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Accuracy Enhancement of Orthoimage Generation for Urban Areas

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***Abstract*—This research addresses the problems of conventional orthoimages created from aerial imagery of urban areas, especially relief displacements, occlusions and information loss caused by man-made objects. An approach is presented to generate more accurate orthoimages based on elevation models that exactly describe the entire surface of the observed region. The approach utilizes the digital building model, in addition to the digital terrain model, in the orthorectification process. Occluded areas are identified and filled in the final orthoimage by merging data from conjugate images. The data used in the research consists of a small block of high resolution aerial images covering an urban area. The images are captured recently with the digital aerial camera UltraCam-D. The image pixel size is 9 μm by 9 μm yielding a nearly 10-cm ground sample distance. The results reached by applying the proposed approach on the test images have been promising. They have proven the validity of the approach in generating more proper orthoimages.**

***Index Terms:* Orthorectification, Digital Elevation Model, Digital Building Model, Conventional Orthoimages, Mosaicking.**

I. INTRODUCTION

The recent evolution towards a digital production has been going on for the last few years. Mapping technologies are changing rapidly as the result of the advancement of related fields and the requirements of spatial information society. In the recent past, static, fixed scale, multi use and highly accurate hardcopy maps compiled over a short period of time was the tradition. Today's world uses a dynamic, variable scale, single use and variable accuracy digital product made from data possibly retrieved from database derived from multiple sources. Modern mapping products range from hardcopy and digital maps, digital terrain models to digital orthoimages and mosaics, digital surface models, three-dimensional city models, perspective views, etc [1].

An orthoimage is an image that is based on an orthographic projection. Orthoimages combine the rich information content of images with the geometric properties of maps. Orthoimages are very important geospatial data, providing an inexpensive and accurate data base for a variety of applications. They can function as a reference map in city planning, or as part of realistic terrain visualizations in flight simulators. They can be merged into one large image of an enormous area. The orthoimage has a reference to a world coordinate system, and can therefore function as an interpreted map [2].

Orthoimages are conventionally generated through an orthorectification process based on a digital terrain model. The model describes the effects of relief displacements that occur from variation of terrain heights through the central perspective projection onto the image plane. However, it is well known that man-made objects above the topographic surface are not modeled in the DTM. Therefore, those objects appear displaced from their correct position on the orthoimage. Additionally, some important information regarding ground features like streets and other objects in urban areas is occluded or hidden [3]. Thus, the superimposition of vector data on conventional orthoimages is almost impossible, which limits their usability. A highly accurate orthoimage that can be used without considering any uncertainties is of great interest.

II. BACKGROUND

The process of orthoimage generation consists of three main phases. They are the phases of reprojection, resampling and mosaicking. Regarding reprojection, there are two basic reprojection approaches; forward projection and backward projection [4]. In the forward projection, the pixels from the source image are projected on top of the DTM of the 3D model and thus the pixel's object space coordinates are calculated. Then, the object space points are projected into the orthoimage. The orthoimage pixels are generated by interpolating projected points. In the backward projection, the object space X,Y coordinates related to every pixel of the final orthoimage are determined. The height Z at a specific X,Y point is calculated from the DTM or the 3D model and then the X,Y,Z object space coordinates are projected in the source image in order to acquire the intensity value for the orthoimage pixel. Resampling in the source image is

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essential because of the fact that the projected coordinates will not fit accurately at the source image pixel centers.

Resampling is a process necessary to get a digital sample at a fractional row and column location. It involves interpolation between the intensity values of existing pixels to generate values that correspond to fractional locations. Several interpolation techniques are available for resampling digital images. However, the most common ones are known as nearest-neighbor interpolation, bilinear interpolation, and bicubic interpolation [5]. The first method uses the value of the closest pixel to assign to the output pixel value. The second method makes use of the data values of four pixels in two-by-two window to calculate an output value with a bilinear function. Bicubic interpolation employs the values of sixteen pixels in four-by-four window to calculate an output value with a bicubic function. This method sharpens the image and smoothes out noise without loss of image information.

Mosaicking is required to put together images after the orthorectification of each of them. The process involves several steps: seamline generation; color matching; and feathering and dodging [6,7]. The seamlines in a mosaic defines where the images are stitched together. They are generated manually or automatically. The goal is to mosaic the images along places where they look very similar. A manual seam line placement is preferable to be placed along the centerlines of the roads [8]. The images mosaicked should have the same color characteristics near the seamlines. If the color or brightness of the images is very different, the result of mosaic will be very poor, and the placement of the seamlines would be visible. Color matching and dodging techniques tries to remove the radiometric differences in the images, by analyzing and comparing the overlapping sections. Feathering tries to hide the remaining differences by making a smooth cut that slowly fades from one image to another. A simpler approach places the seamlines along the centre of the overlap area [9,10].

The process of conventional orthorectification has some shortcomings especially when dealing with images showing urban areas with high buildings and objects. The main shortcoming is that abrupt changes in elevation can not be dealt with properly in the process. Resulted relief displacements can be so significant that they will occlude the terrain and objects next to them. Traditionally generated orthoimages are not satisfactory since the terrain model doesn’t include the buildings, bridges, vegetation, etc. This results in an image where buildings are leaning away from the image centre, and doesn’t get corrected. Only objects that are in level with the terrain are reprojected correctly. Roads running over bridges will look like they bend down to follow the terrain below it. Existed buildings will surely occlude objects close to them, since the walls of the buildings can be thought of as an abrupt change in elevation [11]. Thus, some ground features like streets, manholes, fire hydrants and other utility poles are hidden to the user of the orthoimage and its interpretability is decreased.

The orthorectification shortcomings arise whether a traditional terrain model or a complete surface model including man-made objects is employed. This is due to the fact that if a building is orthorectified, it will get rectified back to its original position, but it will also leave a copy of the building on the terrain. The reason for this is that during the reprojection, rays are reprojected back to both the occluded area and the occluding object, without detecting that occluded data is being rectified. Therefore the wrong image data is rectified in the occluded areas [3]. That means that even with a surface model accurate orthoimage is not guaranteed. In fact, if hidden zones are not detected and corrected accordingly, the gaps are simply filled with the same image leading to a doubling image [12].

III. PROPOSED APPROACH

Given a block of four digital aerial images depicting urban areas, the proposed system used for orthoimage accuracy enhancement consists of a set of modules that are related to each other as shown in Fig.1.

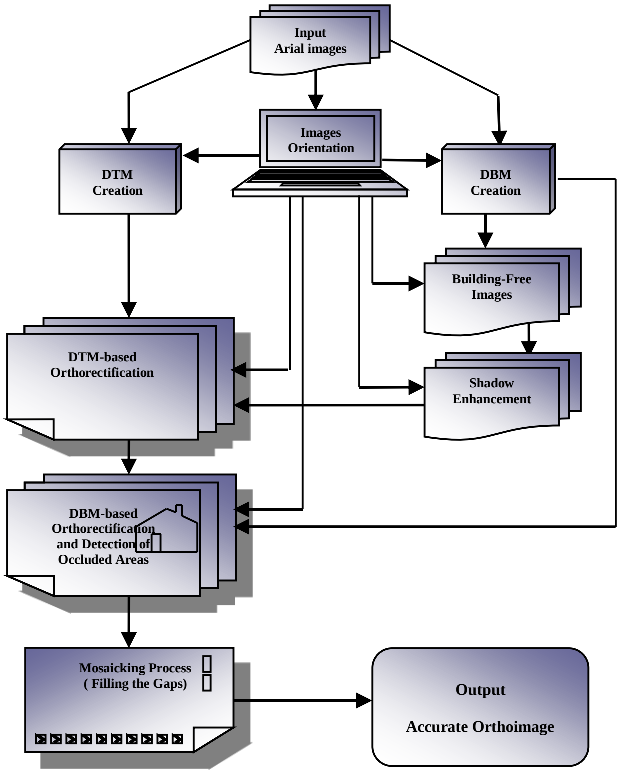


Figure 1.Flowchart illustrating the approach modules.

As depicted in the figure above, the modules of the proposed approach can be outlined as follows:

- Resolving exterior orientation of each image of the block,
- Generation of DTM and DBM for the target area,
- masking out buildings off the block images,
- Detection and enhancement of shadow areas,
- DTM-based orthorectification of the building-free images,
- DBM-based orthorectification to get buildings in their correct position, and
- Mosaicking to fill up occluded areas by combining overlapping orthoimages.

Modules of image orientation and triangulation, creation of digital terrain models, generation of traditional orthoimage and the mosaicking process are to be executed independently with the help of the Leica Photogrammetry Suite (LPS) version 9.0 along with Erdas software. The other remaining modules are to be carried out utilizing a number of a MATLAB prototype programs that have been prepared during the study period.

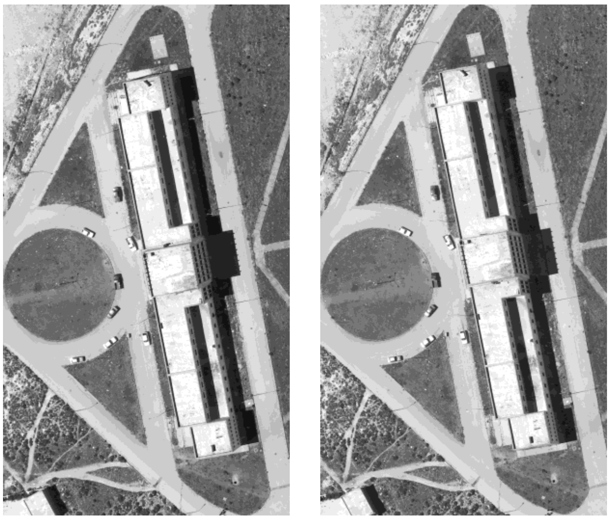
The six exterior orientation parameters of each of the involved images are resolved given sufficient control data. This can be performed using simultaneous least-squares adjustment, based on collinearity condition equations. These parameters are essential for the generation of related digital terrain models photogrammetrically as well as conventional orthoimages. Utilizing the orientation parameters, The DTM and DBM describing the surface of the terrain of the photographed area is generated photogrammetrically. The DTM is created automatically by applying image matching to the terrain points on involved images using camera data and exterior orientation parameters. Buildings are excluded during the process. On the other hand, the DBM revealing the details of buildings is generated interactively via digitizing the corners of those objects.

In order to utilize the created DTM for orthorectification, buildings are masked out (or shaved) off the images. Building pixels that are masked out would be filled up by a specified value. The masking out process can be done by projecting the DBM on the images using the collinearity condition equations. Treating the shadow area can be done after or prior to the masking out process, doesn't matter which one is first. The objective of this module is the visual enhancement of the shadow area caused by the buildings. Treating the shadow involves two steps: shadow area detection and shadow area enhancement. Fundamentally, the shadow can be detected by using information about the direction and altitude of the sun. In case of lacking such information, they can be estimated from measurements of shadow direction and length on the image. More clearly, the azimuth angle of the sun can be estimated from the direction of the shadow, whereas the zenith angle is calculated from the ratio of building height to the shadow length. Shadow areas are given an intensity value equivalent to the mean pixel value of the surrounding area.

Based on the results of the first two modules, the orthorectification process is carried out. The enhanced free-building images are first orthorectified employing the generated DTM. After then, existed buildings are orthorectified by using the generated DBM leading to accurate orthoimages regarding the position of buildings. The occluded areas are then filled up by integrating the overlapping orthoimages to get the missed information. This phase is accomplished by a mosaicking process employing the orthoimages, as explained in Sec. 2. This is the final phase of the module, which yields the desired accurate outcome.

IV. EXPERIMENTAL RESULTS

The experimentation data comprises a small block of four high resolution digital aerial images depicting an urban area in the city of El-baida, located east north of Libya. Figure. 1 exhibits the patches of the four images that exhibit a large multistory building of an academic institute and its surroundings. Figure. 1-a and Figure. 1-b are the patches of the left and right images of the first strip, respectively. Also, Fig. 1-c and Fig. 1-d are the patches of the left and right images of the second strip, respectively. The images are captured recently with the digital aerial camera *UltraCam-D*. The camera format is 7500 pixels along track by 11500 pixels across track. Given that the pixel size is 9 μm by 9 μm, the format is 67.5 mm by 103.5 mm. The focal length of the camera lens is 101.400 mm. The flying height above datum is nearly 1700 m and the average elevation of the imaged area is 620 m. This yields a ground sample distance of nearly 10 cm. The elevation range of the area is about 40 m and the percentages of longitudinal and lateral overlaps between the images are nearly 60% and 25%, respectively.


(a) Image Patch 1 (b) Image Patch 2

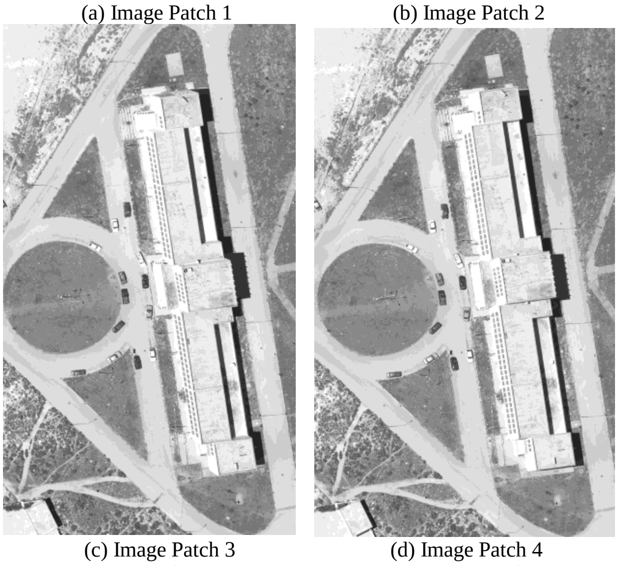

(c) Image Patch 3 (d) Image Patch 4

Figure 2. The four image patches exhibiting the case of study.

The initial values of exterior orientation parameters of each image of the block are provided by direct georeferencing using GPS and INS on board. Table I gives a list of those readings. The coordinates (XL,YL) corresponds to the (E,N) perspective center coordinates referred to the Universal Transverse Mercator (UTM) mapping coordinate system. The reference datum is the World Geodetic Datum 84 (WGS84). The coordinate ZL is the ellipsoidal height of perspective center related to the reference datum.

Table 1. The Initial Values of the Exterior Orientation Parameters of Block Images .

Image ID	1	2	3	4
XL (m)	573100.688	573351.596	573347.159	573594.465
YL (m)	3626133.563	3626226.683	3625471.317	3625563.724
ZL (m)	1690.910	1691.322	1690.836	1691.519
ω (deg.)	0.850	0.660	-0.418	-0.802
ϕ (deg)	-1.277	-1.426	0.953	0.846
K (deg)	285.952	285.834	288.170	288.430

Precise estimates of exterior orientation parameters are achieved by aerial triangulation module embedded in the software package of Leica Photogrammetric Suite (LPS) 9.0. The module starts with loading the block images, defining the camera type, supplying the interior orientation parameters including the pixel dimensions, and providing initial exterior orientation parameters of all images [13]. The reference coordinate system is also set up by selecting a datum and a projection type. Tie points necessary for the triangulation process are automatically selected, matched and measured using *Automatic Tie point Collection* tool of LPS software. The tool enables the user to specify the number of required tie points and to manually edit or exclude any unmatched points. The triangulation results include the estimated global precision of the process, the adjusted exterior orientation parameters, their precision estimates, and the estimated object coordinates of all tie points. Table II illustrates the yielded global precision indicated by the estimated standard error of unit weight, and standard errors of adjusted exterior orientation parameters.

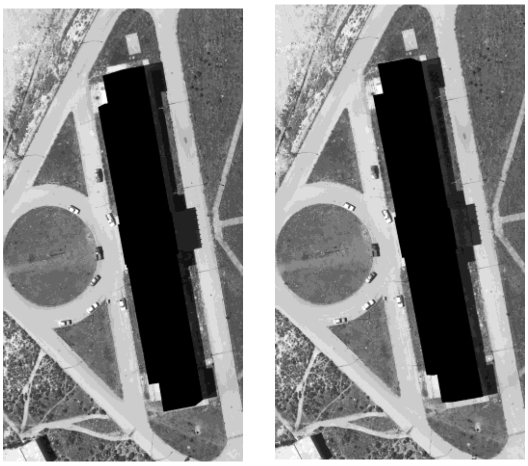
Precision of the triangulation process = 0.33 pixel.						
Precision figures of the estimated exterior orientation parameters:						
Image ID	XL (m)	YL (m)	ZL (m)	ω (deg)	ϕ (deg)	K (deg)
1	0.0264	0.0263	0.0313	0.0043	0.0038	0.0035
2	0.0258	0.0254	0.0272	0.0039	0.0037	0.0033
3	0.0264	0.0265	0.0314	0.0037	0.0044	0.0035
4	0.0264	0.0286	0.0325	0.0037	0.0045	0.0036

Table 2. Part of the Triangulation Report of the Block Under Consideration.

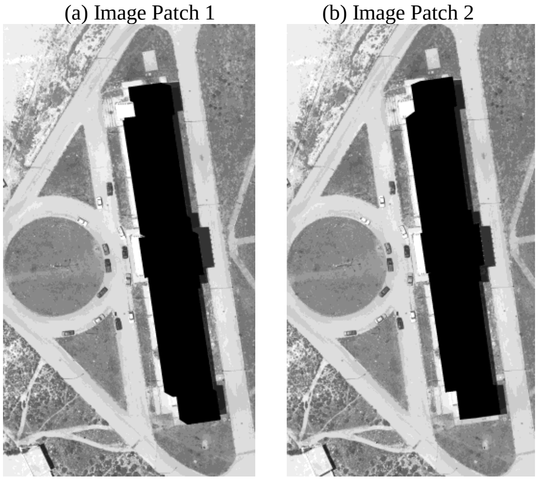
After the accomplishment of the triangulation process, the DTM is created by using the Automatic Terrain Extraction tool of LPS software. The result is a surface that doesn't completely describe the real elevations of the urban areas since manmade objects that have abrupt changes in elevations are wrongly modeled in the surface. Geometrically, every grid point (x,y) in the DTM has a unique elevation (z) because it is mathematically generated by surface interpolation process and that why this model is called a 2.5-D. To guarantee a pure DTM representing only the earth's surface, the building area is excluded from the images during DTM creation and assigned a fixed elevation value instead. This value is equivalent to the mean ground elevation of the area surrounding the object. Alternatively, the created DTM is edited to assign the fixed elevation value to the building area. The created DTM in this research has 1m cell size.

Regarding the DBM generation, prototype MATLAB program is developed especially to generate a dense grid of 3-D coordinates of the roofs and walls of the building. The input to the software is the 3-D coordinates of roof corner points and the Z-coordinate of ground nearby the walls (mean terrain elevation). This information is provided during the triangulation process by interactive measurements of the points of interest using the Point Measurement tool of LPS software. Building walls are generated as vertical planes passing through the roof edges and intersecting the DTM. The grid interval used to generate the DBM is so tiny that a dense grid describing the roof and the walls surfaces is resulted. The output of the process is a text file holding a dense grid representing the building roof and walls.

In order to determine the image areas occluded by the building walls, the developed program is extended to project the previously generated DTM on the images and assign the corresponding pixels a zero intensity value. This ensures masking out the building as well as the hidden terrain by the walls. The input is the raw images, their interior and exterior orientation parameters, and the DBM file. The model used in the projection process is the collinearity condition. Figure. 2 displays the resulted images due to the application of the software.



(a) Image Patch 1 (b) Image Patch 2



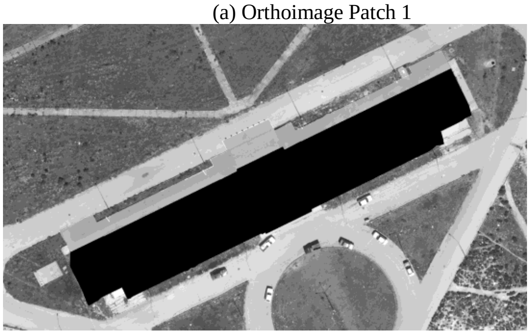
(c) Image Patch 3 (d) Image Patch 4

Figure 3. The image patches after enhancement of the shadow area.

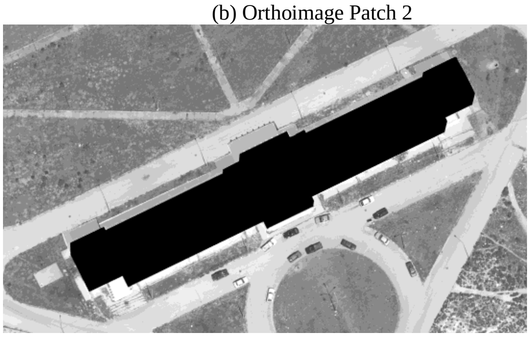
The corners of shadow area due to the building are digitized and computed during the triangulation process. Similar to the generation and projection of the DBM, a dense mesh of 3-D ground coordinates of the shadow area is created and projected on each of the block images. The corresponding pixels are assigned an intensity value equal to the average intensity value of the surrounding area. Figure. 3 presents the resulted after enhancement of the shadow area.

Utilizing the *Ortho Resampling* tool of LPS software and the shaved DTM obtained previously, traditional orthorectification to all the images of Figure. 3 is performed. The resolution of the created orthoimages is specified similar to that of the raw images. Figure. 4 depicts the resulted orthoimages, which are free of the building.

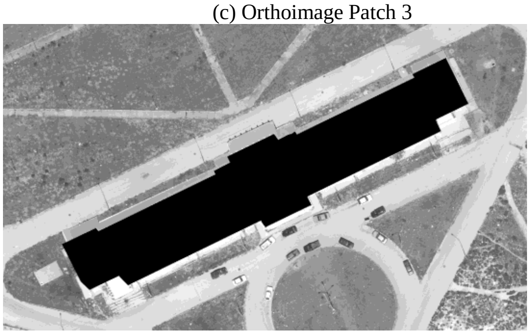
(a) Orthoimage Patch 1



(b) Orthoimage Patch 2



(c) Orthoimage Patch 3

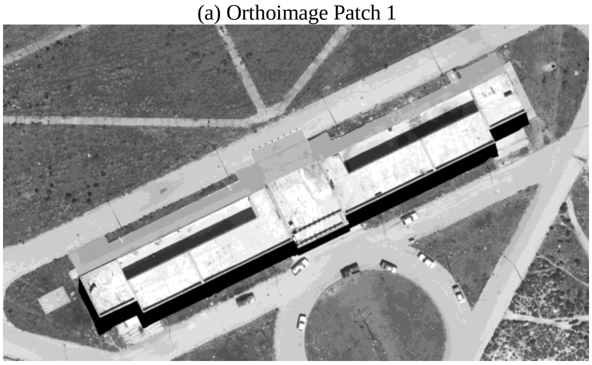


(d) Orthoimage Patch 4

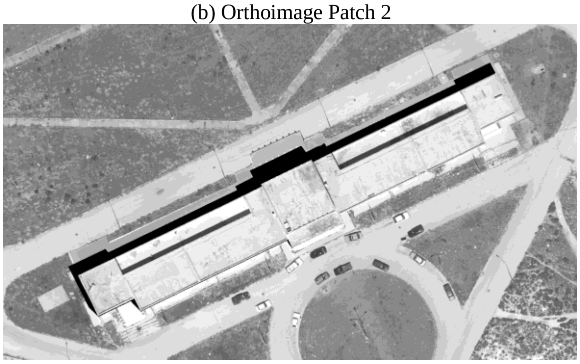
Figure 4. The orthoimage patches due to DTM-based orthorectification.

The next step is to retain the building in its correct geometrical position on the orthoimages. This means that building roof is overlaid on its base and building walls don't appear anymore. Thus it has been necessary to develop a program to project the building roof on the raw images, to extract the intensity value of corresponding pixel using bilinear interpolation, and to put it in the corresponding position on the orthoimage. The orthoimages with the building retained correctly, as resulted by applying the program, are given in Figure. 5. They have the occluded area still blank.

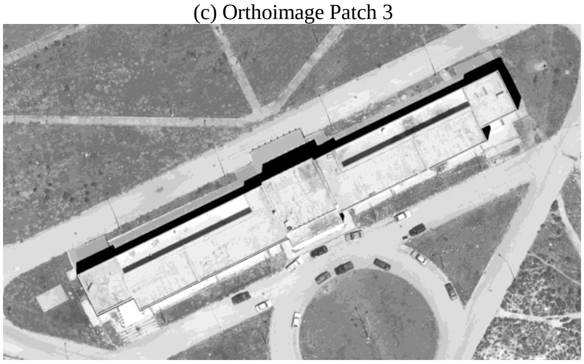
(a) Orthoimage Patch 1



(b) Orthoimage Patch 2



(c) Orthoimage Patch 3



(d) Orthoimage Patch 4

Figure 5. The orthoimage patches with the building retained correctly.

Finally, the four orthoimages are brought into the *Mosaicking* tool of LPS software to fill the gaps and missing information by integrating the information available on corresponding orthoimages. The outcome is one orthoimage restoring all the information missed in the individual orthoimages. Figure. 6 displays the final orthoimage patch yielded by applying all the phases of the proposed approach.

Figure 6. The final resulted orthoimage Patch.

V. CONCLUSIONS

In this research an approach is presented to overcome the problems of conventional orthorectification of aerial imagery depicting urban areas, due to the existence of man-made objects. The approach attempts to generate more accurate orthoimages based on elevation models that exactly describe the entire surface of the observed region. Thus both the DTM and the DBM are generated and employed in the orthorectification process. In fact, the most time consuming and uncomfortable part of the DBM creation is the data acquisition phase. Shadow areas are visually enhanced and areas occluded by the buildings are identified and filled up by combining information from overlapping orthoimages. Thus the approach improves the interpretability of the orthoimages. However, in order to detect all occlusions and to fill in all the gaps it is necessary to have higher longitudinal and lateral overlaps.

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