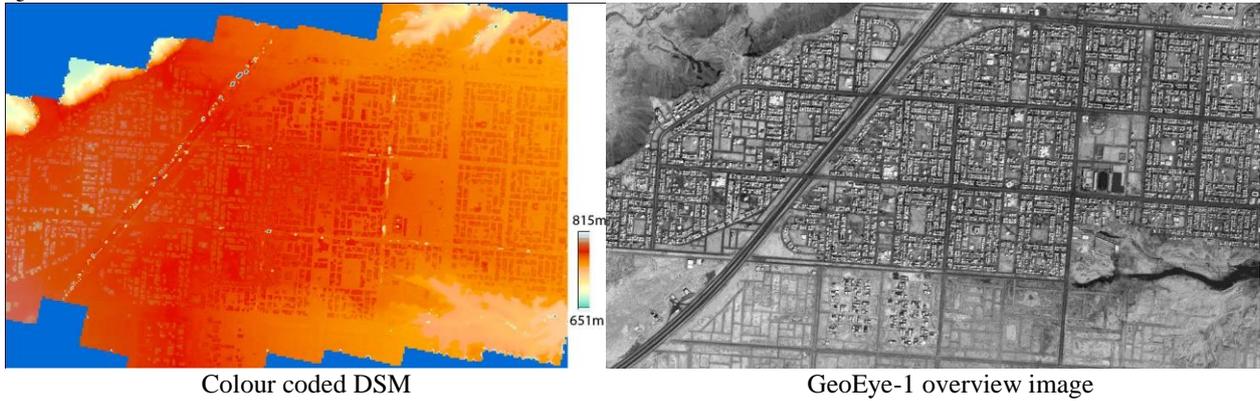


**Figure 7:** difference of height models from IKONOS stereo pair minus aerial image pair (May 2008 – May 2007)

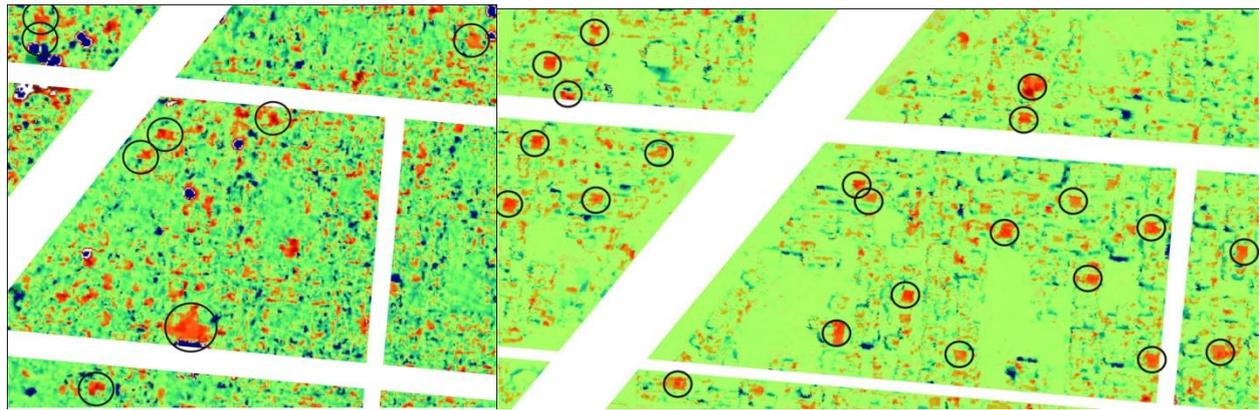


**Figure 8:** difference of height models from GeoEye-1 stereo pair minus IKONOS stereo pair (September 2009 – May 2008)

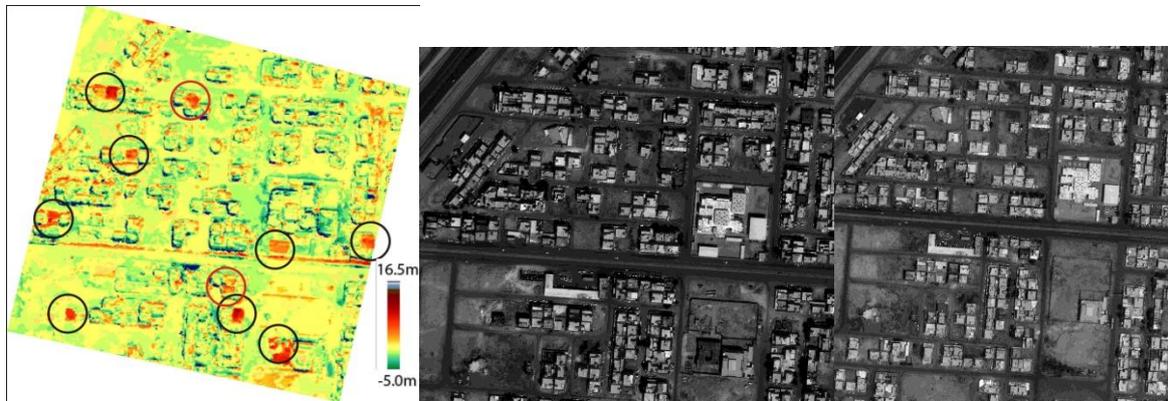
Figures 7 and 8, the differences of DSMs, are indicating the locations of height changes; that means the location of building changes. Caused by noise of the aerial images figure 7 includes several spots not indicating building changes, while this is quite better for figure 8. Nevertheless the shape of spots of height changes shows in most cases clearly building changes as it can be seen in detail in figure 10. The spots of height changes are not clear enough for getting the building shape, so in any case it has to be verified by the original buildings. In figure 10 the major street areas are excluded because LSM failed in the streets not having satisfying contrast and disturbed by moving objects.



**Figure 9:** GeoEye-1 DSM and image, Riyadh



a) IKONOS stereo pair minus aerial image pair      b) GeoEye-1 stereo pair minus IKONOS stereo pair  
**Figure 10:** difference of height models in sub-areas with encircled verified building changes



a) GeoEye-1 – IKONOS      b) sub-area GeoEye-1, September 2009      c) sub-area IKONOS, May 2008  
**Figure 11:** difference of height models determined by SGM and corresponding images

Figure 11 shows the differences of the DSMs from GeoEye-1 and IKONOS determined by SGM. Their shape is slightly clearer as based on LSM (figure 10b), but it is more important to use satisfying images as to use another method of image matching. In figure 11a two buildings are encircled in red, showing buildings where the building height changed. Buildings have been available in May 2008, but the building height changed up to September 2009. It is not possible to identify if the buildings have been turned down and new buildings have been erased or if just a floor has been added, but even by field check this often cannot be seen.

## 6. Conclusions

Building monitoring by differences of DSMs based on stereo pairs from different periods is a promising challenge. The resolution of IKONOS and GeoEye-1 is satisfying under the conditions of a suburb of Riyadh with no small buildings and simplified by no disturbance of trees. Scanned aerial photos with nominally 63cm GSD, but effectively corresponding to 74cm GSD, are disturbed by image noise, complication the image matching. The pixel based matching SGM and DP failed with the scanned photos and the matching quality by LSM, indicated by the correlation coefficient, was not optimal. The differences of the DSMs from IKONOS and the scanned photos do not show changed objects as clear as the differences of the DSMs from GeoEye-1 and IKONOS. The negative influence of the noise in scanned photos to image matching is well known (Haala et al. 2010) and is not present at original digital aerial images.

Semiglobal matching generates clearer building shapes in the DSMs as least squares matching, but both methods do not lead to results which can be included directly into a building data base. The differences of the DSMs indicate very well the location of changes and a human operator will not miss any location where he has to measure the exact location of new and changed buildings.

## References

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