COUNTRY-BASED ANALYSIS OF THE INVESTMENT DIMENSION OF THE AIRBORNE AND SPACEBORNE IMAGERY

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ABSTRACT:

Imagery is the basic input element of the photogrammetric map production. For decades, aerial photography has been the dominant option to fulfill the imagery request of the photogrammetry and the other disciplines. Due to the significant development in the field of remote sensing spacecraft and the on-board sensors, space imagery has become a serious alternative to the aerial photography. High-resolution remote sensing satellite imagery is competitive with the airborne imagery by means of accuracy, availability, up-to-dateness and the cost. This trend had stimulated some countries to focus on having their own remote sensing satellite. Until recent years only few countries like USA, Russia, France was launching and operating big multi-purpose satellites but today situation is changing such that the old space imagery customers are becoming the new owners of task oriented small satellites. In this paper, approximate investment and operational costs of both space and airborne platforms has been discussed.

1. INTRODUCTION

Technological developments have always been adapted to the photogrammetric applications. As a result of this tradition, photogrammetric map production, which has been started with analogue and continued for some time with analytic techniques, is currently conducted with digital techniques that allow applying automation in a great portion of the photogrammetric procedures. Developments in the field of photogrammetry had not only limited to the compilation works but also influenced the sensors and the image capturing process.

Parallel to the developments in data acquisition, substantial progress had been experienced in the field of sensors, which could be generally grouped as passive and active sensors. During the development phase of the passive sensors, analog aerial cameras had been subjected to considerable evolution in optical quality of the lenses and the operational features such as Forward Motion Compensation (FMC), gyro-stabilized camera mount, etc.

Passive sensors, which are also called as electro-optic sensors, require good weather conditions because their operation principle depends on recording the daylight reflectance of the objects on the earth. On the other hand, as a result of the implementation of microwave technology to the sensors, it has become possible to collect imagery data day and night time, regardless of weather conditions, with active sensors. Along the development course of the microwave sensors, novel sensors such as Synthetic Aperture Radar (SAR) and Light Detection and Ranging (LIDAR) have been put into the service.

For the time being, there are several options of acquiring photogrammetric imagery and users have to make choice among the various types of images such as analog or digital and airborne or spaceborne. One of the important facts that affect the image selection is the cost issue. Taking all these facts into account, this paper has focused on the cost analysis of various imagery that are suitable for photogrammetric applications.

2. PHOTOGRAMMETRIC DEVELOPMENTS

2.1 Developments in Photogrammetric Methods

Photogrammetric map production, which has been started shortly after the invention of the photograph, has become standard procedure owing to the developments experienced both in aircrafts and analog photogrammetric equipment after the World War I. Following the widespread utilization of the computer in photogrammetry, which started by 1970s, analog methods had begun to be replaced by analytical methods gradually. In consequence of the high performance computers, which were capable of storing and processing large volumes of digital imagery, coming into the market with affordable prices, digital photogrammetry has begun to become more common starting from 1990s (Jacobsen, 2002).

Photogrammetric map production not only reduced the fieldwork but also gave the opportunity of mapping the areas, which are inaccessible on foot, by using aerial photographs. Determining the terrestrial coordinates of the objects has been realized by the computations that depend to the measurement of the image coordinates and parallax with a stereo comparator. Within the analog period, together with relative and absolute orientation techniques, adjustment methods had been developed as well. Final product of the analog method is a line map on which the height information is depicted by the contours.

Transition from analog to analytic photogrammetry had not been as expeditious as desired due to the need of certain amount of computer technology for analytic application. Main reason for this rather slow transformation could be explained as the high investment costs of computers and the analytic equipment. In order to speed up the orientation procedure and achieve higher accuracy, relative and absolute orientation had been accomplished by adjustment. Exterior orientation parameters derived by analytic equipment could be used continuously and, for consequent images, applying only interior parameters will be sufficient. Instead of direct measurement of contours, which

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requires skilled operator and more time, terrain relief could be formed by accurate grid measurements. Generating digital terrain models not only facilitates and speeds up the computation of the contours, but at the same time, makes the applications such as volume computations, 3D representation of the terrain, profiling, etc. possible.

Speed, flexibility and accuracy exposed by analytic method had accelerated the transition to digital photogrammetry. As it would be figured out from its name, digital photogrammetry requires digital imagery that could be either directly captured by digital aerial cameras or digitized form of an analog imagery captured by film based aerial cameras. Accuracy of the photogrammetric scanners, which are used to digitize analog imagery, has started with 25 µm and improved to 7 µm within years (Baltsavias, 1999). Until recent years, the remote sensing satellites were the only source for acquiring digital imagery but current performance of the airborne digital cameras is capable of fulfilling the imagery demand of the digital photogrammetry. Main drawback of the digital imagery was said to be the storage problem but today it has been overcome by high capacity storage devices and advanced compressing software. Digital workstations are suitable for high degree automation such that automatic interior orientation of the digital aerial images (Kersten &Haering, 1997), determination of exterior orientation parameters by bundle block adjustment and automatic aerial triangulation could be accomplished. Despite the fact that automatic aerial triangulation has become a standard procedure, care should be taken when working with mountainous or dense forest regions and automatic procedures should be supported by manual measurements (Jacobsen, 2002). Automatic image matching feature of the digital photogrammetry enables the generation of Digital Terrain Model (DTM).

Exterior orientation parameters of the sensor can be determined directly by utilization of the Global Positioning System (GPS) and Inertial Measurement Unit (IMU) instead of conducting intensive field work to mark and survey the ground control points that are needed to perform adjustment. Rotation angles (ω, φ, κ) are obtained from the attitude data of the IMU while the projection center coordinates (X_o, Y_o, Z_o) are acquired by GPS component of the system (Cramer & Stallman, 2001).

2.2 Developments in Sensors

Sensors could be classified in two major groups as passive and active sensors according to the source of the reflected ray. Passive systems are the electro-optic sensors that operate by sensing the reflected daylight. Quality of the images acquired by passive sensors totally depends on the weather conditions. On the other hand, active systems are the microwave sensors that record the reflected electro-magnetic waves that are emitted by sensor itself. Since active systems are not weather and light dependent, they are capable of collecting data every time of the day and in all weather conditions.

When to speak about passive airborne systems, film based aerial cameras take the first place. Scanning the aerial films, which are taken by analog cameras, is the indirect way of acquiring digital imagery to be used at digital photogrammetric stations. On the other hand, airborne digital cameras give the opportunity of collecting digital image directly by employing either linear or matrix type Charge Coupled Device (CCD) arrays. Among the digital cameras on the market, ADS40 of Leica GeoSystems operates linear CCD where DMC of Z/I Imaging and UCD of Vexcel operate area (matrix) type CCD.

LIDAR is an active remote sensing technique that resembles to radar but instead of radio waves it uses laser light. The basic components of a LIDAR system are a laser scanner and cooling system, a GPS and an Inertial Navigation System (INS). The laser scanner is mounted to an aircraft and emits infrared laser beams at a high frequency (Figure 1). The scanner records the difference in time between the emission of the laser pulses and the reception of the reflected signal. The round trip travel times of the laser pulses, from the aircraft to the ground, are measured and recorded along with the position and orientation of the aircraft at the time of the transmission of each pulse. Three dimensional X, Y, Z coordinates of each ground point are computed by combining the flight vectors from aircraft to ground and the aircraft position at each measurement instance (Brovelli et al, 2002).

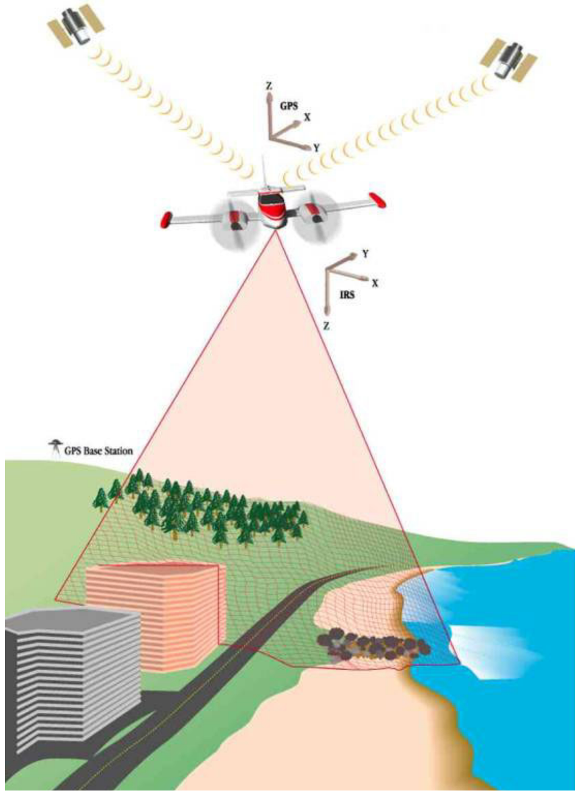


Figure 1. Operating principle of LIDAR system

Another active microwave sensor SAR is a radar system that generates high-resolution remote sensing imagery for more than a decade. Major satellites that have been collecting SAR data are ERS-1/2, JERS, Radarsat-1 and ENVISAT. When compared to optical images of the same pixel size, SAR images expose inferior performance of object identification. In addition to this difficulty, a SAR-image is dependent to the view direction and renders geometric problems of foreshortening, layover and shadows in mountains. (Jacobsen, 2003).

The main advantage of SAR system is the generation of Digital Elevation Model (DEM), example of which is given at Figure 2, by interferometric SAR (InSAR) technique that was started by ERS-1/2 tandem mission. Shuttle Radar Topography Mission (SRTM), during which the earth was imaged between 60^o north and south latitudes, realized the single-pass InSAR technology for the first time ever with a ten-day mission in February 2000 (Bamler et al, 2003).

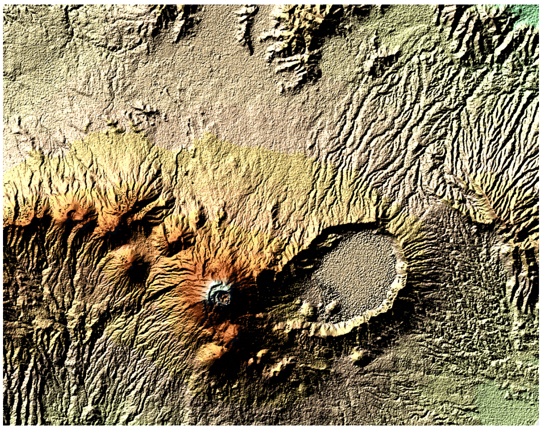


Figure 2. SAR DEM of Santa Ana Volcano, El Salvador

3. COST ANALYSIS

Cost component of a project plays an important role when it is considered from the point of productivity view. Since effective resource management requires economic data acquisition, imagery that is needed for photogrammetric mapping should be obtained at the lowest cost possible. However, the term "economic data acquisition" does not eventually imply getting the cheapest but suggests supplying the most purpose fitting material at lowest price available. In order to figure out the cost aspect of the photogrammetric image acquisition, airborne and spaceborne image cost analysis has been scrutinized separately.

3.1 Airborne imagery cost analysis

Airborne imagery is the set of images that are captured by the sensors mounted to an aircraft. Airborne imaging comprises of flight and ground operations, where flight operations involve aircraft and sensor costs while ground operations cover post-flight procedures such as developing and digitizing the films taken by analog camera or downloading and processing of the data collected by the digital camera.

Aircraft cost is comprised of annual fix cost and direct operating cost. Annual fix cost involves, hangar expenses, insurance payments, crew salary, and various administrative expenses such as pilot recurrent training, maintenance and navigation publication subscription fees, etc. Direct operating cost mainly covers the fuel and maintenance expenses at hourly basis. Aerial survey crew consists of pilot(s), navigator/camera operator and aircraft mechanic. Some crew formations could comprise of only two persons such as pilot/mechanic and navigator/camera operator.

Camera cost covers maintenance and personnel expenses for both analog and digital aerial cameras where an extra film expense should be added in case of analog camera use. Post-flight ground operation costs involve maintenance and personnel expenses, however an additional chemical cost shall be taken into account for developing the exposed films.

Aerial survey aircraft can be sorted in three main categories as low, medium and high altitude airplanes that have 10000, 20000 and 30000 feet ceiling respectively. In order to figure out the fix annual cost share within the hourly cost of the aircraft, estimated annual flight time of the aircraft should be presumed in advance and, in this study, it is assumed to be 400 hours.

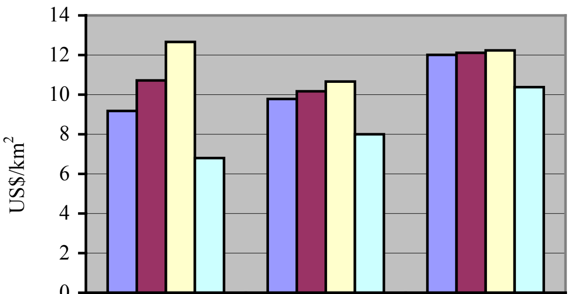
Digital camera operational cost is rather easy to determine while analog camera cost prediction becomes more complicated because of the film. As it is known, analog aerial cameras use mainly three types of aerial films (actually four when B&W infrared film is included) as Black & White, Color and Color Infrared (False Color). Amount of the film required for a photographic mission depends to the photo scale and the size of the area to be surveyed. Due to the divergence at aerial film prices, the film costs are given separately. In order to determine the operational aerial survey costs that are given in Table 3, it is assumed that a region having 40000 km^2 area and 1500 m reference terrain elevation is to be flown with a 23*23 cm frame camera having 150 mm focal length and flight conducted with 60% forward and 30% lateral overlap, and at the maximum ceiling altitude of the aircraft, which corresponds to 1:12500, 1:25000 and 1:50000 photo scales respectively.

Altitude	(feet)	10000	20000	30000
Photo scale	1/…	12500	25000	50000
Aircraft	(US$/hr)	522	643	881
Analog Camera	(US$/hr)	315	315	315
Film (US$)	B& W	32237	8105	2072
	Color	93917	23613	6038
	Color IR	171500	43120	11025
Digital Camera	(US$/hr)	158	158	158

Table 3. Aerial survey costs.

It is obviously noticed from the Table 3 that camera cost is fix for all scales while aircraft cost increases and aerial film cost decreases relative to scale factor. The increase in the aircraft cost is because of the relatively high direct operation costs of the high performance aircrafts, which are capable of getting imagery at small scales. On the other hand, the decrease in film cost arises from the low amount of film and the less laboratory process requirement as a result of small-scale photo survey.

In order to determine the imagery cost at a common basis, which allows comparison with the satellite imagery cost, aerial imagery costs computed in area basis are presented at Figure 4.



	1:12500	1:25000	1:50000
B & W	9,18	9,78	12,01
Color	10,72	10,17	12,11
Color IR	12,66	10,66	12,23
Digital	6,80	8,00	10,38

Figure 4. Airborne imagery costs per sq km

3.2 Spaceborne imagery cost analysis

Spaceborne imagery, which is captured by the sensors mounted to the earth observation satellites, has reached to a competitive position that exposes serious threat to the airborne imagery. High-resolution satellite imagery suitable for photogrammetric applications has become commercially available within last decade. Since last five years, resolution of the high-resolution spaceborne imagery has achieved to sub-meter level.

At present, some remote sensing satellites such as IKONOS, QUICKBIRD, EROS and ORBVIEW are being operated by private companies while the satellites SPOT, LANDSAT and IRS are operated by governmental organizations. Imagery prices of some remote sensing satellites are given in Table 5.

Satellite	Image	Resolution (m)	Band	Cost (US$/km^2)
QUICKBIRD	Standard	0,61	PAN	22,00
		2,44	MS	22,00
IKONOS	Geo	1,00	PAN	21,50
		4,00	MS	21,50
EROS	Standard	1,80	PAN	8,00
IRS	LISS-IV	5,80	PAN	0,51
			MS	0,82
	LISS-III	25,00	MS	0,14
SPOT	Standard	2,50	MS	2,47
			PAN	1,72
		5,00	MS	1,72
			PAN	0,97
		10,00	MS	0,97
			PAN	0,75
		20,00	MS	0,75
LANDSAT	ETM+	15,00	MS	0,05

Table 5. Satellite imagery costs per sq km

When satellite imagery costs are looked into, it will be noticed that cost increase is directly proportional with image resolution. Another factor that excites the cost of the satellite imagery is the electromagnetic band of the image where multispectral imagery comes out to be more expensive than the panchromatic imagery of the same satellite.

3.3 Investment cost analysis

Main components of an imaging system are platform, sensor, and ground facilities. For establishing an airborne imagery system aircraft, aerial camera and hangar are the main items. On the other hand, fundamental requirements of a satellite imagery capturing system are a spacecraft, sensors and ground station for communication with the satellite.

For executing either airborne or spaceborne operations, large volume investments such as airfields and navigation aids for aircraft flights and space centers that have launching ramps and capable of launching the satellite to its orbit with proper launch vehicles are required. Normally, governments realize these kind of huge investments because they are very costly and multipurpose utilities. For example, airfields and air navigation are used by other air traffic as well and space centers or launching sites do not only launch remote sensing satellites but also conduct all kinds of satellite launch operations.

Currently there are only eleven countries (USA, Russia, France, China, Japan, India, Israel, Brazil, Australia, Italy and Spain) that operate one or more launching site because construction and operation of a launching site does not only require high technology but also demands considerable financial resource. When the subject is considered from tip to toe, installation and operation of a launching site is a matter of several billions US$.

Despite the high technology and the financial demand of the satellite system, countries could still have their own satellites. Launching of the satellite could be accomplished at the centers that are operated by countries stated above. Building and operating of a satellite ground station is rather achievable part of the satellite system. There are certain centers that market the satellite technology and give on-the-job training during the production of the spacecraft and/or sensors.

Until recent years, earth observation satellites used to be built and operated by the governmental organizations of some certain countries such as Russia, USA, France and India. However, launching of the private sector owned commercial remote sensing satellites, which are capable of capturing high resolution imagery, not just started a new era but also encouraged some countries to have their own remote sensing satellites. New generation, small satellites could be launched with financial amount expressed as of ten millions US$.

Turkey is one of the countries that have its own remote satellite (Figure 6), which was built at Surrey Satellite Technology Ltd. facilities and launched on September 27th, 2003 by the Russian launch vehicle Cosmos-3. First Turkish remote sensing satellite Bilsat-1 weighs 129 kg and orbits around the earth at an altitude of 686 km with electro-optic sensor having 12 m panchromatic and 23 m multispectral resolution (Leloğlu & Sweeting, 2002).

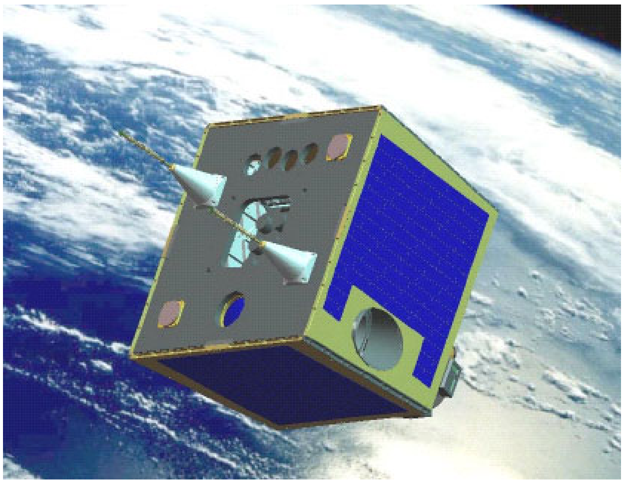


Figure 6. Turkish remote sensing satellite Bilsat-1

From the aerial survey point of view, infrastructure such as airfields and navigation aids are present in almost all countries but every country has this capability proportional to its development level. Therefore there is no need to consider this issue for investment cost analysis purposes that are made for photogrammetric image acquisition. Typical investment costs for founding an airborne imaging unit is given at Table 7.

Item		Cost (US$)
Aircraft	Low	800000
	Medium	2500000
	High	5000000
Camera	Analog	600000
	Digital	850000
Ground Facilities	Hangar	1500000
	Laboratory	800000

Table 7. Airborne imagery investment cost

It should be noted that aerial survey aircraft has to be modified in order to make the aircraft suitable for camera mounting. This modification includes opening a camera well on the bottom fuselage and requires a series of operations over the electrical system of the aircraft. The cost of the modification has been added to the aircraft costs given above. Prices given in Table 7 are, of course, not the exact values but presented with the intention of giving an idea about the amount of the procurement costs of main items required by aerial survey system. Cost varies according to the type of the aircraft and camera, maintenance equipments in the hangar, quantity and quality of the etc.

4. CONCLUSIONS

Aerial photography taken from aircraft is no longer the unique option of the photogrammetry because both digital airborne and spaceborne imagery are available at the market. Before resolving the image acquisition source, administrative personnel that are in charge of management have to evaluate the situation from several aspects and decide for the cost efficient.

Today, satellite imagery has achieved to sub-meter resolution, which is sufficient for some photogrammetric applications but does not meet the needs of all, especially large-scale mapping. In order to accomplish a productive use of the sources, users have to make purpose targeted imagery selection, which implies the acquisition of the most economic imagery that fits to the aim of the production.

It can been concluded that aerial photography will continue for large-scale mapping projects, however it should be noted that imagery captured by the airborne digital cameras expose quite good performance by means of both resolution and cost issues. Digital vs. analog imagery comparison on the investment and operational cost basis yields for the benefit of the digital camera products.

Investment dimension of design, production and operation cost of a multi purpose remote sensing satellite is fairly high. On the other hand, light, designed for specific purpose and affordable new generation earth observation satellites are gaining more interest. Nevertheless, for photogrammetric purposes, it sounds much wiser to acquire satellite imagery by purchasing from the commercial satellite operators.

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