Multi-Temporal Aerial Imagery for Automatic Mapping and Trend Analysis

ROLF BECKER[1]

Abstract: The enormous number of existing aerial photographs - partly also satellite data - document the development of our environment for about 100 years, verifiable, unbiased and free from any ideological or political influence. Development trends are identifiable, not only for specific, isolated areas, but also regarding the reciprocal interference of various trends whose potential effects are only revealed by them. A comprehensive analysis of time-phase aerial images can significantly enhance our knowledge of the development and their causes over the last 100 years, evidence that should not be neglected, but on the contrary help us to predict up-coming events and their consequences. Considering the increasingly complicated environmental issues, this paper to calls attention to the potential contribution of aerial photography for trend identification and analysis globally and with specific attention to periods and areas where Satellite images are not available.

1. Introduction

Newton's 1st Law of Motion: "Every object in a state of uniform motion tends to remain in this state unless an external force is applied to it." This law applies to everything. Left by itself, action, procedures, development, etc. follow a trend that may turn into a routine, a habit. The law could be rewritten as 'Everything follows a trend as long as it is not influenced by another trend".

Trends are the baseline of our actions and ambitions, they define the current norm. Trends can be followed, set, modified or whatsoever, but above all, they must not be ignored. Trends can be dangerous and deceiving, in particular if they have not been identified. Having not come to our attention, they lull us into complacency and make us blind to lateral thinking. But equally, trends if identified point to where we will end up, right or wrong and by understand the consequence of past actions help up make the correct decisions going forward.

Trends must be identified, their origin, their purpose and their consequence. This calls for Trend Awareness! We must search for them, analyse them and find out how they influence each other, and to what extent.

Trend Analysis either conscientiously or sub-conscientiously 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 but develop. They start almost imperceptibly and have a tendency to grow on us. By the time they become apparent, their origin might be no longer traceable. They get turned into a routine and are simply neglected as 'a matter of fact!'. By then, it might be too late to reverse, or even stop a trend.

Trends are identified by analysing some quantifiable measurements over time. In this way we gain evidence of slow-moving action or changes that under normal conditions appear to be static. Likewise, multi-temporal (time-series) aerial photography can provide these data points may so

[1] Geodyn Technology,Suite 623, Building 6EA, DAFZA, Dubai, UAE, E-Mail: rolf.becker@geodyn.com

far have not been identified, nor examined. The analysis of this photography provides a unique possibility to identify a trend curve, pointing to its origin, as well as to the time to come! Prediction is the ultimate decision-making element. It accompanies us from the perception of an activity to its final (eventual) implementation (realization). Prediction need is to be preceded by Hindsight.
As are cannot foresee the future, we must predict the most likely scenario. This applies equally when we go on holiday, choose the profession we want to train for, or design the water supply for a new township. Prediction requires to review the past in order to identify development trends and assess by what 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, confirmable and unprejudiced evidence. In order to looks ahead, we need to assess trends and actions in the light of current awareness.

2. Aerial Survey, Photogrammetry

An enormous number of existing aerial photography – and lately also satellite imagery – trace the development of our environment for over 100 years, impartially and free of ideological or political influences. In addition, they are a testimony (the witness) to our achievements, the ups and the downs. From these imagery trends can be identified, not only for specific, isolated events, but they reveal comprehensively the reciprocal effects and influences of actions that have been taken.
Aerial Photography documents the state of environment at the time the photography was taken in an irrefutable way. This can be done with higher accuracy and reliability, than by any comparable mean. Moreover, Aerial photography depict object in their natural surroundings, which greatly enhances their identification and purpose. Aerial Photography shows details in their relative position. Photogrammetry can map this detail with great accuracy.
We can map the environment as it existed at the time the photograph has been taken. This does not only apply to physical objects, like houses, streets, fences, but can also identify objects or conditions derived from their relative position and neighbourhood, e.g. railway station, parks, industrial/ residential/ commercial zones, flooding, avalanche protection measure, water shortage, noise control measures, danger area of all sorts, accessibility and much more. All these elements that can be extracted form 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 photointerpretation from the original imagery, only a fraction of the information in the imagery was extracted. Moreover, the maps created were application specific with limited details and much of this data has been lost, mostly because it was not digitally recorded or maintained.
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 quantities required, only computerized analysis achieve the trend identification.

Worldwide, a conservative estimate of number of aerial photography frames is hundreds of millions. For instance, the US Department of Agriculture holds in its archives over 40 million frames, and the US National Security Agency (NSA) holds an archive of over 25 million. The U.S. 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 U.S. Defence Intelligence Agency between 1940 and 1945. Most photos were captured at 1:40,000 scale and cover 10 km wide swaths (Fig. 1, LEFSKY 2018). In most counties in the world the state and national mapping agencies also have archives collected at least decadal frequency covering their lands.

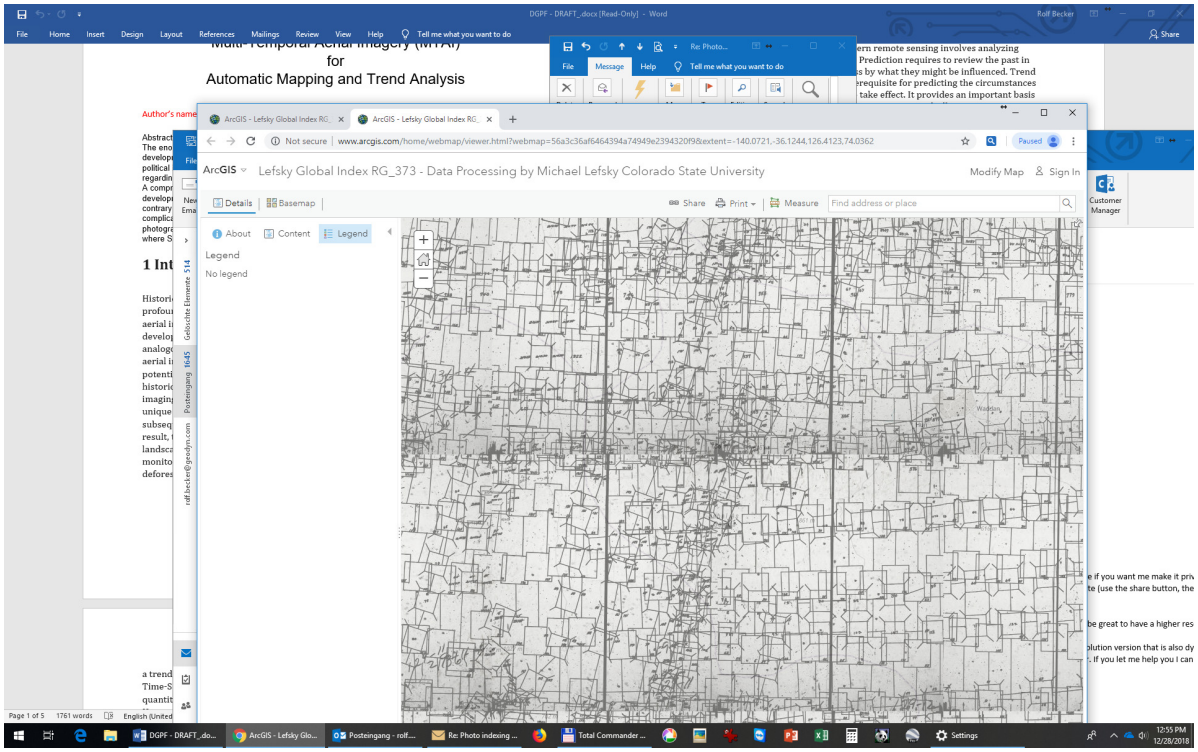

Fig. 1: Section of NARA Photo Index (Approx. 250 frames out of 28 million)

Converted into digital form this data alone would let us to look at how our world has change over the last 80 years. In combination with satellite imagery, this would provide us indisputable evidence for answering question, for instance in such 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 accessible, something that can only be assured thought 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 bulk processing.

Regardless of any immediate need, it is unconceivable that this data remains inaccessible. Already many of these archived images have being 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 personal with the skills to handle the film might no longer be in a position to do so. Apart from, that with age some aerial film deteriorates to the stage where they can no longer be safely handled, e.g. the Cellulose Nitrate Film which over time potentially become explosive.
About 30 years ago, with the introduction of digital photogrammetry, there was a considerable drive for digitizing of aerial photography to enable digital stereo compilation of the films as digital cameras were not performant enough. Since about 15 years, digital cameras and satellite imagery dominate spatial data acquisition, pushing the need for analogue/digital conversion for operational purposes into the background. This freed the established digitizing capacity to digitize the film 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 raising maintenance costs of the few remaining photogrammetric quality digitizer. Today it is estimated to be less than 30 photogrammetric scanned still in production worldwide. This has made analogue to digital conversion of aerial film even less affordable. In addition, procedures for automatic georeferencing and data extraction from aerial photography were not in sight making the digital images hard to use. This has led to most organizations discontinued to systematically digitize their Aerial Photography Archives. This situation prevails in countries almost all over the World. As a consequence, estimate over 9O% of all aerial films still await to be digitized.

3. By today, this scenario has drastically changed

3.1 Analogue/digital Conversion

In spring 2019, after a development of over three years, GeoDyn is releasing Prompt Capture GenTwo. This new equipment and procedures shorten the time required for Analogue/Digital conversion 50-fold and reduces the cost by an order of magnitude. This will provide the economic ability to digitize millions of frames per year with a resolution of 15micron, high geometric accuracy and 14bit dynamic range where the full information content of aerial film can be permanently captured and made accessible. This alone can be considered a paradigm shift.

3.2 Automated Georeferencing

Technological development in massively parallel image matching and bundle block adjustment, the existence of global, accurate high-resolution image basemaps and digital terrain models along with refined procures now enable efficient determination of the interior and exterior orientation of all imagery, even when only limited photo indexes exit. By combining utilizing the correlation between multi-temporal imagery that relative and absolute accuracy of the georeferencing is improved and can be iteratively refined. Inexpensive cloud storage and infrastructure has made storage and dissemination of imagery affectable with the cost of storage continuing to drop

3.3 Time Series Image Maps

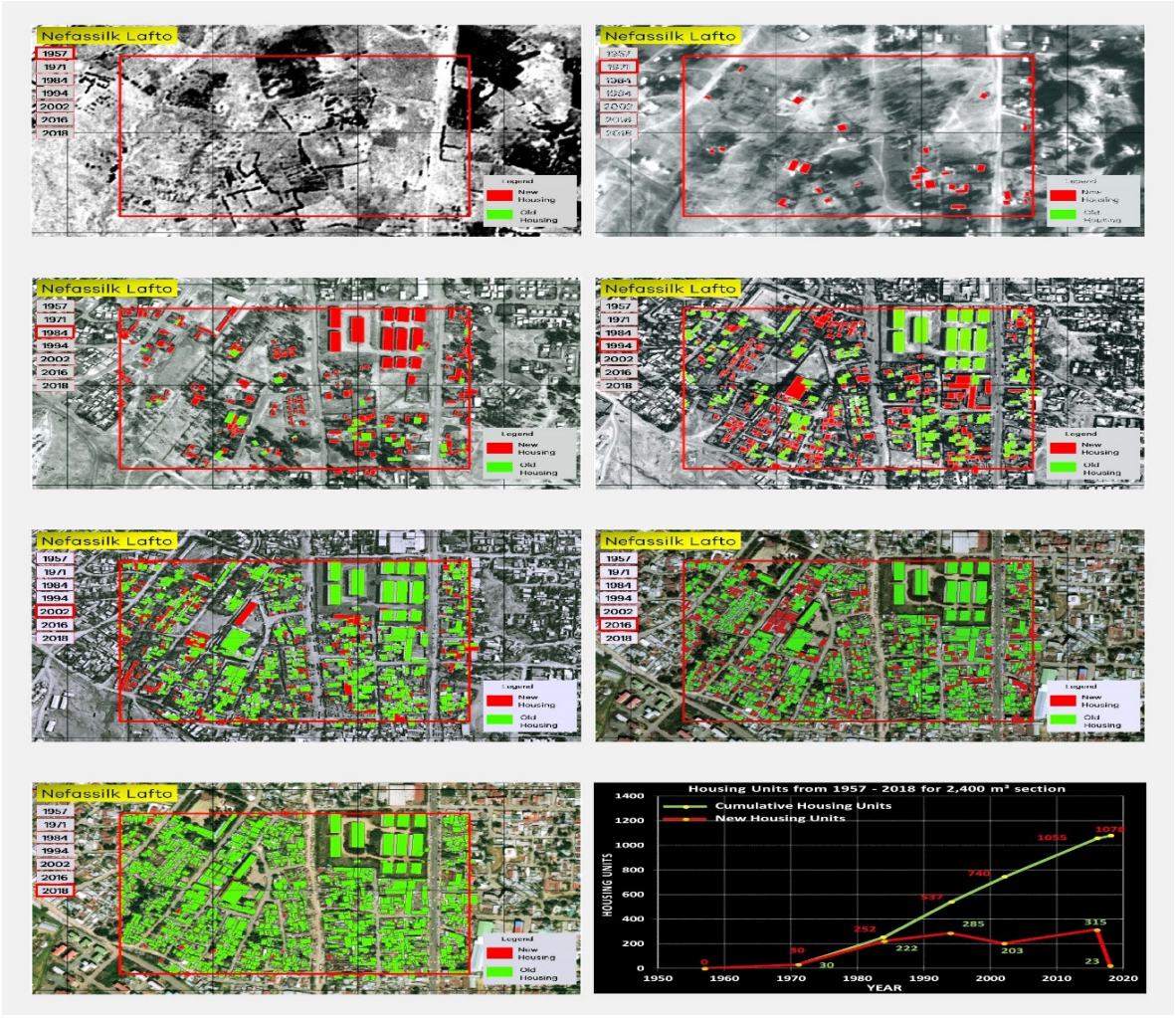

Fig. 2. Multi-temporal imagery and trend analysis of Lafto. Courtesy: Ethiopian Mapping Agency

The georeferenced imagery can be served through the web as dynamic image service that provides access to the full information content and metadata of the imagery. These time-series of digital image maps, provide detail-matching accuracy that can be used for interdisciplinary trend analysis and to evaluate the extent of mutual interference (Fig. 2). These will feed a wide range of Apps for instant review and analysis of the imagery access to the full information content and metadata of the imagery. These time-series of 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 Apps for instant review and analysis of the imagery.

3.4 Automatic (vector) Image Classification and Object Detection from Aerial Imagery

It is to be foreseen that within a few years procedure will become available for the automatic feature identification using Artificial Intelligence. The rapid advance of deep learning for spatial application is resulting in machine learning that can automate the both the identification of objects from scanned aerial imagery as well as change detection and the inference of land use. Mapping organizations that have maintained maps captured from the imagery can utilize the exiting mapping as training data to enable the algorithm to quickly learn and classify feature with higher accuracy. The results are attributed temporal (i.e. Time-phased) map layer, providing inter-disciplinary spatial data in GIS, thereby applicable in many conceivable domains. All features are referenced spatially, i.e. geographically as well as temporally. Thus, a complete inventory of all objects can be created automatically. This procedure does not only identify physical objects, compounded (derived) definitions, such as: danger zone, residential area, orchard, vine yard football field, railway station, areas subject to inundation, etc.

4. Spatial Insights

BigData processing along with improvements in spatial data analytics are enabling the rapid trend detection modelling and prediction. The techniques being developed enable the detection of trends and anomalies. By combining the millions of observations with many other geospatial variables such a distance to roads and towns, terrain form, distance to transportation corridors, 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. Based on the huge data volume, a very high statistical accuracy can be obtained. These models can then be extrapolated to predict future state as well the influence newly planned actions may have.

5. Conclusion

Huge amounts of aerial photography, recently complemented by satellite imagery, can 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 advanced in photogrammetric procedures and image analysis involving AI and Mechanical learning, but notably, because new analogue/digital image conversion technology now overcomes the bottleneck in the conversions of the huge number of aerial photographs held in archives all over the World. With emphasis on the climate change problematic it is recommended that the Photogrammetric Community involve itself in this thematic.

At this occasion, I am not addressing this audience as Austrians, Germans or Swiss, not even as Europeans, but as a Community that has the mandate to maintain the authoritative data sources that our nations have spent billions on. As a community we can contribute through Aerial survey in a joint effort to work towards the UN Sustainable Development Goals (SDG) as per Agenda 2030 adopted by all UN Members in 2015 and reiterated during the United Nations Geospatial Information Congress last December in Deqing/China. Our generation owes it to the next to ensure

all that has happened since the turn of the twentieth century is appropriately recorded so we can learn from the past helping us to make better decisions moving forward.
Digital, multi-temporal (time-series) images from Europe, the US, the Middle East, and many African countries are featured in the article, and may be provided interested parties to prospective students for study purposes (images samples will become accessible over the net).

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