

ASSESSMENT OF INDIAN SATELLITE (IRS - 1C) IMAGERY FOR PRODUCTION OF 1: 25000 PLANIMETRIC CITY MAPS

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ABSTRACT:

A map scale of 1:25,000 satisfies the needs for a wide sector of map users including urban city planners, as well as several GIS applications. Urban and rural areas are viewed as large complex heterogeneous systems that include buildings, road and water networks, bridges, man-made features, natural elements such as agricultural land, water bodies, shorelines, ...etc. All these objects are spatially distributed within a certain geographical extent and have to be associated and linked with a larger external world. Moreover, because of continuous development, expansion, up-grading, and other circumstances, the spatial locations and physical conditions of natural and man-made features can change. Such spatial and physical information is one of the most important data sources in information technology based applications such as city planning, traffic network management, design and maintenance of different utility networks, and many others. Accordingly the need for up-to-date maps is not a matter of choice but it is actually a must.

This paper discusses the possibility of adopting a cost/ effective methodology for the production and/ or updating of 1:25000 planimetric city maps using IRS-1C satellite imagery of the commercial Indian Remote Sensing Satellite for the central part of Metropolitan Cairo city together with a 1:25000 planimetric map obtained from the Egyptian Survey Department for the purpose of comparison, accuracy, and content assessment.

The study also includes a comprehensive comparison between the three most commonly used techniques, namely, surveying, photogrammetry, and remote sensing as far as cost and time is concerned according to Egyptian norms which could easily be applicable to other developing countries.

1. INTRODUCTION

Maps are considered reproductions, at reduced scales, of an orthographic projection of the terrain onto a reference datum plane. Each point, line, or polygon are seen to be projected normal to the reference plane. A map scale of 1:25,000 satisfies the needs for a wide sector of map users including urban city planners, as well as several GIS applications. In fact the Egyptian Survey Authority (ESA) as well as the Military Survey Department (MSD) are including this scale in their National Mapping programs.

The need for up-to-date maps is not a matter of choice but it is actually a must. Maps are the pre-requisite and the essential tools for almost any project aiming towards the welfare of any country. Traditionally, ground surveying techniques have been used for map production. Later on, Aerial photogrammetry has been employed in regional and national mapping since the end of the nineteenth century (Bernhardsen 2002).

Since the early 1960's, numerous Satellite sensors have been launched into orbit to observe and monitor the Earth and its environment. Most early satellite sensors acquired data for meteorological purposes. The advent of earth resources satellite sensors (those with a primary objective of mapping and monitoring land cover) occurred when the first LANDSAT satellite was launched in July 1972. Currently, dozens of orbiting satellites of various types provide data crucial to improving our knowledge of the Earth's atmosphere, oceans, ice and snow, and land.

The subject of satellite remote sensing is expanding at a very rapid and exciting pace. In only a little more than three decades the exacting technology of Earth Observation Satellites has progressed from experimental and limited to fully operational and global. The next decade will see yet more operational satellite systems for Earth observation, with developments such

as the polar platform, imaging radar systems, and high-resolution satellites similar or even with higher resolution than the present family of IKONOS, Quickbird and Orbimage. During this century this little planet will be closely and continuously monitored by a band of satellites and sensors in space.

2. CHARACTERISTICS OF INDIAN REMOTE SENSING SATELLITE

The Indian Remote Sensing (IRS) system has emerged as one of the most high-profile programs in the commercial imaging industry. The focus of the IRS program is to develop space technologies and applications in support of national development. With ever increasing pressure on resources, it has become essential to monitor the existing resources for optimum utilization. Management of resources has become a critical requirement with increased industrial development and growing population.

Keeping these requirements in mind, the government of India Department of Space (DOS) began the IRS program in 1988 with the launch of IRS 1A followed by a series of satellites, 1B, 1C, 1D, P2, P3 and more recently RESOURCESAT-1 (P6).

2.1 Mission

The Indian Remote Sensing Satellite (IRS-1C) was successfully launched into polar orbit on December 28, 1995 by a Russian launch vehicle.

2.2 Orbit

The primary objective of IRS satellites is to provide systematic and repetitive acquisition of data of the Earth's surface under nearly constant illumination conditions. IRS-1C operates in a

circular, sun-synchronous near polar orbit with an inclination of 98.69°, at an altitude of 817 km in the descending node.

2.3 Sensors

Generally Sensors are devices that receive and record energy emitted or reflected from the earth's surface. These sensors have high sensitivity for all wavelengths in the electromagnetic spectrum giving detailed and accurate information of earth features (Harris 1987), table (1).

Sensors	Panchromatic
Ground Resolution	5.2 to 5.8 meter (at nadir)
Imagery Spectral Response	Panchromatic : 0.5 – 0.75 microns Multispectral : LISS Band # 2: 0.52 – 0.59 micron Band # 3: 0.62 – 0.68 micron Band # 4 : 0.77 – 0.86 micron Band # 5: 1.55 – 1.70 micron WiFS Band # 3: 0.62 – 0.68 microns Band # 4: 0.77 – 0.86 microns
Swath Widths	Panchromatic : Nominal swath width 70km LISS : 127 km – 148 km WiFS : 728 km – 812 km
Resolution	Panchromatic : 5 m LISS : 23 M WiFS : 188 m
Revisit Frequency	IRS-1C: 341 orbits/24 days at equator IRS-1D: 358 orbits / 25 days at equator
Viewing Angle	Pan camera is steerable up to $\pm 26^\circ$ (± 398 km across track) off-nadir viewing

Table 1. Sensor characteristics (IRS-1C / IRS-1D)

2.4 Resolution

In the discussion of sensor systems the resolution of the system is of considerable importance when accessing its utility. Two elements of resolution are important: spatial resolution and spectral resolution.

Spatial resolution is commonly quoted as the pixel size, which in turn is a function of the instantaneous field of view (IFOV) of the sensor system. This is particularly common for scanning radiometers. The spectral resolution concerns the width of the waveband used in the sensor system. As satellite remote sensing had developed then systems have been designed with narrower wavebands. The IRS-1C and 1D offer improved spatial and spectral resolution, on-board recording, stereo viewing capability and more frequent revisits

2.5 Experiment Set-up

- **Study Area:** In order to study the suitability of IRS imagery for the updating and production of 1:25000 scale of city planimetric maps as well as to study the effect of number and distribution of ground control points for various 2-D mathematical transformation models, it was important to choose a representative study area to perform our investigation. The study area is also required to assess

the production indicators including resources, hardware, and software and time requirements to produce the final map. Figure (1) shows part of the city of Cairo, Egypt used in the study.



Figure 1. Indian Remote Sensing Image IRS-1C used in the study showing The borders of study area (City of Cairo, Egypt)

2.6 Maps Used

It was essential to compare the produced map with a standard. Accordingly, a 1:25,000 map was obtained from the Military Survey Department (MSD) for West of Cairo covering the study area and used as a basis for comparison and assessment. In addition to the 1:25000 MDS map, a number of 25 map sheets at scale 1:5000 were acquired from the Egyptian Survey Authority (ESA) covering the same area of the 1:25000 MSD map of West Cairo (Figure 1). These 1:5000 maps are plotted from 1977/78 1:10000 aerial photographs with field completion up till 1989. These maps are printed and updated by the Egyptian Survey Authority in 1989. Figure (2) shows a flow diagram of the study methodology used in the research.

2.7 Ground Control Points Measurements

Normally ground surveying techniques are employed to obtain the required ground control points for the sake of performing rectification. These surveying techniques are usually based on total station or Global Positioning System (GPS) measurements. However for the sake of research needs it was necessary to acquire a large number of ground control points to enable studying the effect of number and distribution of GCPs as well as the impact of employing various mathematical models. Not only that, but it is necessary to keep a reasonable number of acquired GCPs as check points without using them in the coordinate transformation adjustment computational process. Accordingly, and due to the availability of 1:5000 accurate maps produced according to international specification by the Egyptian Survey Authority (ESA), these maps were digitized for the study area using AutoCad and ArcGIS software and were used to collect a sufficient number of GCPs to satisfy the study objectives. A total number of seventy nine GCPs were selected and measured for distinct features such as well defined intersections and sharp landmark features (Figure 3).

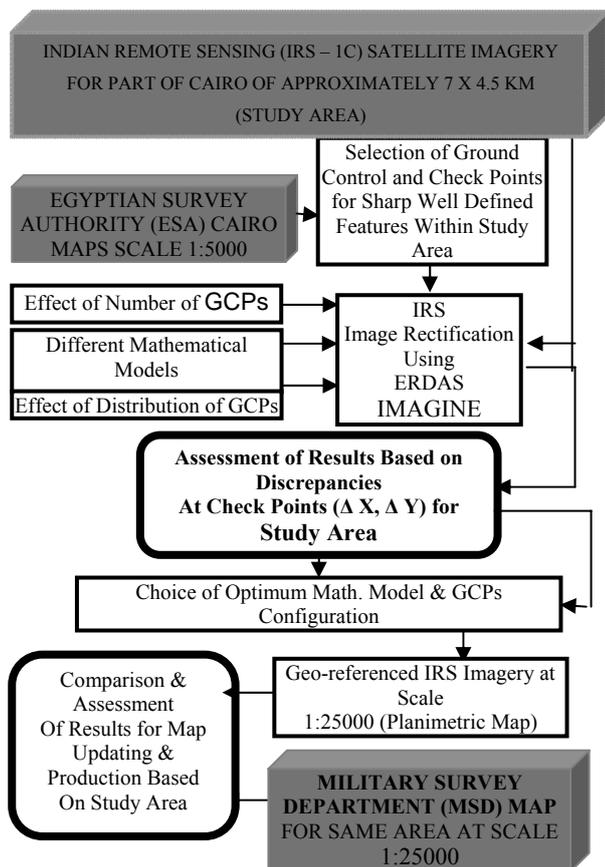


Figure 2. Flow Diagram of Research Out-line

2.8 Image Coordinate Measurements

The same Ground Control Points sampled from the 1:5000 ESA maps as shown in figure 3 were identified on the IRS-1C satellite image and their row and column coordinates were measured.

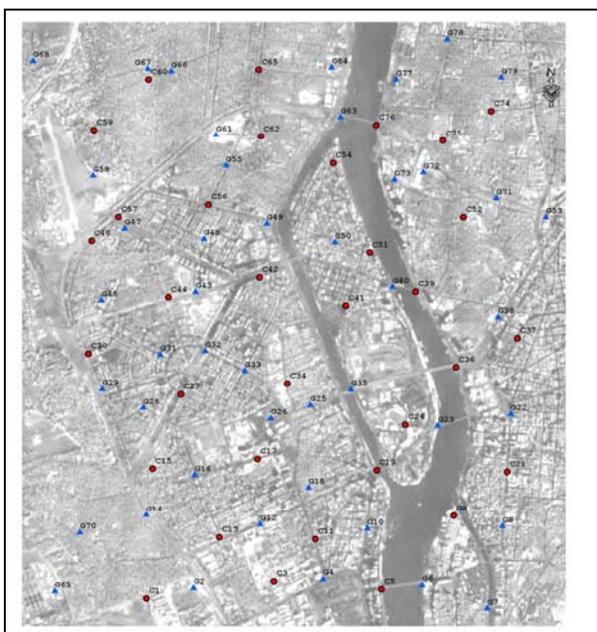


Figure 3. Ground Control Points (GCPs) sampled from the 1:5000 ESA maps for sharp features and district land marks

- ▲ Ground Control Point
- Ground Check Point

3. RESULTS AND ANALYSIS

3.1 Polynomial Transformation

According to figure (2) outlining the research steps to attain the required objectives several case studies were addressed and the obtained results analyzed accordingly. Polynomial rectification procedure was adopted in this study for IRS- 1C registration/ rectification process. Previous studies concluded that global polynomial modeling of image registration/ rectification geometry usually shows good results for satellite imagery, while aerial photographs on the other hand can be easily corrected using the well-known photogrammetric equations for the camera imaging model known as collinearity equations (Konecny and Lehman, 1984). ERDAS IMAGINE commercial software package was used to perform the rectification process for all the study cases. Any image can have one GCP set associated with it. The GCP set is stored in the image file along with the raster layers. Accurate GCPs are essential for an accurate rectification.

Polynomial equations are used to convert source file coordinates to rectified map coordinates. Depending upon the distortion in the imagery, the number of GCPs used, and their location relative to one another, complex polynomial equations may be required to express the needed transformation. The degree of complexity of the polynomial is expressed as the order of the polynomial. The order is simply the highest exponent used in the polynomial. The order of transformation is the order of the polynomial used in the transformation.

3.2 GCPs Requirement

Accurate GCPs are essential and a pre-requisite for an accurate rectification. From the GCPs, the rectified coordinates for all other points in the image are extrapolated. GCPs for large-scale imagery might include the intersection of two roads, airport runways, utility corridors, towers, sharp intersections, or buildings. Landmarks that can vary such as edge of lakes or other bodies, vegetation, etc., should not be used.

As mentioned earlier higher orders of transformation can be used to correct more complicated types of distortion. However, to use a higher order of transformation, more GCPs are needed. The minimum number of points required to perform a transformation of order (t) equals:

$$\text{Minimum Number of GCPs for (t) order polynomial} = \frac{[(t+1)(t+2)]}{2} \quad (1)$$

According to equation (1), the minimum number of GCPs for various order polynomials are given in table (2).

Order of Polynomial	Minimum GCPs Required
1	3
2	6
3	10
4	15
5	21
6	28
7	36

Table 2. Minimum Number of GCPs per Order of Polynomial

3.3 Root Mean Square Error (RMSE)

RMSE is the distance between the input (source) location of a GCP and the transformed location for the same GCP. In other

words, it is the difference between the desired output coordinate for a GCP and the actual output coordinate for the same point, when the point is transformed using a certain polynomial. RMSE is calculated with a distance equation (2):

$$RMSE = \sqrt{(x_r - x_i)^2 + (y_r - y_i)^2} \quad (2)$$

Where:

x_i, y_i are the input source coordinates
 x_r, y_r are the transformed coordinates

3.4 Effect of Order of Polynomial Transformation

To study the effect of the order of polynomial transformation on the accuracy of the rectified image a 1st, 2nd, 3rd and 4th order transformations were tested. Table (3) gives a summary for the results.

Polynomial Order	Total Root Mean Square Error			
	At GCPs in pixels	At GCPs in ms	At check points in pixels	At check points in ms
First Order	2.254	11.268	2.318	11.592
Second Order	2.289	11.445	2.311	11.556
Third Order	2.210	10.052	2.347	11.736
Fourth Order	2.203	11.016	2.534	12.672

Table 3. Effect of order of polynomial on total RMSE at both Ground Control and check points in terms of pixel & ms (The significance of the accuracy figures are only computational as output of ERDAS IMAGINE SW)

Inspection of the accuracy figures in table 3 reveals the fact that the results are almost consistent and the resulting average total RMSE at the GCPs is approximately 2.24 of the original pixel size (pixel size of IRS – 1C equals 5 ms), or equivalent to 11.195ms. However, as we will demonstrate later on, RMSE calculations based on GCPs used in the computations can be very misleading. Accordingly the total RMSE at the checkpoints should be always relied upon. According to table 3 the resulting average total RMSE at the 33 Ground check points is approximately 2.38 of the original pixel size or equivalent to 11.888ms. Generally, the results at the check points showed that a second order polynomial was slightly superior to other order polynomials. However, the difference was insignificant indicating that the order of polynomial was of little influence particularly that sufficient number of GCPs was used. Figure (4) shows the resulting total RMSE at both GCPs and check point for different order polynomials.

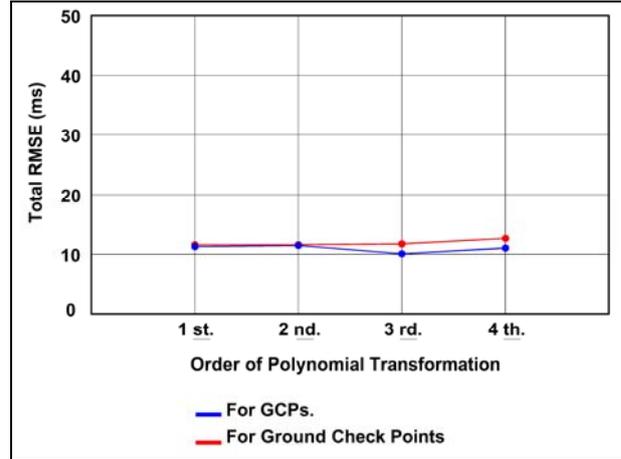


Figure 4. Effect of order of polynomial transformation

Based on the obtained results a second order polynomial transformation was chosen to further study the effect of number and distribution of GCPs on the resulting accuracy.

3.5 Effect of Number of GCPs

Using a second order polynomial and in order to study the effect of increasing the number of GCPs, six case studies were tested. Each case with a different number of well distributed GCPs across the IRS-1C image starting using six, nine, fifteen, twenty four, thirty five, and forty six GCPs. For each case the resulting total RMSE were calculated at both the GCPs as well as the 33 Ground Check Points in terms of pixel size and ms. Results are summarized in table 4.

Number of GCPs	Total Root Mean Square Error			
	At GCPs in pixels	At GCPs in ms	At check points in pixels	At check points in ms
6 GCPs	0.000	0.000	4.277	21.384
9 GCPs	0.893	4.464	2.239	11.196
15 GCPs	1.678	8.388	2.324	11.620
24 GCPs	2.074	10.368	2.321	11.605
35 GCPs	2.052	10.260	2.441	12.204
46 GCPs	2.289	11.445	2.311	11.556

Table 4. Effect of number of GCPs using a second order polynomial on total RMSE at both Ground Control and (33) check points in terms of pixels & ms. (The significance of the accuracy figures are only computational as output of ERDAS IMAGINE SW)

Inspection of the accuracy figures in table 4 shows clearly the extremely important role of ground check points in evaluating the actual accuracy of the polynomial transformation. Using only 6 GCPs, the total RMSE at the GCPs was equal to zero. This by no means denotes the superiority of the resulting accuracy but is simply the result of no redundancy. If we check the total RMSE at the (33) ground check points, the results clearly denotes the deteriorating results of the total RMSE with a value of 21.384 ms when using six GCPs. By increasing the number of the GCPs the reliability of the results increases and a value of slightly higher than two pixel size or 11 ms are attained at both GCPs and ground check points for the cases of 24, 35, and 46 GCPs. Figure (5) shows the resulting total RMSE at both

GCPs and check points for different number of GCPs using a second order polynomial.

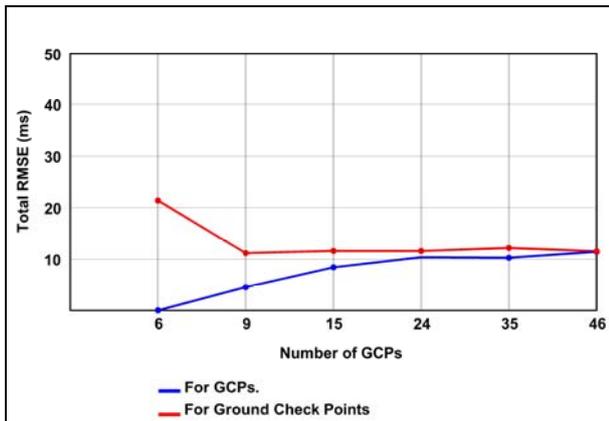


Figure 5. Effect of number of GCPs

3.6 Effect of Distribution of GCPs

To study the effect of the distribution of the GCPs with respect to the IRS-1C image scene, five different case studies were investigated. For each case we fixed the number of GCPs (22 for each case) using the same second order polynomial while the only variable was the distribution of the GCPs. Summary of the pattern of GCPs distribution for the five cases are as follows (figure 6):

Case 1: 22 GCPs distributed along the other perimeter of the IRS-1C image

Case 2: 22 GCPs distributed only in the upper half of the IRS-1C image

Case 3: 22 GCPs distributed only in the left half of the IRS-1C image

Case 4: 22 GCPs distributed in 5 patches in the middle and four corners of the IRS-1C image.

Case 5: 22 GCPs distributed all over the IRS-1C image

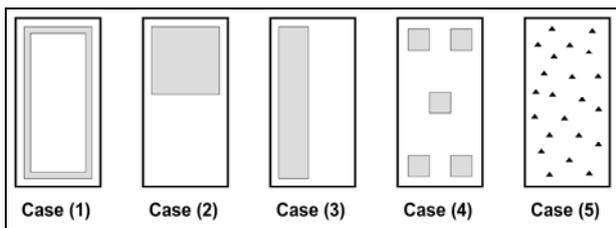


Figure 6. five case studies used to investigate the effect of GCPs distribution (each case using 22 GCPs)

For each case the resulting total RMSE were calculated at both GCPs (22 points) and ground check points (33 points) in terms of pixel size and ms. Results are summarized in table 5.

Case study 22 GCPs for each	Total Root Mean Square Error			
	At GCPs in pixels	At GCPs In ms	At check points in pixels	At check points in ms
Case (1)	2.009	10.044	2.498	12.492
Case (2)	2.016	10.080	8.568	42.840
Case (3)	1.829	9.144	7.207	36.036
Case (4)	2.045	10.224	2.232	11.160
Case (5)	2.167	10.836	2.196	10.980

Table 5. Effect of distribution of GCPs using a second order polynomial with a total number of (22) GCPs on total RMSE at both Ground Control and (33) check points in terms of pixels & ms.

(The significance of the accuracy figures are only computational as output of ERDAS IMAGINE SW)

Figure (7) shows the resulting total RMSE at both GCPs and check points for the five point distribution cases.

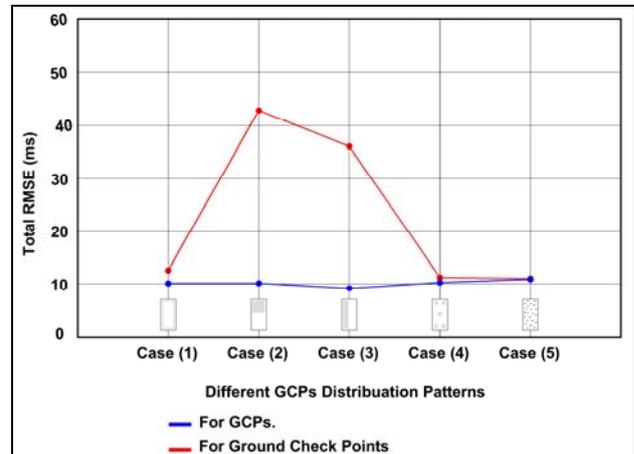


Figure 7. Effect of distribution of GCPs

The obtained result demonstrates clearly the need to assess the accuracy of polynomial transformation based on only ground checkpoints. From figure 7, while the total RMSE from all the cases seems to be constant based on the residuals at GCPs (blue line), the total RMSE based on the residuals at the ground check points leads to completely different conclusion. Cases (2) and (3) give absolutely unacceptable results, while cases (1), (4), and (5) seems to be acceptable. Case (5) with well distributed GCPs is certainly the most accurate of all cases. Accordingly, great attention should be paid to the distribution of GCPs all over the image format. The impact of GCPs distribution exceeds the impact of the number of GCPs as long as enough redundant observations exist and certainly far exceeds the order of the polynomial transformation. Accordingly, from the results and the analysis, a second order polynomial with 22 GCPs well distributed throughout the image format gave optimum results with a value for a total RMSE of 10.980 m which slightly exceeds two times the pixel size of 5 m of the used IRS – 1C satellite image.

3.7 Refinement of Optimum Case (case 5)

Based on the numerical values for Δx , Δy , and r at GCPs selected, it was decided to make another run using ERDAS Imagine after eliminating ground control points number 14, 49, 66, and 77. The residuals at these four GCPs exceeded three times the value of the pixel size (i.e more than 15 m) and by reinspecting these points in the image it was clear that they were poorly defined due to the lack of sharp details also points number 59 and 74 from the list of ground check points were also eliminated for the same reason. Accordingly another run was conducted using 18 GCPs and 31 ground check points. Table 6 gives a brief comparison between case (5) and refined case (5)

Case	Case (5)	Refined case (5)
	22 GCPs & 33 CPs	18 GCPs & 31 CPs
Total RMSE	10.980	9.288
Max (Δx)	-13.527	12.683
Max (Δy)	-24.349	20.425
Max (r)	26.299	20.466
Mean (r)	9.141	8.059

Table 6. Accuracy figures in meters at Ground Check Points for case (5) & Refined case (5)

3.8 Cost analysis

Utilizing IRS-1C remote sensing imagery for maps and GIS database production and updating proved to be useful in savings resources, time, and personnel, hence allowing for major savings in cost and time, when compared with field surveying and photogrammetry. Table (7) shows various activities that are performed when utilizing different techniques for production and updating of medium scale (1:25000) maps.

Activities	Field Surveying	Photogrammetry	Remote Sensing
1. Analysis and design of the surveying process	√	√	√
2. Reconnaissance & acquisition of available maps and data	√	√	√
3. Flight planning design	X	√	X
4. Planning for remote sensing images acquisition	X	X	SC
5. Acquisition of digital images/processing	X	√	√
6. Establishment of base stations/GCPs	√	√	√
7. Establishment and measurement of traverse	√	X	X
8. Infrastructure:			
8.1. GPS	S/M/W	S	S
8.2. Total stations	W	S	S
8.3. Levels	W	S	S
8.4. Tapes	W	M	M
8.5. Transportation	W	S	S
8.6. Supplies	W	S	S
8.7. PCs	M	W	W
8.8 SW :	S	W	W
3.8.1	X	W	X
igital photo	X	X	S
3.8.2 Remote sensing images	M	W	W
3.8.3	W	S	S
IS/ AutoCad	M	W	W
8.9. Field crew			
8.10. Office crew			
9. Field surveying (Field measurements)	√	X	X
10. Digital maps production	√	√	√
11. Field completion	√	√	√

Activities	Field Surveying	Photogrammetry	Remote Sensing
12. Revision, editing & quality control	√	√	√
13. Final outputs	√	√	√
Note:			
√ : Applicable			
X : Non-applicable			
S: Short time			
M: Medium time			
W: Whole time			
SC: Some cases			

Table 7. Activities versus the major techniques used in map productions (field surveying, photogrammetry & remote sensing)

The cost model for the three most-commonly used techniques are illustrated in table 8, which shows the cost comparison model/ unit kilometer area using the averages of cost values for different activities using various production techniques.

Activities	Field Surveying	Photogrammetry	Remote Sensing
1. Analysis and design of the surveying process (4 days)	10	10	10
2. Reconnaissance & acquisition of available maps and data (2 days)	5	5	5
3. Flight planning design (2 days)	X	5	X
4. Planning for remote sensing images acquisition (2 days)	X	X	5
5. Acquisition of digital images/processing	X	50	4
6. Establishment of base stations / GCPs	20	20	20
7. Establishment and measurement of traverse points	50	X	X
8. Field surveying (field measurements)	1270	X	X
9. Digital maps production	X	140	30
10. Field completion	X	115	115
11. Revision, editing & quality control	7	7	7
12. Final outputs	1	1	1
Total cost / km ²	1363 L.E.	353 L.E.	197 L.E.
Equivalent total cost/km ² in U.S.\$	235\$	60\$	35\$
Ratio (Approximate)	7	1.8	1
Note:			
X : Non-applicable			

Table 8. Cost model analysis in L.E. per unit kilometer area for the three most commonly used techniques (field surveying,

photogrammetry, & remote sensing) based on 200 km² project coverage

The previous cost figures in table 8 are evaluated taking into consideration the following rules:

1. Some activities have the same cost for various techniques.
2. Project area is taken as 200 km² and all cost values are given in Egyptian pounds (One U.S. \$ equals to 6 L.E).
3. Depreciation rates for the hardware & equipment is taken 5 years.
4. Depreciation rates for the software is taken 10 years.
5. Cost of using hardware & software taken from available average prices.
6. Number of working days/year are taken as 300 days.
7. Working hours/day for the field crew is taken 10 hours/day.
8. Working hours/day for the office crew is taken 14 hours/day (two shifts * 7 hours/shift).
9. Consultation fees/day is taken as 500 L.E.
10. Number of base stations/GCP's are taken as 10 for various techniques. However, for maps updating using remote sensing technique, the cost of this item is null as GCP's will be taken from available maps of larger scales. Number of traverse points is considered 100 stations/ project area.
11. Block adjustment, triangulation, radiometric correction and geometric correction are taken into consideration in item (5).
12. Rate of production of field surveying crew (4 persons) for 1:25000 scale maps is approximately 0.2 km² per day. Monthly salary is assumed 1500 L.E. for the engineers and 700 L.E. for the surveyors.
13. Rate of production of operators using photogrammetric technique for 1:25000 scale maps is approximately 1 km² per day. Monthly salary is nearly 1500 L.E.
14. Rate of production of an operator for 1:25000 scale maps from IRS remote sensing image is approximately 3 km²/day. Monthly salary is nearly 1500 L.E.

4. CONCLUSIONS

Results showed that using a second order polynomial for IRS-1C image rectification with 18 well distributed GCPs resulted in a total RMSE of 9.288 m for a number of 31 ground check points which is less than the value of two pixel size of IRS-1C imagery. This satisfies the requirements of the 1:25000 scale planimetric map accuracy standards that requires 90% of all ground check points be accurate within 0.05 centimeters on the map. At 1:25000 scale, this value (0.05 cm) is equivalent to 12.5 meters.

The acquisition of ground control and ground check points from 1:5000 ESA maps proved to be a very cost effective way of obtaining sufficient number of ground points to enable testing various configurations and scenarios to make good testing and assessment of results. A total number of 46 GCPs and 33 ground check points were available for the experiment. Had these points been acquired using GPS or total stations, the cost would have been extremely high. This approach proved also to stress the practicality and cost effectiveness of using GCPs from ESA 1:5000 maps to rectify IRS-1C images producing 1:25,000 planimetric city maps according to acceptable map accuracy standards.

In our study covering part of the city of Cairo for an area of approximately 7500 feddans in a rectangle of 7 x 4.5km, results indicated that a second-order polynomial was slightly superior to other order polynomials. However, the impact of the

polynomial order was insignificant and this conclusion is expected in view of the near flat nature of the study area. In areas where the ground is undulating, the order of the polynomial could be more significant.

As expected increasing the number of GCPs resulted in increased accuracy. This is true as long as the accuracy of the GCPs is homogeneous and is well distributed all over the image format. In our experiment using a number of well distributed GCPs ranging from 10 to approximately 20 covering the whole study area (7500 feddans) resulted in acceptable results. This is equivalent to 1 GCP each 750 to 375 feddans respectively, or 1 GCP each 3 to 1.5 km². The problem of using only 10 GCPs is that the degrees of freedom of the system will be reduced thus reducing the reliability of the obtained results.

The impact of GCPs distribution exceeds the impact of the number of GCPs as long as enough redundant observations exist and certainly exceeds the order of the polynomial transformation.

Comparison between the three most commonly used techniques (surveying, photogrammetry & remote sensing) for planimetric 1:25000 city mapping could not be absolute. It will depend on the extent and type of area to be mapped. A detailed cost analysis should be performed before deciding on the technique to be used. However, in general terms one can conclude that for limited areas with less planimetric details ground surveying technique could be a good choice. However, since cities usually cover reasonably large areas with dense details the choice is usually between photogrammetry and remote sensing. For our intended scale 1:25000 remote sensing technique besides being faster seems also to be more cost effective.

5. REFERENCES

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