International Journal of Applied Social Science ***RESEARCH PAPER***
Volume 5 (11&12), November & December (2018) : 1019-1039 ISSN : 2394-1405 (Print)
Received : 16.05.2018; Revised : 02.06.2018; Accepted : 17.06.2018

Geospatial Analyses using Photogrammetric Algorithms: A Study of Aerial Photograph's Formats, Measurements and Modelling for Landscape of Real-World

MADAN MOHAN
Associate Professor of Geography
Centre for Study of Regional Development, School of Social Sciences – III,
Jawaharlal Nehru University, New Delhi (India)

ABSTRACT

The aerial photograph play a significant role in the cadastral surveying and mapping as ordinarily used by the surveyors, foresters, geologists in the fields of land utilisation, deforestation, geology, geomorphology, hydrology and so on for various purposes for landscape's development. Aerial photographs are proved to be much more effective medium for land resource mapping and surveying than the time-consuming ground surveys. It is noteworthy to point out that in recent times, the new nano-technological innovation as the UAV and Drone have opened avenues for application in real-time for any area or region exploration of real-world with small format digital aerial photograph. The scale accuracy and multispectralphotographs are highly in demanded for various development and planning purposes. So, the vertical aerial photographs are playing a vital role in real-world's surveying and mapping of resources, infrastructure development as well as survive-lance in real-time. However, aerial photograph have limitless applications with multiple functions in the fields of geography, geology, hydrology, ecology and environmental studies of the physical landscape, on the one hand and the rural, urban and regional studies of the cultural landscape, on the other hand. The aerial photographs have lots of prospectus for betterment of the humanity on this planet earth. Thus, the aerial photograph records the ever-changing natural and cultural features accurate geospatial information obtained from the earth's surface which are used for various planning and development purposes in real-time of the real-world.

Key Words : Aerial Photograph, Photogrammetric Algorithms, Geospatial Technology,Environmental Studies, Landscape Development

INTRODUCTION

The aerial photograph, in general, is any photograph taken by airborne aircraft or unmanned aerial vehicle (UAV) or by Dronefor aerial imaging of the earth's surface. More precisely, the aerial photographs are taken vertically from an aircraft with the help of highly-accurate aerial camera system. So, the aerial photographs are taken with the help of an aerial camera fitted with photographic lens system and optically calibrated to record information on film or in digital imagery of the earth's surface. In addition to this, the aerial photographs are taken vertically from an aircraft

How to cite this Article: Mohan, Madan (2018). Geospatial Analyses using Photogrammetric Algorithms: A Study of Aerial Photograph's Formats, Measurements and Modelling for Landscape of Real-World. *Internat. J. Appl. Soc. Sci.,* **5** (11&12) : 1019-1039.

using a highly-accurate aerial camera. There are several components of aerial photograph which determine individual photographs characteristics different from one another of the same region based on the types of film, scale, overlap, stereoscopic coverage, flight line and so on. Aerial photographs are proved to be much more cost-effective medium for land resource mapping and surveying than the time-consuming ground surveys. For instance, the aerial photography was more commonly used by the national mapping organisations which was continuously developed throughout the 19th century, as by the United Kingdom's (UK) Ordnance Survey, the official cartography agency or map-making body of the British or Irish government. Since then, aerial photography had extensively been used in various fields as environmental studies for mapping of forests, changes in vegetation cover over times; changes in river beds or channels; changes to the physical landscape due to natural and man-made processes as forests fires and landslides, respectively. However, the aerial photograph have limitless applications with multiple functions in the fields of geography, geology, hydrology, ecology and environmental studies of the physical landscape, on the one hand and the rural, urban and regional studies of the cultural landscape, on the other hand.

Aerial photograph's potentially military applications were well-known in the beginning of 20th Century. In lieu of this, the use of aerial photography was rapidly matured during the wars over the periods. For instance, during the World War I, the aircrafts were equipped with cameras to record enemy movements and defences. In Europe, the Germany adopted the first aerial camera in 1913. Likewise, the French aircrafts were equipped with camera and then prints were provided to military for use in field in real-time. The Britain also started to use aerial photography for experiments at the same time. So, by virtue of this, by the end of the war, aerial cameras had dramatically increased in number; but reduced in size with improved focal length power which resulted into production of half a millions of aerial photos for various applications and usages. However, the aerial photography received greater attention in the interest of military reconnaissance during World War I. Besides this, during the World War II, the improved aircraft were equipped with high-altitude, high-speed stereoscopic photographic system for exploration and surveying by the military. This had resulted into production of more than one million aerial reconnaissance photographs which were particularly taken for military purposes. However, over periods, with the advancement in geospatial technology, there were easy feasibility of solutions for larger area mapping and surveying by use of the aerial photographs (Jensen, 2007). So, the aerial photography was developed to use in several areas as topographic surveying and mapping, land use land cover mapping, environmental and urban studies and so on. It was also used for creation of three-dimensional models of the physical landscape. Later on, during the Cold War, the military applications were remained continued by the development of colour photography, on the one hand. And, for the wider environmental and urban applications were also developed during this period, on the other hand. Infra-red photography became crucial to vegetation mapping as well as for tracking and identifying diseased plants and trees. So, the function of taking physical landscape photographs at different colours of the spectrum opened up a wide range of applications across the broadest possible scope for the study of environment and urban development, at large.

Aerial photograph contains of areal landscape's geospatial precise and accurate locational information as mountains, planes, plateaus, river systems, forest's covers and other natural features and resources. Besides this, the human settlements, residential and industrial areas, roads and rails networks and so on other socio-economic information are also visible and geographically locatable on aerial photograph. So, the aerial photograph interpretation produces many practical applications as map-making, urban and rural planning, environmental impact studies, civil law cases, real estate evaluations, and so on for regional planning and development. In other words, the aerial photograph records the ever-changing natural and cultural features accurate geospatial information obtained from the earth's surface which are used for various planning and development purposes in real-time of the real-world (Lillisand, Kiefer and Chipman, 2009). So, the aerial photography is an important source of information for the researchers, planners and policy makers for local and regional development of the landscape. It is often difficult to comprehend elements of the landscape on the ground, because there are many features which can easily be missed out of the landscape. It may cause an insignificant features missing from ground level which can become more significant in a wider context. Likewise, there are some landscape types which are difficult to access on foot. The alternative solution is the aerial photographs which are vital to surveying and mapping of the inaccessible landscapes for further detailed study for sustainable developments. So, the Aerial photographs have many different usages and applications for geospatial analyses of the landscape for regional planning and development in real-time of the real-world.

Aerial Photographs :

While studying aerial photography, there are many types of aerial photographs. These can be classified on the basis of different criteria. There is need to better understand the fundamentals of aerial photograph, their intricacies with detailed explanations and their basic technical details and concepts, which are thoroughly discussed as follows:

1) On the basis of direction of camera axis, aerial photographs are classified as a) Vertical Aerial Photograph; b) Horizontal or Terrestrial Aerial photograph; c) Oblique Aerial photograph; and d) Composite Aerial Photograph. Details of these aerial photographs are discussed below:

   *a) Vertical Aerial Photograph:*In theory, the vertical aerial photograph is the one which is looking down on a subject at an angle of less than or equal to 3 degrees from the vertical angle as is illustrated in the Figure 5 and 6; 7,8 and 9.The ground area covered by a vertical aerial photograph approximates to the shape of a square or a rectangle. The objects and features on truly vertical aerial photograph appears true in their shape and size. It delivers a bird's eye view of the area which is not the normal view as experienced by the people in the area. These photographs contains 60 per cent overlap and 30 per cent sidelap. There are many advantages of vertical aerial photograph. Distance and direction vary across the photograph. Direction can also be measured more accurately from vertical aerial photograph. Measurement of directions are easier than on oblique photograph. The scale is essentially constant throughout the photograph. Within limits, a vertical aerial photograph can be used as map with the addition of grids and marginal information. The vertical aerial photographs are often easier to interpret than oblique aerial photographs. So, the vertical aerial photograph cover smaller area. The scale remain constant over the entire coverage. This makes it perfect photograph for surveying and mapping purposes. Besides, these are also sometimes used as substitute of map where the map is not available for the area or region for various development purposes.

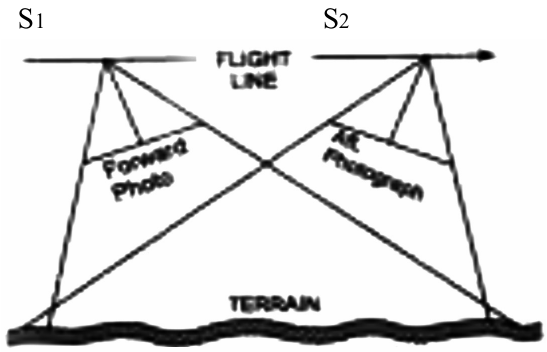
   b) Horizontal or Terrestrial Photograph: Such photographs is taken with the photo-theodolite from camera stations on the ground along with the axis of camera horizontal which presents more familiar elevation view. It is also possible to take such photograph with normal good quality camera. There are number of usages of such kinds of aerial photographs. Such as, the photograph is used for surveying of structures or monuments of architectural or archaeological value. Whereas, the terrestrial photograph is taken with the normal good camera. Such photograph can also be of considerable value and usage in supplementing photo interpretation of the vertical aerial photographs, particularly in geology and forestry where the soil profile may be taken into consideration.

c) *Oblique Aerial Photograph:* Such aerial photograph is taken with an optical axis of the aerial camera which is tilted from the vertical and hence is called oblique photograph. In other words, the oblique aerial photograph is taken with a camera axis tilted intentionally between the horizontal and vertical axis which is resulting into formation of oblique geometry with respect to ground surface. The photograph contains large coverage area of the ground. But the clarity of details diminishes towards the far end in the photograph. Oblique photograph can be classified into two classes as the (i) Low Oblique Photograph; and (ii) High Oblique Photograph.

Low Oblique Photograph is the aerial photograph on which horizon does not appear. The camera lens system is inclined by 30^0 angle from the vertical axis. Such photograph cover relatively small area. The ground area covered is trapezoidal though the photograph is square in geometry. The appearance of objects have more familiar view which resembles with the viewer's perception as obtained from a high vantage point. For instance, the view attained from a hill or a roof-top of a high rising building. The scale varies throughout the photograph which is resulting into distortion of objects in form of distance and directions.

High oblique photograph is the aerial photograph which is tilted sufficiently to encompass the horizon. In this kind of photograph, horizon is clearly visible. In the photograph, the camera axis is tilted at 60^0 angle from the vertical axis. The main feature of such photograph is that it encompasses large ground area. The photograph also records the side view of the terrain. The familiarity of the view depends upon the height from which the photograph is taken. Scale is variable, therefore, distance and directions are not true. The relief can be seen, but it is sometime distorted. The familiarity of view varies depending upon the height from which aerial photograph is taken.

d) *Composite Aerial Photograph:* This kind of photograph is comprised by combination of photographs taken with the help of two or more camera units in a photographic plane. The photograph further classified into two categories as the (i) Convergent Aerial Photograph, and; the (ii) Trimetrogen Aerial Photograph. *Convergent Aerial Photograph* is the low oblique photograph taken with the two cameras exposed simultaneously at successive camera stations. The camera axis tilted from the vertical at a fixed angle in the direction of flight line. So, the resultant of forward exposure of the first station (S1) forms a stereo pair with the backward exposure of the next station (S2) as is shown in the Fig. 1. Each of the camera axis is inclined in opposite direction with orientation to flight line. The camera axis is such oriented that the forward and backward photograph exposure stations makes a stereo-pair. So, special kinds of plotting instruments are required for preparation of maps from convergent aerial photographs.



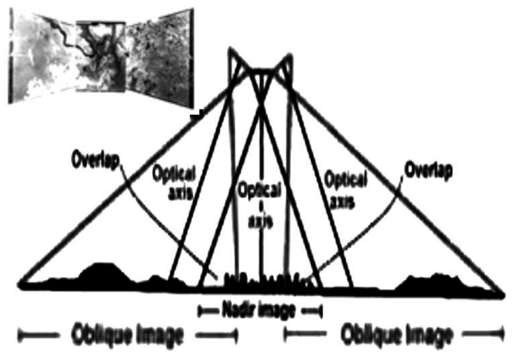


Fig. 1 and 2 : Convergent; and Trimetrogen Aerial Photographs

Trimetrogen Aerial Photograph is taken simultaneously with the help of three cameras, held in a single mount. One of the camera is held vertically and photograph the area below the plane. And, the other cameras are aligned at right angles to the azimuth. These cameras are held obliquely at an angle of 60^0 from the vertical axis. These cameras takes photograph of the area adjacent to the photograph taken by the vertical camera. The geometry of camera axis is schematically illustrated in the Fig. 2. So, the photograph is taken with the help of three cameras which is a combination of one vertical and the other two are low oblique aerial photographs. In other words, the central camera takes the vertical aerial photograph while the other two cameras fitted on both sides take low oblique aerial photographs. The photograph is used for a rapid production of reconnaissance maps on small scales.

2) On the basis of the angle of coverage, the aerial photographs are classified as a)Narrow Angle Photograph; b)Standard or Normal Angle Photograph; c) Wide Angle Photograph; d) Super-wide/ Ultra-Wide Photograph. Details of all these aerial photographs are given below:

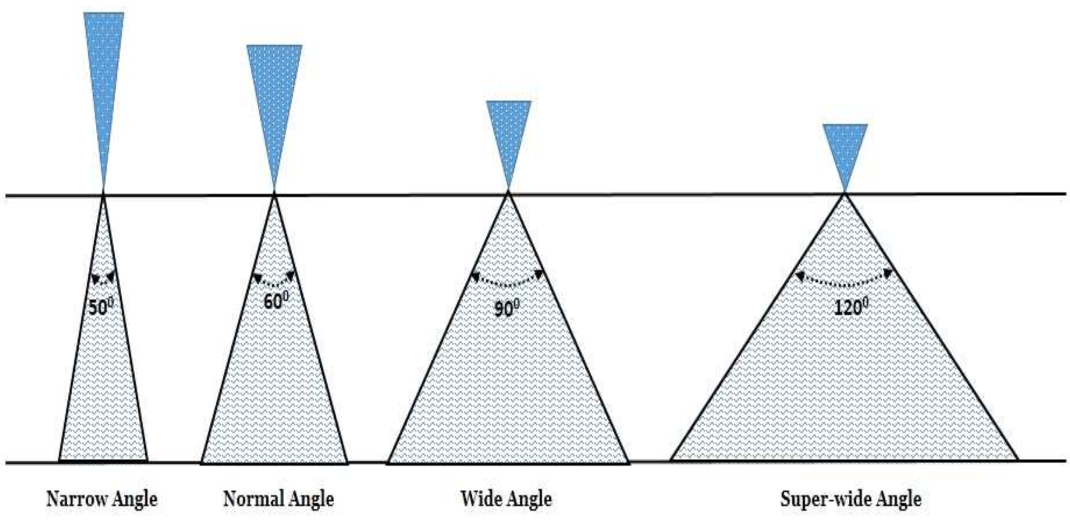


Fig. 3 : Aerial photograph classification based on angular coverage

a) *Narrow Angle Photograph*, is that aerial photograph in which the angle of coverage is of order of less than 50^0 as evidenced by the Fig. 3. The photographic prints format sizes are in two forms. One of them size is 18 cm × 18 cm or 7 inch × 7 inch; and 23 cm x 18 cm or 9 inch x 7 inch; and the other one size is 23 cm x 23 cm or 9 inch x 9 inch; and 12 cm x 12 cm or 4.5 inch x 4.5 inch.

b) *Standard or Normal Angle Photograph*, is that aerial photograph in which the angle of coverage is of the order of 60^0 as evidenced by the Fig. 3. The photographic prints can be obtained on two formats sizes. One of them format size is 18cm × 18 cm, focal length = 21 cm; and the other one's size is 23 cm x 23cm, focal length = 30 cm.

c) *Wide Angle Photograph*, is that aerial photograph in which the angle of coverage is of the order of 90^0 as evidenced by the Fig. 3. The photographic prints can be obtained on two formats sizes in which one of them size is 18 cm × 18 cm, focal length = 11.5 cm; and the other one's size is 23 cm x 23 cm, focal length = 15.0 cm.

d) *Super-wide/ Ultra-Wide Photograph*, is that aerial photograph in which the angle of coverage is of 120^0 as evidenced by the Fig. 3. The photographic prints can be obtained on two formats sizes in which one of the size is 18 cm x 18 cm, focal length = 70 mm; and the other one's size is 23 cm x 23 cm, focal length = 80 mm.

3) On the basis of scale, the aerial photographs are classified into three broad categories as large, medium and small scale aerial photographs. The First category is of the Large Scale Aerial Photograph. This aerial photograph scale ranges 1: 5,000 – 1: 20,000. The Second category is of the Medium Scale Aerial Photograph. This aerial photograph scale ranges 1: 20,000 – 1: 50,000. The Third category is of the Small Scale Aerial Photograph. The scale of this aerial photograph ranges 1: 50,000 and more.

4) On the basis of spectral and radiometric characteristics, the aerial photographs are classified

Black-and-white | Natural colour | Colour infrared

Source: Above aerial photographs were obtained from the U.S. Geological Survey

Fig. 4 : Single frame aerial photograph types are as Blank-and-white, Natural colour, and Colour infrared of the Napa River Bridge in Vallejo, California

in to five types. These aerial photographs are as a) Black-and-white; b) Natural colour; c) Colour infrared; d) Thermal; and e) Multispectral. All these kinds of aerial photograph's characteristics and their applications are discussed in details as follows:

a) *Black-and-White or Panchromatic Aerial Photograph*, is normally taken during the visible electromagnetic spectrum of light. This photograph contains objects and features in normal form in which the dark object appear darker whereas the light object appear brighter in colour as evidenced by the Fig. 4. Such photograph is generally used for field survey. The photograph have limitations in terms of their usages due to haze, dust particles and cloud covers.

b) *Natural Colour or Colour Aerial Photograph*, is also known as the True Colour Aerial Photograph. Such aerial photograph is normally taken in the visible spectrum of light which is distinguishable into three distinct bands as the blue, red and green. More specifically these bands spectral width is ranging between 0.4 – 0.7 μm. These bands are useful in separation and identification of vegetation types and more appropriately different tree species in the woods as clearly evidenced by the Fig. 4. The colour quality of the photograph is affected due to the prevailing atmospheric condition as haze at the time of taking of aerial photograph.

c) *Colour Infrared or False Colour Composite*, aerial photograph is obtained in the visible spectrum of light including a small portion of infrared light. The main difference of this aerial photograph is that it is produced with the spectral bands of the green, red and near-infrared radiation in place of the usual blue, green and red lights. So, the objects and features become clearer to distinguish between natural and man-made objects, healthy *vs* disease-ridden tree species, deciduous *vs* evergreen tree species in forests and the surface water bodies etc. features of the surface of earth as clearly evidenced by the Fig. 4.

d) *Thermal Aerial Photograph*, is usually obtained in the thermal spectrum of light which is ranging between 12.1 – 14.1 μm. This aerial photograph is used for specialised purposes as the photograph is used to suggest temperature regime for an area. In spite of the limited usages, the photograph is particularly used in detection of forest fires, coal mine fires and eruption of active volcanoes and so on. So, the aerial photograph is widely used for environmental impact analysis in real-time for the real-world natural and environmental phenomena.

e) *Multi-spectral/ Multi-band Aerial Photograph*, is obtained using multiple films ranging from visible to thermal bands of the electromagnetic spectrum of lights. Many camera with multiple films are used for specific purpose. This kind of aerial photograph have significant applications, particularly in the rocks identification and its related geological studies. The aerial photograph is also used for detailed survey of geological and geomorphological investigations of specific objects on the surface of the earth.

5) On the basis of print surface, the aerial photograph is classified into two categories as a)

Glossy Paper Print; and b) Matte Paper Print. The quality of paper also determines to the easy and sharp identification of objects on the paper. This make the aerial photo interpreter's job more easy and reliable for mapping of the natural and the man-made features on the surface of the earth for various planning and development purposes in the real-time of the real-world for quick, better and reliable information analyses for the sustainable development.

So, the types of aerial photographs are based on various criteria as on the basis of direction of camera axis; on the basis of the angle of coverage; on the basis of scale; on the basis of the spectral and radiometric characteristics; and on the basis of print surface. All these kinds of aerial photographs with their characteristics and applications have been discussed in greater details in the above mentioned text.

Research Objectives :

The present research mainly focus on the geospatial characteristics and the processing of aerial photographs in order to work out the real-world problem's solutions through analyses based on photogrammetric algorithms in real-time for the landscape's development. So, the main objectives of present research are mentioned as follows:

i. to study significance, types, characteristics and applications of aerial photograph;
ii. to analyse vertical aerial photograph based on techniques, methods and algorithms;
iii. to apply photogrammetric algorithms for geospatial modelling for the real-world;
iv. to suggest suitable strategies based on aerial photograph for landscape's development.

So, the geospatial features and their digital information are obtainable from aerial photograph. Such extracted information are not only available at meters, centimetres; but these are available at sub-centimetres and upto millimetres scale in real-time of the real-world. Such kinds of geospatial information are extracted and based on vertical aerial photographs which are analysed by application of the photogrammetric algorithms in real-time. So, the geospatially processed information results become easily accessible to the planners and policy makers in real-time for all round urban and regional developments of the landscape.

METHODOLOGY

The present research is based on the vertical aerial photographs. These photographs were obtained from the (Earth Resources Observation and Science) EROS Data Center (EDC) situated in Sioux Falls, South Dakota, and is operated by the U. S. Geological Survey (USGS) as a repository for aerial photographs acquired by the National Aeronautics and Space Administration (NASA), the USGS, and the many other federal agencies and organisations. A computerised database at EDC provides an indexing system for information pertaining to available aerial photographs. The aerial photography single frame high resolution data provide access to photogrammetric quality with sufficient resolution to reveal landscape's details and to facilitate the interpretability of various features of the landscape. Aerial photograph coverages for the United States are provided by the various agencies and organisations, out of which the important coverages have been acquired for the present research of which details are given as follows:

Table 1: Details of aerial photograph coverages for the United States.

Organizations	Frames	Scale Range	Date Range	Film Type
USGS	2,931,349	1:3,000 - 1:125,000	04/1937 - 09/2008	B/W, BIR, Color, & CIR
NASA AMES Research Center	167,878	1:2,000 - 1:199,000	01/1972 - 07/1999	B/W, BIR, Color, & CIR
EROS Miscellaneous	99,112	1:1,740 - 1:130,000	09/1937 - 04/2006	B/W, BIR, Color, & CIR
Urban Area	72,581	1:4,800 - 1:40,000	04/2001 - 10/2010	B/W, Color, & CIR

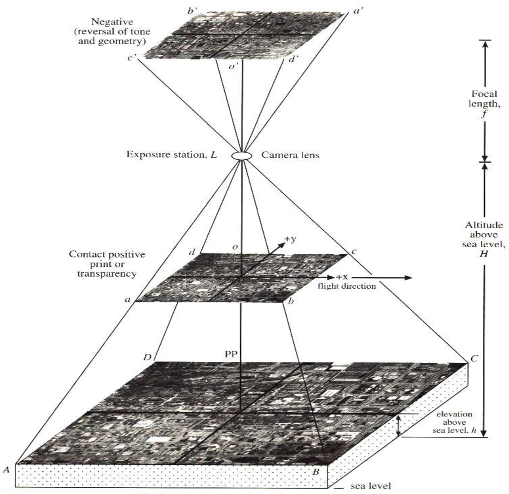
Source : Above table was compiled on the basis of available data obtained from the U.S. Geological Survey.

The USGS is the largest organisation possesses the largest collection of aerial photographs. Individual photographs are varying in their scale, size, film type, quality, and coverage. While keeping in view these characteristics, the vertical aerial photographs for the present study were obtained from the USGS. Nevertheless, the aerial photographs form the primary source of information for compilation of large scale maps, especially for the large-scale topographic mapping, the environmental impact analyses studies and the urban and regional studies. So, the vertical aerial photographs are valuable and make available as map substitutes or as map supplements. Aerial photograph record complex details of the varied patterns and features which constitute geospatial information for any landscape. However, in the present research, a number of photogrammetric methods and algorithms were devised, developed and applied for the geospatial analyses of vertical aerial photographs of the real-world. All these newly invented methods and algorithms have been discussed in details as well as applied in the present research along with the building of model for sustainable development of landscape of the real-world.

Geometric Elements of Vertical Aerial Photograph :

There are many basic photogrammetric procedures which involve in the production of vertical aerial photograph. Vertical photograph is that photograph in which the camera axis directed as vertical as possible. In other words, for a truly vertical aerial photograph, the camera axis would be in perfect alignment with the direction of gravity. In fact, due to unavoidable angular tilt of the aircraft during the instant of exposure, virtually all aerial photographs are slightly titled. So, the unintentional tilt is normally less than 1 degree and sometimes tilt is greater than 3 degrees. For many photographic analyses, such tilt is negligible and resulting photograph is treated as being truly vertical without serious error, *i.e.* the tilt is less than 3 degrees. The vertical aerial photograph and its basic geometric elements are illustrated in the below Fig. 5 and 6.

It is apparent from the above Fig. 6 that the light rays from terrain object are imagined in the plane of the film negative after intersecting at the camera lens exposure station, *L*. The negative is located behind the lens at a distance equal to the lens focal length, *f*. And, the positive image position is depicted in front of the lens in a plane located at a distance, *f*. While both the x and y coordinate positions of image points are referenced with respect to axes formed by straight line joining the opposite fiducial marks recorded in the positive as illustrated in the Fig. 5 and 6. The x-axis is arbitrarily assigned to the fiducial axis most nearly coincident with the line of flight and is taken as positive in the forward direction of flight. Whereas, the positive y-axis is located 90 degree counter clockwise from the positive x-axis. This is because of the precision with which the fiducial marks and the lens are placed in a metric camera. The photo coordinate origin, '*o*', can be assumed to coincide exactly with the principal point (PP). At this point, the lens optical axis and the film plane intersect together. The point where the prolongation of optical axis of the camera intersects the



Source: Vertical Aerial Photograph was obtained from U.S.Geological Survey; and Geometry of Vertical Aerial Photograph was acquired from Jenson, J.R. (2007) *Remote Sensing of the Environment*, New Delhi, Pearson Education, Inc.

Fig. 5 and 6 : Vertical aerial photograph; and Geometry of vertical aerial photograph (flat or plane terrain)

terrain is referred as ground principal point, 'PP'. Besides this, the images of terrain point *A*, *B*, *C*, *D* appear geometrically reversed on the negative as *a'*, *b'*,*c'*, *d'*. Likewise, all these are existed in proper geometric relationship on the positive as *a*, *b*, *c*, *d* which are clearly illustrated in the Figure 6. So, the knowledge and understanding of geometry of vertical aerial photograph helps in the better analyses and interpretation as well as for the analytical solution of the problems of the real-world.

However, while taking into consideration to the above mentioned factual details, it is resolved that most of the aerial photographs are not perfectly vertical. The aerial photograph contains three different photo centres which are as the principal point, the nadir point, and the Isocentre. Each one of these photo centres with their characteristics and details in context to aerial photograph are illustrated as follows:

a) *Principal Point:* It is the optical or geometric centre of photograph. It is the image of the intersection between the projection of the optical axis and the ground. The principal point is assumed to coincide with the intersection of the x-axis and y-axis. The location the principal point on a single photo is obtained by the intersection ofline drawn between opposite side or corner fiducial points, as schematically illustrated in the Fig. 7.

b) *Nadir Point:* It is also called a vertical point or plum point. It is a point which exist vertically beneath the camera at the time of exposure. The nadir point is important because of the relief displacement is radial from this point. In other words, it is a function of the displaced image from this point radially as schematically presented in the Fig. 8. Contrasting to the principal point, there are no marks on the photograph that permit to locate the nadirpoint. Location of the nadirpoint on a tilted aerial photograph usually involving sophisticated stereoscopic plotting techniques which require expensive instrument and ground control information.

c) *Isocentre:* It is a point halfway between the principal point and the nadir and on the line segment joining on the aerial photograph. The isocentre is the focus of the tilted displacement. It is the point from which tilt displacement in radial. On a truly vertical photograph, the principal point, the nadir point and the isocentrecoincide at geometric centre *i.e.* principal point 'PP' of the photograph as geometrically illustrated in the Fig. 6 and Fig. 7, 8 and 9. In this case, there is no tilt displacement, only relief displacement and it is radial from the geometric centre of the aerial photograph.

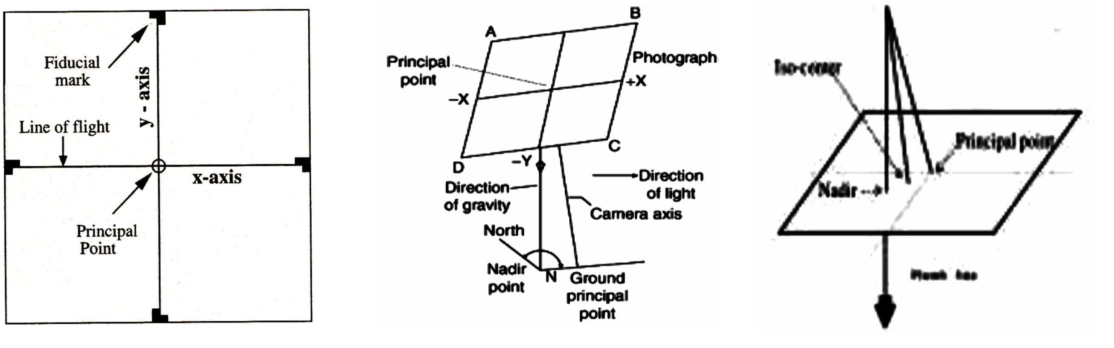


Fig. 7, 8 and 9 : Single aerial photograph with kinds of photo centres:Principal Point (PP); Nadir Point; and Isocenter

So, the geometric elements of vertical aerial photograph are discussed and illustrated in the above mentioned paragraphs. All these intricacies of the vertical aerial photograph are important in understanding by the photo-interpreter for further analyses and interpretation and then creation of the geospatial information for the real-world.

RESULTS AND DISCUSSION

1) Scale of Vertical Aerial Photograph :

The scale of aerial photograph is expressed into different forms as a verbal scale or as a representative fraction which is dimensionless. For instance, if 1 inch on an aerial photograph represents 2,000 ft. or 24,000 inches on the ground. So, what will the scale of aerial photograph and how it is expressed numerically? In this context, the verbal scale is 1 inch = 2,000 feet. Both the numerator and denominator values are in different proportion. There is a need to convert them into the same proportion. So, the calculation of scale of aerial photograph is explained as follows:

$$Verbal\ scale = \frac{1\ inch}{2{,}000\ feet}$$

$$Ratio = \frac{1}{24{,}000}$$

Representative Fraction (RF) = 1: 24,000

So, the aerial photograph scale can be explained as a ratio of the unit distance on the photo image to the actual distance on the ground as explained above. Hence, the larger integer value in the scale expression, the smaller the scale of the aerial photograph.

i. Scale of Vertical Aerial Photograph over Flat Terrain :

There are two main methods for determining the scale of aerial photograph over the flat or level terrain. These methods are as a) scale calculation by matching real-world object size versus photographic image size; and b) scale calculation by connecting focal length to altitude above ground level. Both these scale calculation procedure are explained in context to the real-world aerial photographs as follows:

a) Scale Calculation by Matching Real-World Object Size vs Photographic Image Size: Scale is "the ratio of a unit distance on the photo image to the actual distance on the ground". So, the scale of aerial photograph is expressed through the equation given as follows:

$$SP = \frac{\text{Photo Distance}}{\text{Ground Distance}}$$

For instance,

$$S = \frac{ab}{AB}$$

Where:

S = scale of aerial photograph;
ab = size of the object on the aerial photograph;
AB = actual length of the object in the real-world.

b) Scale Calculation by Connecting Focal Length to Altitude above Ground Level (AGL): Scale calculation take into consideration the camera focal length, *'f'* and flying height above the ground, *'H'* by comparing the geometrically similar triangles. For instance, in a truly vertical aerial photograph geometry, Loa and LPA are locatable and schematically illustrated in the below given Fig. 10. So, the scale of the aerial photograph is computed as follows:

$$\textit{Photo Scale} = \frac{f}{H}$$

Where:

f = focal length
H = flying height

From above equation, it is evidenced that the scale of a vertical aerial photograph is directly proportional to camera focal length *i.e.* image distance and it is inversely proportional to flying height above ground level *i.e.* object distance. Such kind of relationship is geometrically illustrated in the below given Fig. 10.

For example, the focal length of the camera lens is 15 cm and the height of the aircraft at the time of exposure is 1,500 mts. Calculate the scale of the vertical aerial photograph? In this case, the scale calculation is based on the above stated second equation. So, the scale of vertical aerial photograph over level terrain is computed as follows:

$$= \frac{15\text{ cm}}{1{,}500\text{ mts}}$$

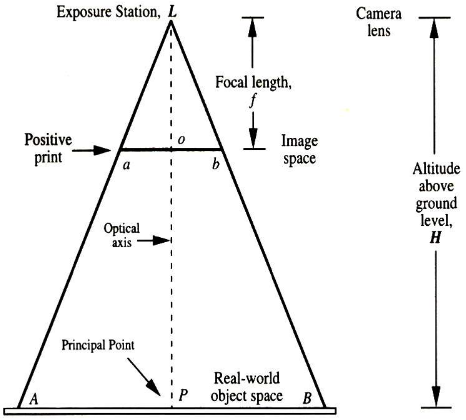


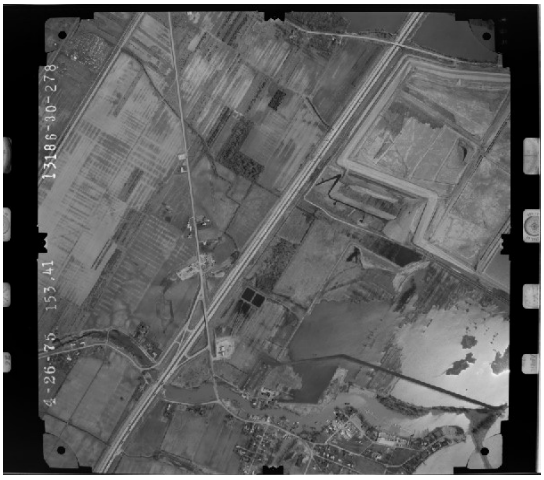
Fig. 10 : Geometry of vertical aerial photograph over relatively flat terrain

$$= \frac{15}{1{,}500 \text{ x } 100}$$

$$= \frac{1}{10{,}000}$$

So, the representative fraction or verbal scale is 1:10,000. In other words, a unit on the aerial photograph is equal to 10,000 units on ground of the real-world.

In this context, the scale measurements of the vertical aerial photograph can easily be work out using the configuration attributes values provided along with the aerial photograph of the real-world as are given for the Fig. 11. In this case, the focal length of the camera lens is 152.85 mm and the flying height of the aircraft at the time of exposure is 3000 feet. So, what will be the scale of the vertical aerial photograph?



Source: Vertical Aerial Photograph, 1975 was obtained from U.S. Geological Survey; and Reference Imagery of *Detroit-Toledo Expressway* was acquired from Google Earth Satellite Imagery 2018, Digital Globe, U.S. Geological Survey.

Fig. 11 and 12 : Vertical aerial photograph; and Reference imagery from Google Earth

On the basis of the above provided information for the truly vertical aerial photograph of the real-world, the scale is calculated by using of the equation given as follows:

$$Photo\ Scale\ = \frac{f}{H}$$

Where:

f = focal length

H = flying height

$$Photo\ Scale\ = \frac{152.85mm}{3000\,feet}$$

$$= \frac{152.85\ \ mm}{914400\ \ mm}$$

$$= \frac{15.285\ \ cm}{91440\ \ cm}$$

$$= \frac{1\ \ cm}{5982\ \ cm}$$

So, the vertical aerial photograph's representative fraction or verbal scale is 1: 5982. In other words, a unit on the photo is equal to 5982 units on the ground of the Real-World.

ii. Scale of Aerial Photograph over Undulating Terrain :

In case, the topographic elevation decreases within a certain portion of the aerial photograph relative to other areas, then that portion of the photograph will have a smaller scale then the rest of the photograph. It is because of the fact that the land will have 'moved away' from the aerial camera that is flown at constant altitude. On the contrary, in case a topographic feature such as a mountain or a building portion above the average elevation of the local terrain, the scale will have

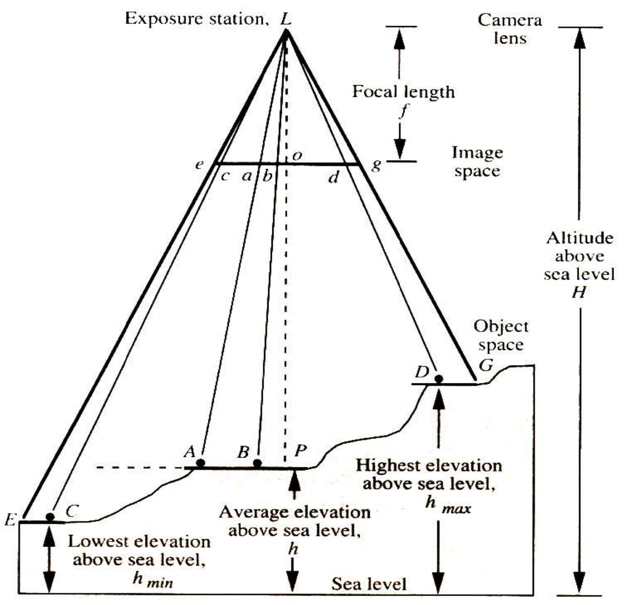


Fig. 13 : Geometry of vertical aerial photograph over undulating terrain with variable relief

'moved closer' from the aerial camera in the flying direction at constant altitude. So, the geometry of a single vertical aerial photograph taken over undulating terrain with variable local relief from exposure station *L* is illustrated in the below Fig. 13.

On the bases of the above mentioned geometry of a vertical aerial photograph, the point '*A'* and '*B'* of the real world object are located on level terrain. And, these points are recorded on the positive print image spaced at '*a*' and '*b*'. Whereas, the '*H*' represent the height above the ground level. In this context, it is important to mention that there are two scales calculation i.e. the 'point scale' and the 'average or nominal Scale' for the vertical aerial photograph.

Point Scale is the ratio between the focal length of the camera and the difference in the height of aircraft at the time of exposure. Actually, the aircraft height is calculated as the height of point above mean sea level on which the aerial photograph taken. So, the point scale is calculated using the equation given as follows:

$$Scale = \frac{f}{H-h}$$

Where:

f = focal length of the camera
H = flying height/altitude of aircraft at time of exposure
h = flying height/elevation above sea level

Average or Nominal Scale is the ratio of the focal length of the camera lens and the aircraft height. Here, the difference between the height of the aircraft at the time of exposure and the height of all the points above mean sea level are taken into consideration. So, the average scale is calculated by using of the equation given as follows:

$$S_{avg} = \frac{f}{H-h_{avg}}$$

Where:

f = focal length of the camera
H = flying height/altitude of aircraft at time of exposure
h_{avg} = flying average height/elevation above sea level

For example, the elevation values as the maximum elevation, average elevation and minimum elevation of the terrain are given as 10,000, 8,000 and 6,000 ft. above sea level, respectively. The flying height of the aircraft above sea level in 20,000 ft. And, the camera focal length is 6 inches. So, calculate the scale of the vertical aerial photograph taken over variable terrain.

In this case, the height average is calculated of the variable terrain by using of the below given equation:

$$h_{avg} = \frac{Max\ Elevation + Mini\ Elevation}{2}$$

$$= \frac{10{,}000 + 6{,}000}{2}$$

$$= \frac{16{,}000}{2}$$

$= 8{,}000$ ft

So, the computed value of the Height Average (h_{avg}) is 8,000 ft.

Now, there is a need to in-put the above calculated height average values in the below equation for calculation of the average scale of the vertical aerial photograph as follows:

$$S_{avg} = 6'' / ([20{,}000]' - [8{,}000]')$$

$$= 6'' / [12{,}000]'$$

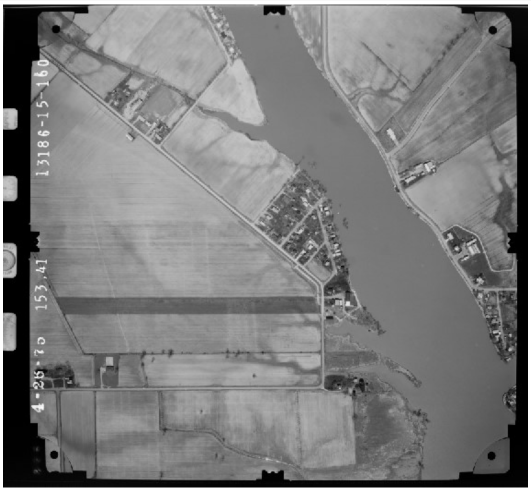
$$= \frac{6}{12{,}000 \; x \; 12}$$

$$= \frac{6}{144{,}000}$$

$$= 24{,}000$$

So, the average scale of vertical aerial photograph is calculated as 1: 24,000.

In this context, in order to work out the real-world landscape analyses, there is a need of the vertical aerial photograph with variable terrain, which is given below in the Fi. 14.



Source: Vertical Aerial Photograph, 1975was obtained from U.S. Geological Survey; and Reference Imagery of surrounding area of *Detroit River International Wildlife Refuge*was acquired from Google Earth Satellite Imagery 2018, Digital Globe, U.S. Geological Survey.

Fig. 14 and 15 : Vertical aerial photograph taken over undulating terrain with variable relief; and Reference imagery from Google Earth

For the above vertical aerial photograph, the approximate maximum elevation is 587 feet (179 meters) located in nearby the Little Swan Creek. The Detroit River is at an elevation of 579 feet (176 m) above sea level. The river drops only about 8 feet while entering into Lake Erie at 571 feet (174 m). In other words, the Lake Erie mean elevation is about 571 feet (174 m) above sea level. So, the maximum elevation, average elevation and minimum elevation of the terrain are 587 feet (179 m), 579 feet (176 m) and 571 feet (174 m) above sea level, respectively. The flying height of the aircraft above sea level is 3000 feet and camera focal length is 6.02 inches (152.85 mm). So, calculate the average scale of vertical aerial photograph taken over variable terrain.

The height average is calculated by using of the equation given as follows:

$$h_{avg} = \frac{Max\ Elevation + Mini\ Elevation}{2}$$

$$= \frac{587 + 571}{2}$$

$$= \frac{1{,}158}{2}$$

$$= 579 \text{ ft}$$

So, the calculated value of the Height Average (h_{avg}) is 579 ft.

In this context, there is a need to in-put the above calculated height average values in the below equation for calculation of the average scale of the vertical aerial photograph as follows

$$S_{avg} = 6'' / ([3{,}000]' - [571]')$$

$$= 6'' / [2{,}429]'$$

$$= \frac{6}{2{,}429\ x\ 12}$$

$$= \frac{6}{29{,}148}$$

$$= 4{,}858$$

So, the average scale or nominal scale of the vertical aerial photograph for the undulating terrain with variable relief as given above in the Figure 14 numerically calculated is 1: 4,858. Such kind of scale calculation helps in geospatial analyses of the different objects and features as obtained for real-world in the vertical aerial photograph for landscape's development.

2) Height Measurement based on Shadow Length of Object :

The height of an object or feature is calculated by measuring the length of shadow on the vertical aerial photograph. In fact, the sun's rays are basically parallel on vertical aerial photograph, hence the length of an object's shadow on a horizontal surface is directly proportional to its height. So, the trigonometry is involved which is a branch of mathematics that studies relationships involving lengths and angles of triangles. Such trigonometric relationship included in determining object height based on shadow length measurement which is schematically illustrated by the below given Fig. 16 as well as flowed by the equation as follows:

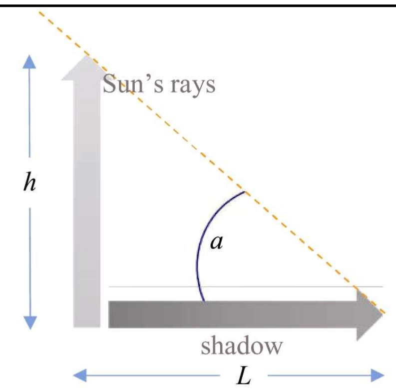


Fig. 16 : Measurement of height based on shadow length of the object or feature

So, the trigonometric equation used for height measurement of an object is propounded with detailed explanation as follows:

$$\tan\ a = \frac{opposite}{adjecent}$$

$$= \frac{height, h}{shadow, L}$$

Here, the tangent of angle *a* would be equal to the opposite side, *h*, over the adjacent side, which is the shadow length, *L*. So, all these elements are mathematically input into the trigonometric equation as follows:

$$\tan\ a = \frac{h}{L}$$

So, based on above height equation, it is solved with explanation as follows:

h = L x tan a

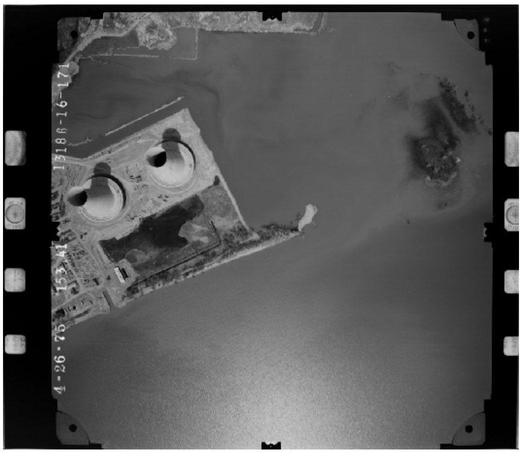
For instance, an object height is 172.75 ft. It casts a shadow onto level ground that is 0.241"in length on the aerial photograph. The scale of photograph is 1: 5,957 or 1" = 496.46'. So the shadow length on the photograph is 119.65 ft. The tangent of angle is calculated using above equation as follows:

$$\tan\ a = \frac{h}{L} = \frac{172.75'}{119.65'} = 1.44'$$

So, likewise the other shadow lengths on the aerial photograph can be measured and their height is multiplied by 1.44' to determine it's length. For example, the shadow of a tower is 59.1" onto level ground in the aerial photograph. Hence, the height of the tower is computed as follows:

h = L x tan a = 59.1' x 1.44 ' = 85.10'

However, it is also verified that the actual height of the tower is about to 85 ft. based on the measurement of the surveyor's information.



Source: Vertical Aerial Photograph, 1975was obtained from U.S. Geological Survey; and Reference Imagery of *Enrico Fermi II NPP* (Nuclear Power Plant), Newport, Berlin Charter Township, Monroe County, Michigan was acquired from Google Earth Satellite Imagery 2018, Digital Globe, U.S. Geological Survey

Fig. 17 and 18 : Vertical aerial photograph; and Reference imagery from Google Earth

In this context, the height of the objects of real-world is computed by measuring the length of shadow on the vertical aerial photograph as given in the Fig. 17.

So, the scale of aerial photograph on the basis of the Fig. 17 is calculated based on the above mentioned equation which is also used for scale calculation for the vertical aerial photograph as given in the Fig. 11. Hence, the vertical aerial photograph's calculated representative fraction or verbal scale is 1: 5982. In other words, a unit on the photo is equal to 5982 units on the ground of the real-world.

On the basis of the aerial photograph as presented in the Figure 17, the visual interpretation reveals that there are two important objects of the *Enrico Fermi II NPP (Nuclear Power Plant)* which is consisted by two towers. Each one of these two towers height is 400 ft. Besides this, each of these two towers individually cast a shadow onto level ground of which measurement is 0.866" in length on the aerial photograph. The scale of the aerial photograph as calculated above is 1: 5,982 or 1"= 498.50'. So the shadow length on the photograph is 405.80 ft. The tangent of angle *a* can be calculated using the below equation as follows:

$$\tan\ a = \frac{h}{L} = \frac{400'}{405.50'} = 0.986' \cong 1'$$

So, likewise the other shadow lengths on the aerial photograph can be measured and their height is multiplied by 1' to determine their length. For instance, the shadow of a tower is 400" onto level ground in the aerial photograph. Hence, the height of the tower is calculated as follows:

$$h = L \times \tan a = 400' \times 1' = 400'$$

So, it is also verified that the actual height of the second tower is 400ft based on the actual measurement information, on the one hand and the above calculated value from the aerial photograh, on the other hand. Both the towers of the nuclear power plant, the actual height and the height measurement based on the above trigonometric equation are the same. Thus, such kind of the vertical aerial photograph's objects analyses produces remarkable results for systematic interpretation and explanation of geospatial information for the landscape's development in real-time and proposes prospects for future development of the real-world.

Conclusions and Suggestions

Aerial photographs are obtained through an aircraft or other flying object. There are many platforms developed over the periods for aerial photography which include fixed-wing aircraft and the unmanned aerial vehicles or drones. So, latest advances in radio controlled models have made it possible for model aircraft to conduct low-altitude aerial photography. Miniature vehicles do not replace full size aircraft, as full size aircraft are capable of longer flight times, higher altitudes, and greater equipment payloads. They are, however, useful in any situation, but a full-scale aircraft would be dangerous to operate at low height. Vertical photographs are taken straight down with special large format cameras with calibrated and documented geometric properties. Aerial photography offers a simple, reliable, flexible, and inexpensive means of acquiring geospatial information. The transition from the analogue systems that formed the foundation for aerial survey in the 20th century to digital systems is now basically completed in the 21st Century.

The aerial photographs are used for the cadastral surveying and mapping purposes by the surveyors, foresters, geologists so on researchers and scientists for the betterment of humanity on this planet earth. However, aerial photograph have limitless applications with multiple functions in the fields of geography, geology, hydrology, ecology and environmental studies of the physical landscape, on the one hand and the rural, urban and regional studies of the cultural landscape, on the other hand. The aerial photographs have lots of prospectus for betterment of the humanity on this planet earth. The geospatial information are extracted and based on vertical aerial photographs which are analysed by application of the photogrammetric algorithms in real-time. So, the processed information results become easily accessible to the planners and policy makers for all round urban and regional developments of the landscape. However, the aerial photograph records the ever-changing natural and cultural features accurate geospatial information obtained from the earth's surface which are used for various planning and development purposes in real-time of the real-world. Consequently, in the present research, a number of photogrammetric methods and algorithms were devised and developed for the geospatial analyses of vertical aerial photographs of the real-world. All these newly invented methods and algorithms have been discussed in details as well as applied in the present research in form of the model building for development of landscape of the real-world.

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