# IMPROVING PLANIMETRIC MAPPING ACCURACY FOR URBAN AREAS FROM AERIAL IMAGERY USING GEOMETRIC CONSTRAINTS

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## Abstract

*Traditional terrestrial surveying techniques in mapping urban areas are usually inadequate for many reasons. For example, road networks always suffer large volumes of vehicles and personnel mobilities that affect road map production. Accordingly, both airborne and spaceborne techniques help so much in this issue, although defining and segmenting road regions and edges from these remotely sensed data will be kept as a challenging task due to large variations on road surfaces. The corresponding developments in these techniques include imagery systems, imagery platforms and imagery processing. The paper addresses this motivation by increasing the horizontal accuracy of output roads map from airborne imagery system. In this context, a stereopair of aerial images (0.80 m GSD) are available for a certain study area within many road segments and edge varying in lengths and heights. This stereopair is initially processed through the well-known conventional bundle adjustment algorithm using the commercial ERDAS Imagine 2016 software. Then, some geometric constraints concerning the straightness, curvature and intersections of tested edges are implemented and added in a new developed MATLAB program. The output results show the verification of the developed program when compared with the commercial one, besides the used constrained bundle adjustment yields to better accuracy reaches up to 45%.in the final produced road map.*

Keywords: Geometric constraint, Road Network, Airborne Stereopir, Constrained Bundle Adjustment.

## 1. Introduction

Road information is fundamental not only in the military field but also common daily living. It offers references for city planning, transportation database, map updating, and land resource management, as well as guidance during emergencies and disaster rescue operations [Wang et al., 2016]. Also, knowledge of road regions provides contextual informationthat benefits many analysis tasks. It has been shown that incorporating the information of road extent gives a clear improvement on detecting vehicles and capturing spatial relations among objects [Yuan and Cheriyadat, 2014]. Hence, road regions and extents should be surveyed and identified very accurately to meet these requirements and needs, in order to constitute a basic road map for urban planning, environmental monitoring and updating geographic information systems (GIS).

With the advances made in remote sensing data acquisition imagery systems and platforms, large volumes of high-resolution aerial images have been collected to be used in this field. However, it is a challenging to accurately identify road regions from high resolution images. In images with sub-meter resolutions, road region appearances vary vastly. In addition to the pavement materials and markings that cause the appearance variations, road regions can be largely covered by vehicles, vegetations, and

shadows. In addition, urban areas exhibit a large variety of reflectance patterns, with large intra-class variations and often also low interclass variation [Montoya-Zegarra et al., 2015]. Moreover, enhancement may be carried out in image processing as a modification in the used algorithm applied to extract 3D information from aerial images.

Accordingly, the above-mentioned challenges and developments will be considered as the main motivation behind the current paper. So, the main corresponding objective is endeavoring to increase the horizontal accuracy of identifying all road segments from a steropair of aerial images, to be even comparable with the corresponding ones output from traditional ground surveying methods. In this context, some constraints concerning the geometry of these road segments should be added in the adopted conventional bundle adjustment algorithm. To achieve and test this purpose, a certain MATLAB program has been developed to accommodate all possible geometric constraints. This program has the ability to adopt the conventional bundle adjustment algorithm, to verify its correctness first compared with the available commercial software; besides the constrained bundle adjustment algorithm that expected to increase the required accuracy.

## 2.  Description of Field Experiment

Since the research focuses mainly on a road network as an urban area to be tested. a certain study site is selected as a part of road networks located in the ring road, Cairo, Egypt. It is composed of a nearly flat segment with is the highway Cairo-Suez road with a variation of heights approximately up to 0.50 m. In addition, four loops act as ramps with a height difference reaches 10.0 m. This selected area satisfies the needs for the required edges that comprise straight segments and many curves with different radius. This configuration helps much in imposing the geometric constraints in the final bundle adjustment algorithm during the stereopair solution. Finally, the whole test area covers a rectangular region of size nearly 1280.0 m x 560.0 m. Figure (1) depicts this selected area as captured from Google Earth, with all tested roads besides the position and distribution of the available used ground control points needed for image rectification.



Figure (1): Google Earth Scene for the Study Site within the Selected Ground Control Points

### 3. The Available Data

The study area is shown in an aerial stereopair taken by Leica RC30 camera with 0.80 m grid spacing. One of the corresponding capture aerial images of the study area is shown in figure (2). In addition, the full details and specifications of the corresponding imagery system (Leica RC30 camera) characteristics during data capture for the study area are listed in table (1).



Figure (2) Captured Used Airborne Imagery

Table (1) Main Characteristics of the Used Camera

| Item | RC30 |
|---|---|
| Sensor Type | Airborne |
| Sensor Name | Leica RC30 |
| Product Line | CCD-line digital camera |
| Pixel Size | 0.800 m |
| Sensor average height | 4.680 km |
| Bits per Pixel per Band | 8bits |
| Percent Cloud Cover | 0 |
| Resolution | 1.00 m |
| Swath width | 5.1km |

Moreover and in order to satisfy the main aim of this research, as a positional accuracy evaluation and its corresponding improvement, a base of accuracy assessment should be considered. In this terminology, a field land surveying for the study area is carried out from the available GCPs using Topcon 712 GTS total station, for acquiring a corresponding base map. Hence, a certain number of check points were selected and their 3D computed coordinates from the performed ground surveying will act as the comparison datum. As illustrated before shown in figure (1), four well-distributed ground control points (GCP) have been selected within the study area. These points are well-defined and sharp targets to be clearly identified in both aerial and satellite images. The corresponding 3D positions of these points were determined with a sub-centimeter accuracy Trimble R3 precise GPS geodetic receiver.

### 4. Methodology of Investigation

In order to achieve the main objective of the current research that states the improvements of the horizontal accuracy of urban area airborne mapping, a new developed program should be written to accommodate the geometric constraints inherit in the geometry of the road networks. This is due to the fact the all commercial software packages apply the conventional photogrammetric mathematical models. The developed program should be tested first to verify its correctness just prior to its usage.

In this terminology, the following corresponding theoretical and practical steps that should be done are summarized as follow:

- Using the commercial ERDAS Imagine 2016 software to finally gives an orthoimage from which the required planimetric and height coordinates can be easily reported and assessed.

- Developing a new MATLAB program within the concept of conventional bundle adjustment algorithm that depends on the well-known collinearity equations with the help of the available ground control points.

- Checking the correctness of the developing program by comparing the output 3D ground coordinates of all check points in both commercial and developed software..

- Studying all possible geometric constraints that can be added to the conventional bundle adjustment algorithm, concerning mainly the road geometry.

- Implementing these constraints and recomputing the 3D ground coordinates at the same check points.

- Assessing the horizontal accuracy improvements resulted from the adopted constrained bundle adjustment algorithm.

It should be noted here that, the positional accuracy evaluation and comparison will rely mainly on the statistical parameters, especially the root mean squares error (RMS), of the resulted discrepancies at those check points. These discrepancies are simply expressed as the differernce between the land coordinates and the corresponding ones from both conventional and constrained bundle adjustment algorithms, and will be the main criteria for the horizontal accuracy assessment. Also, some of these check points are intersection road points, while the remaining ones are located on road edge spaced by number of cross sections as a difference between both drawing edges at each cross section.

## 4.1 Conventional Bundle Adjustment

Bundle adjustment (BA) is a common estimation algorithm that is widely used in machine vision as the last step in a feature-based three-dimensional (3D) reconstruction algorithm, as it optimizes the resulting estimates of the 3D point coordinates and position [Albl and Pajdla, 2013]. It can be considered as the most accurate method of triangulation and estimates all photogrammetric measurements simultaneously [Lee and Yilmaz, 2010]. BA is essentially a non-convex non-linear least-square problem that can simultaneously solve the 3D coordinates of all the feature points describing the scene geometry, as well as the parameters of the camera. It is an optimization technique, which involves simultaneously refining the camera parameters (focal length, center pixel, distortion, position or/and orientation), as well as the 3D coordinates of all the feature points describing the object [Triggs et al., 2000].

The well-known collinearity equation is used to georeferencing the aerial stereopair to the ground using the chosen ground control points (GCP). It mainly relates the object point, its homologous image point and the perspective center to be collinear [Wendt and Dold, 2005]. The basic idea is to compute both intrinsic orientation parameters of the camera (IOP) and the extrinsic orientation parameters of each image (EOP), by using GCP as an indirect method or GPS/IMU as a direct method. Both camera orientation parameters and the lens distortion parameters can be combined as one set of unknown

parameters, usually termed as nuisance parameters. On the other hand, the 3D ground coordinates of all object points of interest aretermed as primary unknown parameters to be determined. Moreover, conventional BA algorithm either takes a parameter as known (fixed-value), or as an unknown variable (unconstrained). The former case may result in an incorrect 3D reconstruction with known but inaccurate parameters [Gong et al., 2014]. The latter case may cause erroneous estimation of the camera and the object parameters since the optimization gets trapped in a dramatically wrong local minimum. The full details of equations with their corresponding elements and solution can be easily found in many literatures as [Wendt and Dold, 2005].

## 4.2 Constrained Bundle Adjustment

In the past decade, many approaches have been developed to make the bundle adjustment as efficient as possible [Jeong et al., 2012]. The inclusion of geometric constraints in a bundle adjustment greatly improves the process of generating accurate, detailed site models, increasing both the precision and the reliability of the solution [Chris, 1995]. Constraints are logical conditions that bound the estimation with allowable error, reflecting the real-world restriction of tolerance. Different types of geometric constraints can be applied in the bundle adjustment for redundancy. They include object space constraints (e.g., object point constraint, collinearity, coplanarity and angles between two lines); and objects relationshipsconstraints (e.g., parallelism, perpendicularity, symmetry, straightness, curvature and same slopes). These added constraints do not give extra unknown but causing extra equations that increasing redundancy for the final unknown parameters [e.g. Dini et al., 2013]. Hence, the constraint equations can be used as observations in the bundle adjustment. In this context, two different types of constraints are implemented here regarding the geometry of the existing roads. The first one is concerned with the straightness of the road edges, whereas the second one is concerned with the corresponding curved ones. The definition, behavior and the corresponding constrained equation are discussed below.

### 4.2.1 Straight Edges Roads

The straightness of the road edges may be used as constraint in the bundle adjustment solution. In this case, knowing the 2D ground coordinates of just two points on this edge will be taken as a constraint defining the equation of this straight edge. Simply, the corresponding constraint equation is written as:

$$AX + BY + C = 0 \qquad\qquad ..... (1)$$

This type of constraint forces all the check points to satisfy the straight line equation. The strength of this constraint that it is not necessary to depend on the absolute coordinates of the start and end points, but on the corresponding line equation. Hence, the required coordinates have not being to be measured precisely or even measured in the same required ground coordinate system. Consequently, the slope of the line and the corresponding intersected part of the vertical axis can be easily determined. Also, as long as this edge is precisely modeled, the other parallel edges will be constrained by the parallelism geometric constraints too. Moreover, more than two points may be taken in order to reach at the best fitting equation of the straight road edge, to finally yield to better results. Accordingly, no extra information is needed to be added in the developed program since the only change of the input data will be the parameter of the line equation.

### 4.2.2 Curved Edges Roads

Similarly, the curvature of the road edges may be used as constraint in the bundle adjustment solution. In this case, knowing the ground coordinates of just three points on this edge will be taken as a constraint defining the equation of this curved edge. These curved edges usually are arc of a circle with a fixed radius and sometimes are representing a parabolic curve. Simply, the corresponding constraint equation representing both cases of curvature respectively is written as:

$$X^2 + Y^2 + AX + BY + C = 0 \qquad ..... (2)$$

$$Y = A + BX + C X^2 \qquad ..... (3)$$

Again, this type of constraint forces all the check points to satisfy the circle equation. All the previous-mentioned conditions that strengthen straightness constraint will be available here also, concerning the requirement of the measured ground coordinates used in the constraint besides the nature of the formed constrained equation.

### 5. Experimental Results

As stated before regarding the consequent steps to be carried out for achieving the main purposes of the current research, the stereopair are processed using the commercial Earth Resources Data analysis System (ERDAS) Imagine 2016 software. This release creates powerful new analytical recipes such as increasing levels of flexibility for users to implement new geoprocessing algorithms, to annotate or encrypt spatial model content, and to add new resampling technique. This software finally gives an orthoimage from which the required planimetric and height coordinates can be easily reported and assessed. Figure (3) depicts the output rectified orthoimage for aerial stereopairs.
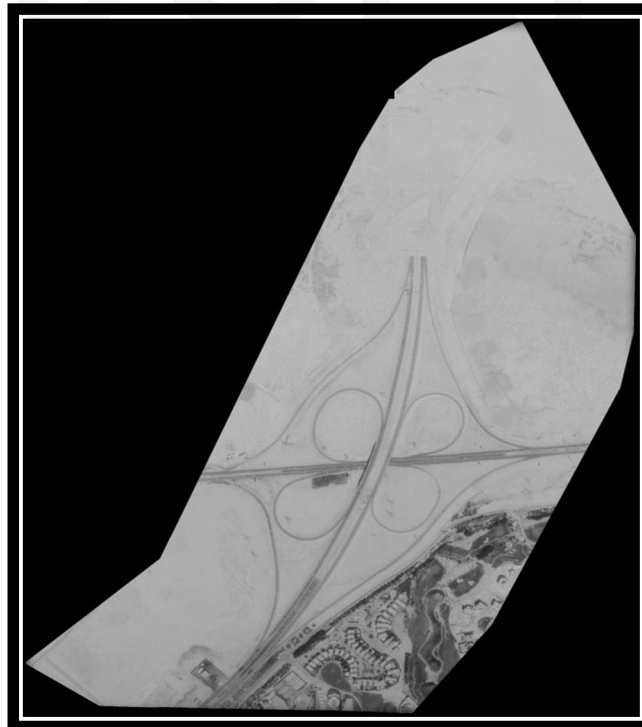


Figure (3) Final Output Airborne Rectified Orthoimage

Before digging into the discussion of the constrained bundle adjustment along with the expected accuracy enhancement of the imposed geometric constraints, the correctness of the MATLAB developed program should be verified. This is simply done by comparing its output results with the corresponding ones obtained from the (ERDAS) commercial software for processing the stereopair images in conventional bundle adjustment. Table (2) lists the output discrepancies at all selected check points of both commercial and developed software for all tested area, compared with the base ground map.

Table 2. RMS of Check Points Discrepancies by Conventional BundleAdjustment using both MATLAB Program and ERDAS Software

| Assessment Criterion | | Discrepancies at Check Points | |
|---|---|---|---|
| | | ERDAS | MATLAB |
| RMS (m) | X | 0.902 | 0.897 |
| | Y | 2.423 | 2.438 |
| | P | 2.585 | 2.598 |
| RMS (m) | Z | 2.997 | 3.001 |

From this table, it is easily concluded that the developed program has been proven to be correct in all written mathematics. This is quite clear from the slight change in the 3D coordinates discrepancies between both ERDAS and MATLAB software at each selected check points. This finally reflects the reported horizontal and vertical accuracy reported from both commercial and developed programs to be nearly identical.

It should be mentioned here that, the final reported positional accuracy is still optimistic since most of the selected check points are not sharp and well-defined on the rod edges, rather than few intersection points. Hence, better results concerning the positional accuracy will be expected in case of other applications such as city maps, in which the check points are easily marked and being more sharp targets..

Moving to the influence of added geometric constraints, the two types of investigated constraints will be added to the developed program. These constraints will be logically treated separately for the straight segments and ramps respectively. The output results concerning each one of tested constraints will be investigated and discussed in the following two subsections, as a constrained bundle adjustment algorithm.

## 5.1 Straightness Constraint

Concerning the straight segment road, the straight line equation is added to the conventional bundle adjustment algorithm, in order to be solved simultaneously. In this case, the main highway Cairo-Suez road will be taken with its corresponding three edges (left edge, center and right edge). The output horizontal accuracy of the road within all edges is listed in table (3). Also, figure (4) illustrates the improvements in the corresponding RMS in both directions and the corresponding spatial position,

whereas figure (5) depicts both discrepancies compared with the ground coordinates. Both figures are related to the left edge, for example.

Table 3. RMS of Discrepancies for both Conventional and Constrained Bundle Adjustment using Straight Edge Constraint

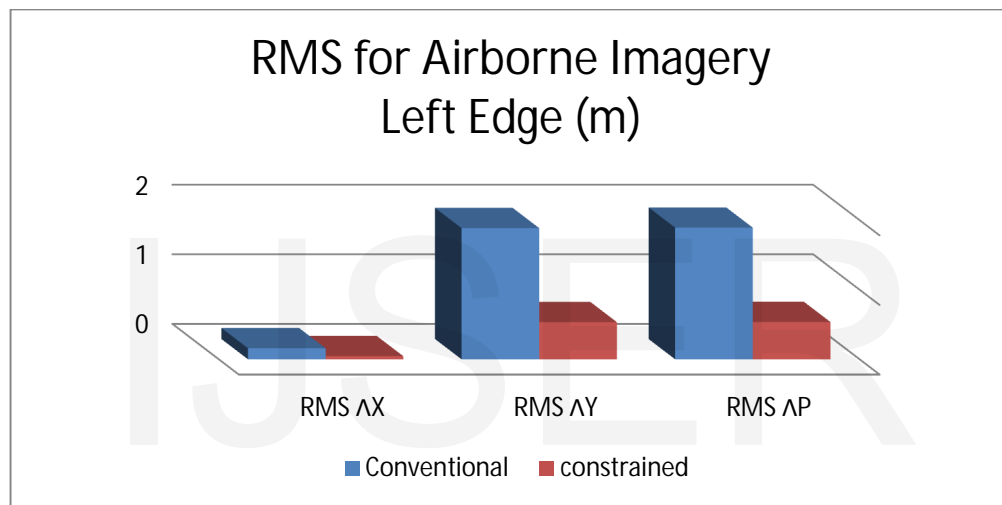| Direction | RMS of Discrepancies of Straight Edges at all Check Points | | | | | |
| | Conventional Bundle Adjustment | | | Constrained Bundle Adjustment | | |
| | RMSX | RMSY | RMSP | RMSX | RMSY | RMSP |
| --- | --- | --- | --- | --- | --- | --- |
| Right Edge | 0.213 | 2.540 | 2.549 | 0.055 | 0.658 | 0.661 |
| Center line | 0.091 | 1.091 | 1.095 | 0.017 | 0.210 | 0.211 |
| Left Edge | 0.158 | 1.885 | 1.892 | 0.045 | 0.534 | 0.536 |



Figure (4) Accuracy Improvements of Straight Edge Constraint Expressed as RMS of the Discrepancies
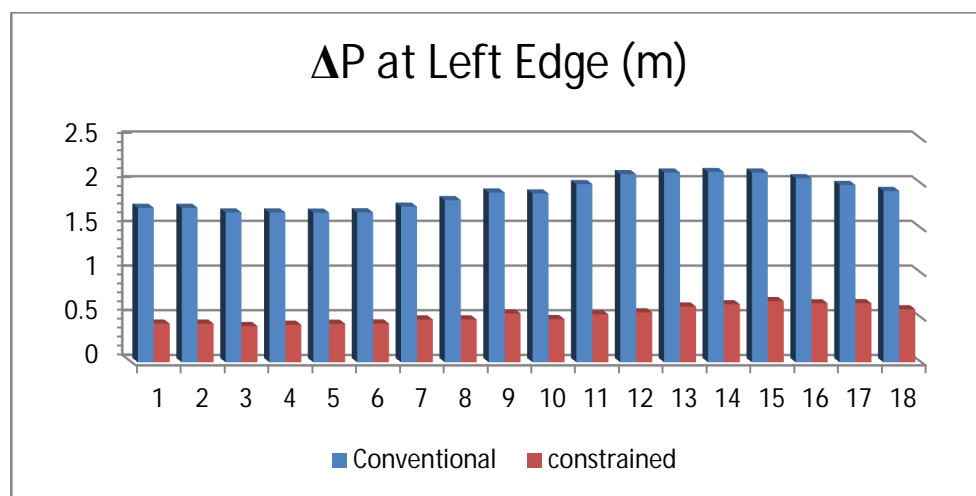


Figure (5) Positional Discrepancies at All Check Points

From the above table and figures, one can easily notice the great improvement in the final horizontal accuracy, expressed as significant enhancement in the positional discrepancy at all tested points and hence the final reported RMS. This improvement reaches nearly up to 70% in all road edges after applying the straight edge constraint. Also, the parallelism of all road edges is almost maintained among them and to the base road edge at the same time. The schematic layout of all edges is illustrated in figure (6). Finally, the reported accuracy of the center line is obviously better than the corresponding edge ones, concerning the discrepancies between airborne and ground mapping besides the improvements after applying this geometric constraint, as typically depicted in the shown cross sections. This is logically happened due to the misidentification of the natural edges rather than the signalized center line defined by the concrete barriers.
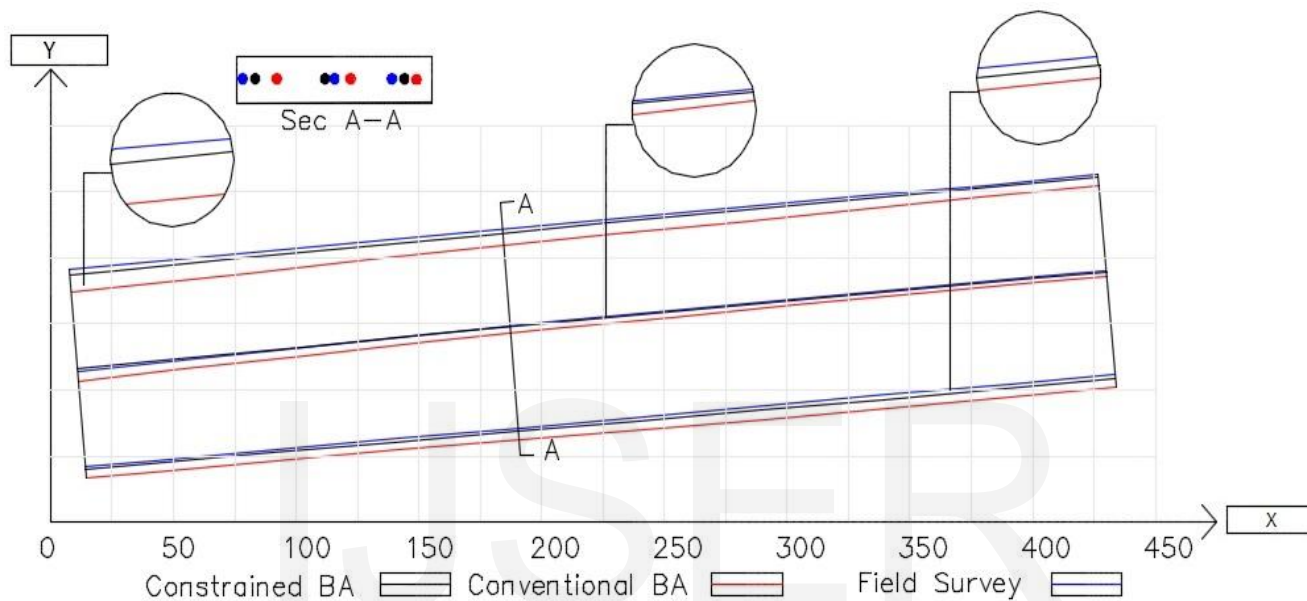


Figure (6) General Layout of all Tested Straight Road Edges

## 5.2 Curvature Constraint

As steated before concerning the chosen study area as a roads network, it consists also from a number of ramps and loops as an arc of circle. The corresponding arcs related to those ramps and loops are varying in length, width, radius and height difference. In this context, the circle equation is added also to the conventional bundle adjustment algorithm, in order to be solved simultaneously. Some selected arcs are tested to assess the improvement in the positional accuracy using the adopted constrained bundle adjustment algorithm. Table (4) lists the accuracy, expressed as RMS in both directions as well as the spatial position, of airborne stereopair in mapping the tested area using both cases of bundle adjustment algorithm, which is also illustrated schematically in figure (7).

Table 4. RMS of Discrepancies for both Conventional and Constrained Bundle Adjustment using

Arc Edge Constraint

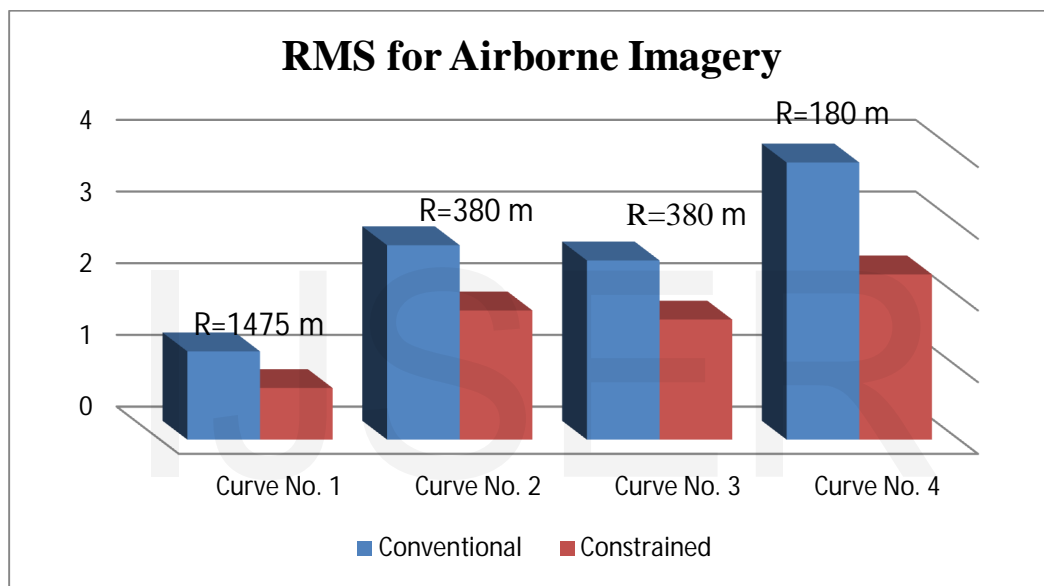| Curve No, | Radius (m) | RMS of Discrepancies of Arc Edges at all Check Points | | | | | |
|---|---|---|---|---|---|---|---|
| | | Conventional Bundle Adjusment | | | Constrained Bundle Adjusment | | |
| | | RMSX | RMSY | RMSP | RMSX | RMSY | RMSP |
| 1 | 1475 | 0.936 | 0.799 | 1.231 | 0.569 | 0.442 | 0.720 |
| 2 | 380 | 1.199 | 2.431 | 2.711 | 1.011 | 1.492 | 1.802 |
| 3 | 380 | 0.718 | 2.394 | 2.499 | 0.486 | 1.603 | 1.675 |
| 4 | 180 | 1.503 | 3.561 | 3.865 | 1.483 | 1.764 | 2.305 |



Figure (7) Accuracy Improvements of Arc Edge Constraint Expressed as RMS of the Discrepancies

Table 4 indicates clearly the positional accuracy improvement for all tested curve using the arc edge constraints with nearly 40%. Of course, this percentage is logically expected to be less than the corresponding one using the straight edge, due to the behavior of surveying the curve as small straight segments. Generally, the attained accuracy improvements are still optimistic to be adopted in the solution of the bundle adjustment. In addition as being seen from figure (7), the improvement is nearly the same at all tested curves that varies in radius, but the difference lies mainly in the obtained accuracy in both cases of bundle adjustment. The smaller the radius of the curve the minimum the accuracy obtained from the airborne imagery sollution.

## 1. Conclusions

This paper addresses and introduces the constrained bundle adjustment for mapping road networks in a certain urban area. The existing roads represent some geometric constraint to be added in the airborne stereopair imagery, which in turn enhances the accuracy and reliability of the imagery processing solution. These constraints increase the number of equations in the bundle adjustment

algorithm to strengthen the final solution without imposing any extra new parameters. Hence, it gives better adjustment results for the final output positional accuracy in mapping, compared with the corresponding bundle adjustment results without constraints.

In this context, the two tested types of constraints deliver significant improvements in the positional accuracy in mapping road networks. The straightness constraint yields to an accuracy enhancement up to 70%, whereas the curvature constraints gives nearly a corresponding enhancement reaches 40%. These constraints are easily implemented and considered in mapping such urban areas due to the existing geometry of all designed roads. Thus, the number and location of required surveyed points should be precisely considered, in order to construct a correct edge constraint equation for each road segment.

Finally and to reduce the required field survey, it is recommended initially for the ground control points (GCP) to be selected to serve these types of constraints. For example, GCP may be the intersection point between straight and arc segments. Moreover, the width of the road can be used as parallelism constraints between any two edges constitute a road segment. As a closing remark, the added geometric constraints may have a great advantage and privilege when being to the corresponding mathematical models used for satellite imagery solution. This will be much focused for further researches and investigations.

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