Multi-Temporal Aerial Imagery for Sustainable Development of Africa

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Abstract

The enormous number of existing aerial photographs, together with satellite imagery, document the development of African environment for over 80 years – a document that is comprehensive, objective, and verifiable. Aerial photographic data are also unbiased and free from any ideological and political influence. Development trends are identifiable, not only for specific, isolated areas, but also regarding the reciprocal interactions of various trends whose potential effects are only revealed by them. A comprehensive analysis of time-series aerial imagery can significantly enhance our knowledge of the development and their causes over the last 80 years. This is evidence that should not be ignored, but on the contrary exploited to predict upcoming events and their consequences. Considering the increasingly complicated environmental issues, this paper calls to attention the potential contribution of historical aerial photography for trend detection and analysis, with specific attention to time periods and geographic areas where high-resolution satellite imagery was not available.

1 Introduction

Development in Africa can be separated between Colonial and Independent periods. In Africa, only after independence in 1950s the development effort started, since only by then measures could be taken to reach development goals. Multitude of agencies, from many different countries participated in proposing, implementing, and financing the development measures to be undertaken. Many of those agencies translated their knowledge and experience gained in their country into the situation of Africa, an area that they were not necessarily familiar with. This resulted in many different concepts being introduced, at a time when there did not exist national planning authorities that could evaluate and coordinate the different implementations with regards to the interests of the developing countries.

1.1 GeoDyn

GeoDyn is a new company; however, its personnel has experience dating back 50+ years in Africa. The founder of GeoDyn is also the founder of **MAPS geosystems**, a company that had carried out numerous aerial photography mapping projects in different parts of Africa during the period 1966 to 2007. Thus GeoDyn has rich first-hand experience and vast knowledge about the people, culture, and topography of Africa. More importantly, GeoDyn possesses extensive information about the technical specifications of the aerial photographs and the resulting topographic maps produced over many decades for different organizations in Africa.

Capitalizing on the rich experience of aerial photography in Africa and other parts of the world, the company today offers innovative technology and procedures to support the developments in Africa and help achieve its sustainable development goals. Geodyn can help African users unlock the full potential of geospatial data by emphasizing on its time attribute. The name GeoDyn denotes the dynamic nature of geospatial data and the company's tag line … *access to the What, Where, and When* also reflects the same.

2 Trends

Newton's first law states that every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force. This law applies to everything in nature. Left to itself, actions, procedures, developments, etc. follow a trend that may turn into a routine, a habit. This law could be paraphrased as "everything follows a trend as long as it is not influenced by an action."

Trends are the baseline of our actions and ambitions, they define the current norm. Trends can be followed, assessed, and modified but they must never be ignored. If they are not identified early, trends can turn out to be hazardous and treacherous. They lull us into complacency and make us blind to any thinking, if not noticed by us. But equally, trends, if identified, can point to where we will end up, right or wrong, and by understanding the consequence of past actions, help us make the correct decisions to go forward.

Trends must be identified, including their origin, their purpose and their consequences. This calls for trend awareness! We must look for them, analyze them and find out how they influence our planning, and to what extent.

2.1 Trend Analysis

Trend Analysis provides us with hindsight, an indispensable element for prediction, which is part of everything we engage in. Trends can be difficult to detect or identify as they do not happen suddenly but develop gradually. They start almost imperceptibly and tend to grow on us slowly. By the time they become apparent, their origin might no longer be traceable. They become routine and are simply ignored as 'a matter of fact'!. By then, they might be too late to be controlled, reversed, or stopped.

Trends are identified by monitoring some quantifiable measurements over time. In this way we gain evidence of slow-moving changes or processes, that under normal situations might appear static. Likewise, multi-temporal aerial photography, providing several measurements for the same location, may not have been established so far, nor examined. The analysis of time-series aerial photographs provides us with a unique possibility to identify a trend curve, pointing to its origin, as well as to the future outcome! (fig.) It steers us from the inception of an activity to its eventual culmination. This prediction of the trend's outcome is an important element for decision-making and it needs to be preceded by hindsight.

2.2 Trend Assessment

Though we cannot foresee the future, we can predict the most likely scenario. This applies equally well when we go on a holiday, when we choose the profession we want to train for, or when we design the water supply for a new township. Prediction requires reviewing the past in order to identify development trends and assess what factors they might be influenced by. Trend Analysis is an important prerequisite for predicting the circumstances prevailing at the time a projected measure is to take effect. It provides an important basis for planning and development projects. Prediction is an essential, all-encompassing planning element, needed right up to the time a decision must be taken, or action to start. Prediction must not simply rely on reports, but foremost on reliable, conformable and unbiased facts. In order to look ahead, we need to assess trends and actions in the light of current awareness.

3 Aerial Photography

An enormous number of existing aerial photography – and lately also satellite imagery – traces the development of Africa for over 80 years, impartially and free of any ideological or political influences. In addition, they are a testimony of our achievements, the ups as well as the downs.

3.1 Mapping from Aerial Photography

Aerial photography documents the state of the environment in an irrefutable way, at the time the photography was taken. This is done with high accuracy and reliability, compared to any other methods. Moreover, aerial photography depicts objects in their natural surroundings, which greatly enhances their identification and purpose. Aerial photography also shows details in their relative positions. Photogrammetry, the science of making measurements from photographs, can map these details with great accuracy.

We can map the environment as it existed at the time the photograph was taken. This applies not only to physical objects, like buildings, streets, fences etc. but also to objects or conditions derived from their positions on the ground relative to their neighborhood, e.g. railway stations, parks, industrial / residential / commercial zones, flooding, avalanche protection measures, water shortage, noise control measures, hazardous areas of all sorts, including their ease of accessibility and much more. All these elements can be extracted from aerial imagery and managed in a GIS.

Much of what we would like to know today had not been measured or predicted previously. Although much detail was extracted into maps by photo-interpretation of the original imagery, only a fraction of the information contained in the imagery was extracted. Moreover, the maps created were application specific containing limited details and much of this data has been lost, mostly because the imagery was not digitally captured or maintained.

3.2 Multi-temporal Aerial Photographs

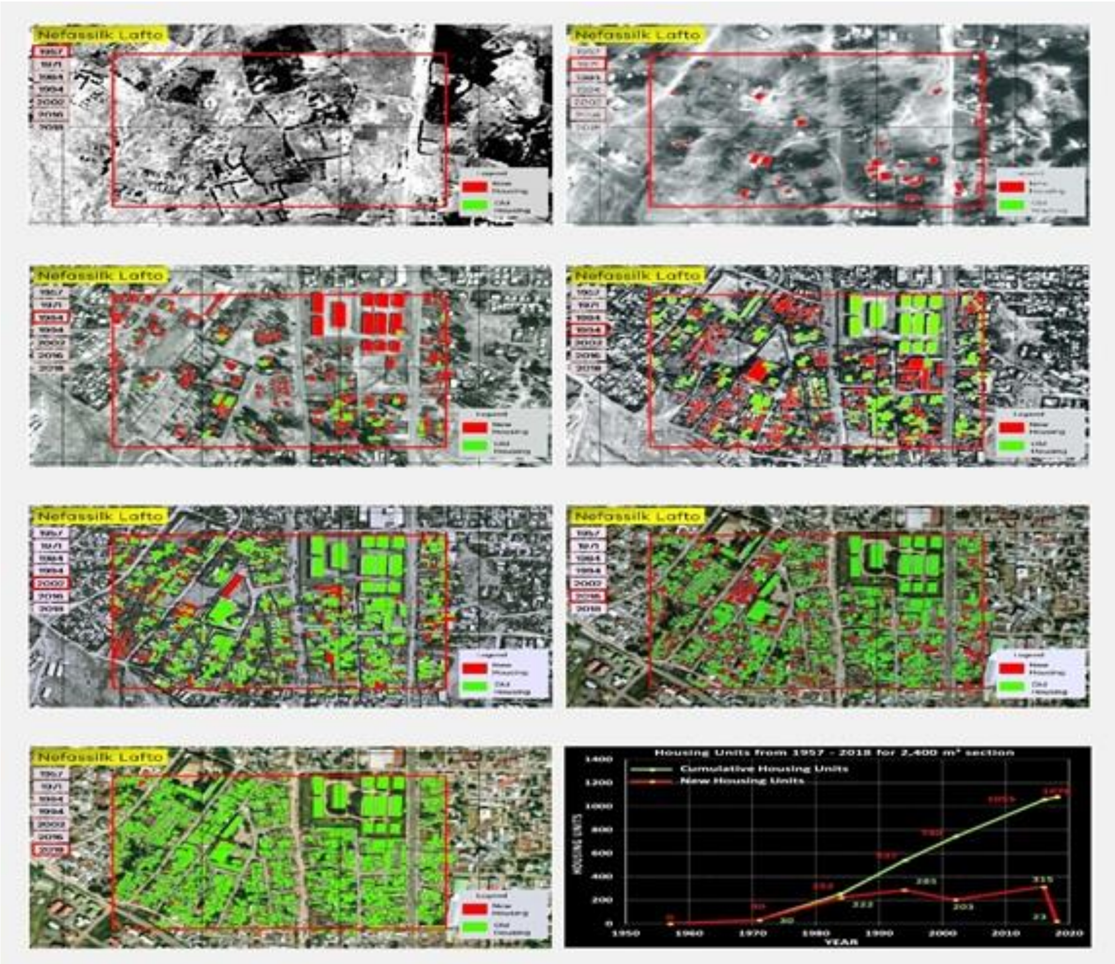


Figure 1: Multi-temporal imagery and trend analysis.
(Courtesy: Ethiopian Mapping Agency)

Development by definition involves the time factor. Developments do not happen, but are implemented over a period of time. Development trends must be recognized and assessed; and to assess trends our data must be time-related.

Location data with its time attribute makes analysis of spatial data very powerful. Hence multi-temporal aerial imagery is an important asset for planning. Time related spatial data portrays the dynamic nature of the changing landscape. From the time-series imagery, trends can be identified, not only for specific, isolated events, but also to reveal comprehensively the reciprocal effects and influences of actions that have been taken.

The concept of using multi-temporal aerial photography is not new. However, up to now, the required data have not been available nor accessible, at least not to the extent as is required to reach conclusive results. In view of the enormous data volumes involved, only computerized analysis can achieve the trend identification.

3.3 Archives of Aerial Photographs

Worldwide, a conservative estimate of the number of aerial photography frames runs into hundreds of millions. For instance, the US Department of Agriculture (USDA) holds in its archives over 40 million frames, and the US National Security Agency (NSA) holds an archive of over 25 million frames. The US National Archives (NARA) holds multiple agency-specific archives, including a globally-distributed archive of 28.5 million trimetrogon photo triplets, an estimated half of which were captured by the US Defense Intelligence Agency between 1940 and 1945. Most photos were captured at 1:40,000 scale and cover 10 km wide swaths. In most countries in the world, the national and state mapping agencies also have archives of aerial photos collected at decadal frequency covering their lands.

Converted into digital form, this data alone would allow us to look at how our world has changed over the last 80 years. In combination with satellite imagery, this would provide us indisputable evidence for answering questions, for instance, in the much disputed topic of climate changes. Aerial photography also contributes to document a Nation's heritage. For its safeguard, it is essential that this data become easily accessible, something that can only be assured by converting them into a digital format. However, the bulk of this aerial photography is presently being stored in archives all over the world, still awaiting to be converted into a digital format. To date, the lossless conversion cost of about $10 per frame has made creating a digital version an impossible undertaking. The required equipment for such conversion has become scarce and no longer available for high-volume processing.

Regardless of any immediate need, it is inconceivable that this data remains inaccessible. Already many of these archived images have been lost due to organizations not realizing their value or not being able to adequately maintain the film in the required large cooled spaces. In the foreseeable future the necessary personnel with the skills to handle the film might no longer be in a position to do so. Apart from that, with age, some aerial films deteriorate to a stage where they can no longer be safely handled, e.g. the Cellulose Nitrate Film which, over time, potentially becomes explosive.

3.4 Digitizing of Aerial Photographs

About 30 years ago, with the introduction of digital photogrammetry, there was a considerable drive for digitizing of aerial photographs to enable digital stereo compilation of the films, since digital cameras were not performant enough. Since about 15 years, digital aerial imagery and satellite imagery dominate spatial data acquisition, pushing the need for analog to digital conversion for operational purposes into the background. This freed the established capacity to digitize the films from the archives, but it soon became apparent that the established scanning capacity was insufficient to cope with bulk digitizing of archived aerial films. This was aggravated by (a) the slow conversion rates of 3 to 6 frames per hour, (b) photogrammetric scanners no longer being produced, (c) the rising maintenance costs of the few remaining photogrammetric-quality digitizers.

Today it is estimated that less than 30 photogrammetric scanners are still in production worldwide. This has made analog to digital conversion of aerial film even less affordable. In addition, procedures for automatic georeferencing and data extraction from aerial photographs were not in sight, making the digital imagery hard to use. This has led most organizations discontinue the systematic digitization of their aerial photography archives. This situation prevails in countries almost all over the world. As a consequence, it is estimated that over 90% of all existing aerial films still await to be digitized.

4 Paradigm Shift in Digital Conversion

Presently, GeoDyn has brought in a fundamental change in the approach and practice of how the large volume of archived aerial films are converted to digital format in a high-speed and highly-automated production environment. The resulting digital aerial imagery is geo-referenced and is loaded into a Data Cube structure to create analysis ready data that can be easily accessed and analyzed using computerized tools.

4.1 Fast and Cost-effective Digitization

In spring 2019, after a development of over three years, GeoDyn released its **Prompt Scan 3,** the latest system for analogue-digital conversion of aerial films. This new equipment and procedures shorten the time for conversion by 50 times and reduces the cost by 10 times. For example, 1,000 days of traditional conversion are shortened to 20 days and the cost of $100,000 reduced to $10,000. This new technology makes it economically feasible to digitize millions of frames with 15 or even 11 micron geometric resolution and 14-bit radiometric resolution so that the full information content of aerial films can be faithfully captured and the resulting data made easily accessible. This indeed is a paradigm shift in the analog-digital conversion practice of aerial photographs.

4.2 Automated Ortho-rectification and Geo-referencing

Technological development in massively parallel image matching and bundle block adjustment, the existence of world-wide availability of accurate high-resolution image base maps and digital terrain models, along with refined procedures now enable efficient determination of the interior and exterior orientation of all imagery, even when only limited photo indexes exist. By combining the correlation between multi-temporal imagery, the relative and absolute accuracy of the georeferencing is improved and can be refined in an iterative manner.

These time-series digital image maps, provide detail-matching accuracy that can be used for interdisciplinary trend analysis and to evaluate the extent of mutual interference. These will feed a wide range of applications requiring instant review and analysis of the imagery, with easy access to the full information content and the metadata.

4.3 Analysis Ready Data in Data Cubes

The decreasing cost of earth observation (EO) imagery as well computing technology over the last decade have enabled a new approach, broadly referred to as a Data Cube, to organize, manage, access, analyze, and share huge volume of imagery data. Data cubes are large collections of multi-temporal, multi-spectral, multi-variate data sets typically consisting of Analysis Ready Data (ARD) of EO imagery. Big Data tools facilitate meeting the Volume, Velocity, and Variety challenges of imagery data produced by the large number of earth observation satellites, which continuously generate and transmit a variety of sensor data types. Thanks to the inexpensive cloud infrastructure and storage facility, the cost of the storage and dissemination of huge amount of imagery data is currently highly affordable, with the cost continuing to drop.

The geo-referenced imagery can be served through the web as dynamic image service that provides access to the full information content and the metadata of the imagery.

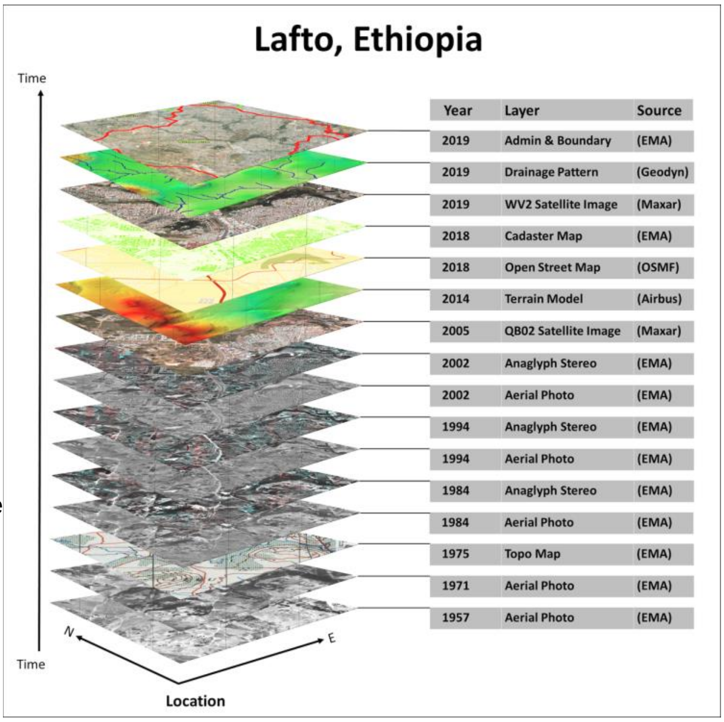


Figure 2: Imagery Data Cube

4.4 Automated Information Extraction

With the rapid advances in Object-Based Image Analysis (OBIA) technology involving Artificial Intelligence and Machine Learning that can automate both the identification and classification of objects from the scanned aerial imagery, it has become possible to prepare detailed land-cover maps of large areas and analyze the patterns and effects of long-term changes, such as the expansion of urban areas and deforestation.

Mapping organizations that have maintained maps captured from the imagery can utilize the existing mapping as training data to enable the image analysis algorithm to quickly learn and classify features with higher accuracy. This results in attributed temporal (i.e. time-series) map layers, providing inter-disciplinary spatial data in GIS, thereby applicable in many conceivable domains. All features are referenced geographically and temporally, i.e. spatially as well as in time. Thus, a complete inventory of all land features can be created automatically. This procedure not only identifies physical objects, but also compounded (derived) objects, such as: residential areas, orchards, vine yards, football fields, railway stations, areas subject to inundation, hazardous zones, etc.

4.5 Spatial Insights

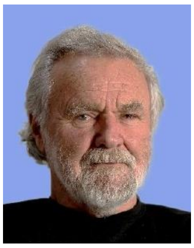
Big Data processing technology along with improvements in spatial data analytics are enabling rapid trend detection modeling and prediction. The techniques being developed enable the detection of trends and anomalies. By combining millions of observations with many other geospatial variables such as distance to roads and towns, distance to transportation corridors, terrain form, weather and seasons, the algorithm employs Machine Learning to determine correlations between possibly unforeseen events to determine the trends, the change in the trends and the influencers of these trends. Because of the huge amount of multi-temporal data involved, a very high statistical accuracy can be achieved. These models can then be extrapolated to predict the future state as well analyze the influence that the newly planned actions may have.

5 Conclusion

Huge amounts of historical aerial photographic data, complemented by more recent satellite imagery, provide irrefutable evidence of developments of the past and thereby improve on the prediction for the near future. This becomes possible not only because of advances in photogrammetric procedures and image analysis involving AI and Machine Learning, but notably because of new analog-digital image conversion technology that now overcomes the bottleneck in the conversion of the huge number of aerial photographs held in the archives of different organizations.

On this occasion, I am addressing the African community that has the mandate to preserve the authoritative data sources that different nations have spent billions of dollars on. With the recent emphasis on the effects of climate change and global warming issues it is recommended that the GIS community actively involve itself in preserving the unique heritage of crucial interest for planning and development. As a community we can contribute in a joint effort to work towards the UN Sustainable Development Goals (SDG) as per Agenda 2030. Our generation owes it to the next to ensure that everything that has happened since the turn of the twentieth century is accurately recorded so that we can learn from the past, helping us to make better decisions moving forward.

About the Author



Rolf Becker's 50+ years of aerial mapping and GIS experience has been predominantly in the Middle East and Africa, but also spans the Far East. He has been actively involved in both the fast-paced, modern development planning projects and implementations of the oil-rich Gulf States and in the markedly different practices of Africa.

With the hindsight gained over fifty years in these contrasting development environments he is at a vantage position to evaluate the historical and current situations in the light of today's technology and developments.

His recent creative work culminated in a "breakthrough" device for the high-speed digitization of aerial films. This led to the founding of GeoDyn Technology and the development of an automated turn-key system for the provision of analysis ready data of multi-temporal aerial imagery. His innovations and technical achievements at the former company he founded (MAPS geosystems) included an automated digital mapping system, pioneering of GPS-controlled global aerial triangulation, the imagery pre-processing and georeferencing system – all of them eventually becoming industry standards worldwide.

Passion for innovation drives the thoughts and activities of the author.

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