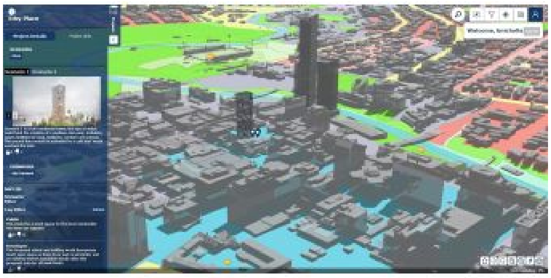
MODERN MAPPING SYSTEMS AND TECHNIQUES

The Relevance of Aerial Mapping in 2019 and Beyond




Government of India
Ministry of Science & Technology
Survey of India

PROCUREMENT OF NON-CONSULTANCY SERVICES UNDER ICB

for

Provision of services for Acquisition, Processing and Delivery of DEM and Digital Ortho Image

Project: NATIONAL HYDROLOGY PROJECT

Employer: Surveyor General of India, Survey of India, Dehra Dun

Country: India

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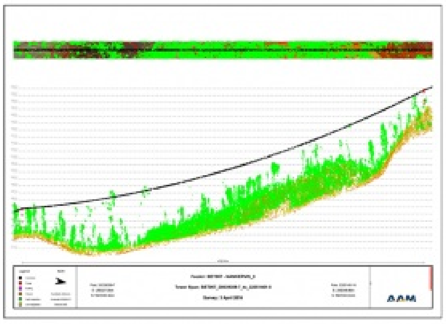
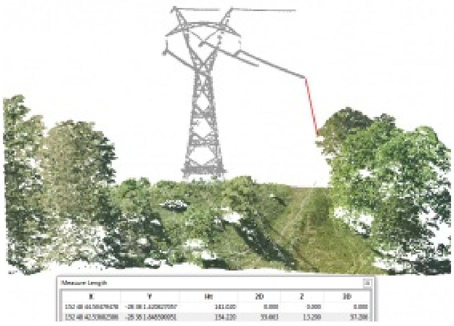
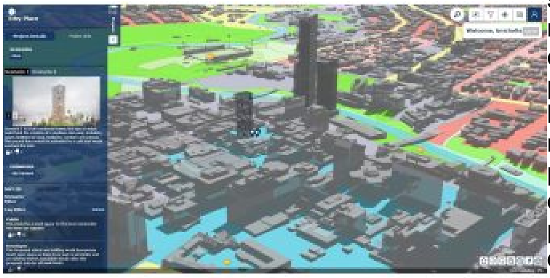




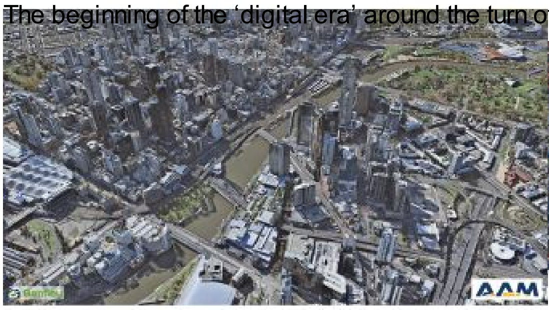


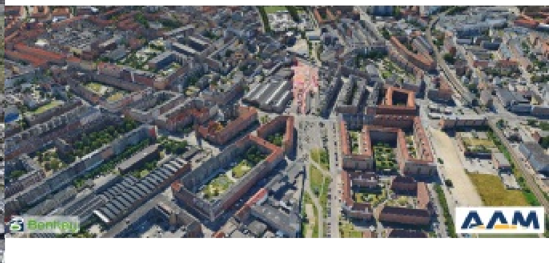
Reality 3D models, Lidar points clouds, superhigh-resolution aerial imagery and artificial intelligence from aerial imagery… these are just a few of the products derived from aerial mapping that the GIS sector takes for granted in 2019. Despite the plethora of high-resolution Earth observation satellites and the exponentially increasing impact of unmanned aerial vehicles (UAVs or 'drones') on the aerial mapping sector, most large and medium-scale ‘topographic’ or GIS map data is still derived from manned aircraft, whether fixed-wing or rotary. But the multitude of systems and processes can make selecting the correct aerial mapping technology a complicated and confusing process. This article takes a brief look at the latest aerial mapping systems and processes, along with the ever-expanding range of products and services derived from such systems.

The development of aerial mapping from manned aircraft can be largely traced back to military applications developed between the First and Second World Wars. From the 1950s onwards, photogrammetric mapping from large-format aerial film cameras became commonplace in civilian life, as governments and (to a lesser extent) the private sector adopted photogrammetry for small and medium-scale topographic mapping. Entire continents were mapping using the specialized film cameras and optomechanical ‘stereo plotting’ machines developed by companies including Wild (Leica), Zeiss and Kern.

Figure 1: Survey of India procurement request for aerial mapping services.

The beginning of the 'digital era' around the turn of the 21st century saw the commercial introduction of airborne Lidar systems





that directly measured thousands of ground points per second, along with the move to fully digital cameras and high-powered computers for data processing. New digital workflows saw the previously under-utilized ortho-rectified photo map (orthophoto) rapidly evolve to become a 'de facto' base map, especially for large-scale GIS and mapping applications. The last decade years has seen the development of more and varied airborne sensors and downstream digital production. Data capture and production is faster and more cost-effective than ever. Aerial mapping and the multitude of derived products mean that users have more options to map, measure, visualize and interpret the natural and built environment than ever before.

Imaging Sensors

Today's aerial cameras can capture hundreds of megabits of data per second, with resolutions ranging from 70cm to 1-2cm and coverages of up to 1,000km per hour. Aerial cameras come in a range of configurations, from conventional vertical-looking cameras to sweeping and push-broom sensors (similar to satellite imaging sensors), vertical and oblique configurations and focal lenses supporting high and low-level aerial mapping applications. Most modern aerial camera sensors incorporate an integrated positioning system that provides extremely precise absolute camera position (X,Y,Z) and camera orientation (pitch, roll and drift angle) information for each camera exposure (image). The integration of high-quality positioning systems from companies such as Applanix with its POS AV range provides a direct georeferencing ability that dramatically reduces the need for ground control and test points to accurately 'position' the aerial survey. Many aerial cameras also incorporate a gyro-stabilized mounting system that enables the aerial camera system to maintain a consistent (almost perfectly stable) orientation, irrespective of the angle of the aircraft. Such systems help to improve the quality of aerial imagery as well as the downstream data processing.

Figure 2a and 2b: Airborne Lidar data for powerline mapping and monitoring.

The majority of modern aerial camera systems are still mounted in either single or twin-engine, manned, fixed-wing aircraft. In most cases, specifically modified aircraft are required (i.e. the aircraft has a camera 'hatch' cut into its base where the aerial camera system is mounted), although some newer aerial camera systems – such as the Simplex aerial camera – can be externally mounted. Smaller systems such as PhaseOne and MIDAS aerial camera systems can also be mounted in helicopters. Whilst copters are generally more expensive to operate than fixed-wing aircraft and generally do not have the same flying speed (and hence capture speed), they are suitable for small-area projects or linear aerial mapping projects such as power lines or road and railway line surveys.

Figure 2a and 2b: Airborne Lidar data for powerline mapping and monitoring.

Most commercial aerial camera systems incorporate proprietary software (and sometimes firmware) for pre-processing and initial georeferencing of the captured imagery, e.g. Leica HxMap, VisionMap LightSpeed and Vexcel UltraMap. Once pre-processing of the imagery is complete, there are numerous software packages and Software as a Service (SaaS) solutions that further process the aerial imagery into derived products, e.g. BAE Systems Socet Set, Trimble Inpho and Simactive's Correlator 3D.

Vertical Image Sensors (Aerial Cameras)

Despite the large variety of aerial sensors now available, the vertical aerial camera capturing overlapping (stereoscopic) imagery remains the most common aerial imaging system in use. The general applications range from wide-area imaging and mapping, right down to very-high-resolution, small-area and linear (corridor) mapping.

Wide-area Imaging Sensors

Large-area, medium to high-resolution aerial photography continues to be a large part of the aerial imaging market. Much of this wide-area image capture supports national or regional government mapping programmes, although in most countries the aerial capture work is largely undertaken by the private sector. Applications for wide-area mapping include traditional topographic mapping, border protection and homeland security, agriculture and forestry monitoring, generation of digital elevation models

(DEMs) for flood plain and water catchment management, for instance, as well as land tenure and land use mapping. In developing countries, wide-area mapping projects are often funded by donor agencies such as The World Bank or regional development banks. Examples of wide-area aerial mapping projects include the mapping component of the Indian National Hydrology project managed by the Survey of India (see Figure 1) and the US government's National Agriculture Imagery Program (NAIP).

Figure 3: Singaporeâ€™s â€˜Virtual Singaporeâ€™ project is based on a framework of highly accurate 3D city models built from aerial mapping.

Modern wide-area sensors collect at higher resolutions than satellite imagery (anywhere from 5cm to 70cm) and are capable of covering thousands of kilometres per hour. Wide-area vertical sensors typically acquire imagery across the three visual spectral bands (RGB) as well as the near-infrared spectral band. These aerial sensors typically incorporate lenses with a relatively short focal length, allowing for flying heights of up to 3,000 to 4,000m above ground level. The relatively short focal length provides a wide field of view which – coupled with very large image sensor arrays – facilitates very rapid, large-area collection. For example, the UltraCam Condor captures a 9km swath width at 25cm image resolution which equates to roughly 800km^2 of coverage per hour. Sensors in this category are typically supplied by the traditional aerial camera vendors and include the Leica ADS100 and DMC III and the Vexcel UltraCam Condor.

High-resolution Imaging Sensors

Small-area, high-resolution (7.5cm to 20cm) and very-high-resolution (< 7.5cm) aerial imaging has exploded in popularity over the past ten years. Ever-higher-resolution digital sensor arrays, digital motion compensation, decreasing sensor size, weight and cost, and ongoing exponential increases in computer processing and storage mean that the capture and processing of high-resolution aerial imaging has never been easier or more affordable – not to mention the impact of drones on this market segment.

Applications for high-resolution aerial mapping include both area-based (e.g. city-wide mapping or full-site mining survey) projects and linear-based ones (e.g. existing roads, railways or power lines or planned linear infrastructure). As per wide-area aerial imaging, the (very) high-resolution digital orthophoto or orthomosaic has become the de facto base map or product for high-resolution aerial imaging. Applications for this sector include municipal mapping for engineering, town planning and asset management, maintenance of existing infrastructure and planning for new infrastructure (e.g. roads, rail, pipelines, renewable energy projects), mining, quarry and stockpile mapping, forestry and agriculture, etc.

The aerial sensors available include the traditional aerial mapping vendors (e.g. Leica and Vexcel) along with many other players including VisionMap with the A3 Edge sensor that combines very high resolution with extremely rapid data capture rates. In the past few years, we have seen the emergence of companies such as PhaseOne, whose very-high-resolution cameras can be used as standalone camera systems or can be used by other system integrators to configure custom camera systems such as the MIDAS oblique camera system.

Figure 4: The Urban Pinboard application is based on highly detailed 3D models built from aerial mapping (www.urbanpinboard.com).

Oblique Image Sensors (Aerial Cameras)

An increasing number of 'oblique' aerial camera systems have been introduced over the past decade. Traditional oblique camera systems involve mounting a number of different lenses on a single camera mount, with each camera typically mounted at an approximate 45-degree angle to the horizon along with one conventional, vertically mounted lens. The additional oblique images are useful for projects such as urban asset mapping and construction of 3D city models.

Over the past three years, the rapid emergence of 3D mesh modelling software and systems has produced an increased demand for oblique camera systems, since traditional vertical camera systems do not provide the 'look angles' or multiple views of the same point on the terrain surface required for successful 3D mesh modelling. Current systems include conventional oblique cameras by Vexcel and MiDAS as well as 'swinging' oblique systems such as the Simplex system.

Lidar Sensors

The emergence of airborne Lidar sensors in the early 2000s has revolutionized aerial mapping. Lidar sensors 'shoot' hundreds of thousands of laser pulses per second to the ground, effectively providing hundreds of thousands of direct distance measurements per second. When combined with a direct georeferencing system, these direct distance measurements allow the very rapid creation of digital terrain models (DTMs) and digital surface models (DSMs). The ability of the Lidar system to measure multiple laser returns means that airborne Lidar can even produce terrain models in thick vegetation, as some laser points inevitably reach the ground. The multiple return effect also provides the ability to measure multiple surfaces simultaneously, such as forest canopy or powerlines along with the ground surface. Most Lidar systems also provide an intensity value for each laser point, which can help to interpret from which type of surface or vegetation the laser beam is reflected.

Figure 5: 3D reality mesh model of Melbourne, Australia, built from VisionMap A3 imagery and Bentley's ContextCapture software.

Like aerial imaging sensors, most airborne Lidar sensors are now optimized for either wide-area coverage or small-area or corridor mapping coverage. Although more and more suppliers are emerging, the major suppliers of airborne Lidar systems remain Leica, RIEGL and Optech. Each supplier provides a range of instruments, varying in power, Lidar pulse rate, scan angle and scan rate, flying heights and weight/size, to suit a variety of applications and platforms. Airborne Lidar sensors can be mounted in fixed-wing and rotary platforms, with rotary platforms being more widely used than fixed-wing ones in aerial imaging applications, particularly in small-area and corridor applications. Most modern airborne Lidar sensors are integrated with a vertical aerial camera system, such as by PhaseOne. This allows for the simultaneous capture of both Lidar and imaging where appropriate.

Modern Lidar systems have significantly evolved over the past few years. This results in greater point densities (4 to 10 points per square metre is now common) and faster capture rates. Point densities of 20 to 50 points per square metre are now routinely achievable, although there is a notable tradeoff between point density and capture time/cost.

Whilst modern digital aerial cameras and photogrammetric software can now generate very high-accuracy and high-resolution DSMs, Lidar remains the most appropriate tool for mapping terrain in areas covered by vegetation such as scrub or forests, or where multiple 'surface returns' are required such as in powerline (Figure 2) or forestry mapping applications. Lidar sensors also typically measure the 'intensity' of the returned laser pulses, which assists in determining the type of surface from which the laser beam is reflected (e.g. roads vs footpaths vs trees, etc.)

Figure 6: 3D reality mesh model of Copenhagen, Denmark, built using high-resolution oblique aerial imagery and Bentleyâ€™s ContextCapture software.

Single-photon and Geiger-mode Airborne Lidar

Over the past few years, some new sensors have begun to emerge that utilize a different laser-based measurement approach. These sensors can capture data at significantly greater flying heights and hence higher coverage rates than conventional airborne Lidar systems. However, accuracy and attribution may be affected, as the technology is commercially relatively new.

Hybrid Sensors

As the range of imaging sensors and processing technology increases, so too does the number and type of sensors. It is now common to find commercial airborne mapping sensors that combine both high-quality aerial camera systems with airborne Lidar systems. These systems can be used in many areas; however, they appear to be especially well suited to the burgeoning field of high-resolution 3D city mapping (e.g. the Leica CityMapper airborne hybrid sensor).

Drone Mapping

There is absolutely no doubt that unmanned aerial vehicles or 'drones' are set to revolutionize the aerial mapping industry. There are literally hundreds of affordable commercial drones available. Coupled with a small vertical-looking camera or oblique camera systems and modern photogrammetric software, drones can create highly detailed maps, often at significantly lower cost than conventional mapping. Drones fitted with Lidar systems are now also becoming commonplace. However, drones are restricted in their use and application by multiple factors, including:

- Where they may fly (generally not in highly urbanized areas or within Civil Aviation-controlled zones and generally not beyond visual line of sight)
- The size and weight of the sensor they can carry
- The flying time for each flight
- The flying altitude and hence coverage area for mapping.

For small-area surveys, repeat-area surveys such as mine or quarry sites or for certain corridor mapping projects, drone mapping now presents a viable alternative to conventional mapping. However, users should be careful not to expect that a drone weighing 5kg, for instance, can achieve the same mapping accuracy and coverage as can be achieved with a manned aircraft fitted with a high-end aerial mapping system. As the Civil Aviation regulations regarding drone usage develop in parallel with drone technology, over the next few years drone-based mapping will increasingly open up new mapping applications and, to some extent, eat into the manned aerial mapping market.

Figure 7: 3D reality mesh model of a building in Brisbane, Australia, created using very-high-resolution drone-based imagery and Bentleyâ€™s ContextCapture software.

Products and Applications

As has been discussed above, the range of products and applications that can be derived from aerial mapping is constantly expanding. Image and point data resolutions continue to increase, orthophoto mosaics are a standard product, discrete 3D city models such as those specified by the Open GIS Consortium (OGC) CityGML standard have become increasingly common. Cities such as Singapore have based their entire 'smart city' framework on a very-high-resolution 3D city model built from aerial mapping techniques (Figure 3).

The relatively new 3D reality mesh models have created a quite an impact over the past few years and will continue to develop rapidly. Reality models can be generated rapidly and have found significant use in areas including infrastructure and construction as well as 3D city mapping.

Big Data, Machine Learning and Artificial Intelligence

The data captured from aerial mapping is, by its very nature, ‘big data’. The rapidly developing fields of machine learning and artificial intelligence will make increasing use of the data products from aerial mapping. Applications range from automated building and feature extraction, e.g. for 3D smart city applications and autonomous vehicle maps, to automated detection of faults and vegetation encroaching on powerlines, to monitoring of forest and crop health. This trend is not yet fully developed, but it is certain that the amazingly detailed and accurate data available from aerial mapping will been utilized in ever-more automated ways in the next few years.

Figure 8: 3D reality mesh model of a building in Kuala Lumpur, Malaysia, created using very-high-resolution drone-based imagery and Bentleyâ€™s ContextCapture software. The right-hand side of the image illustrates the â€˜meshâ€™ that provides the model framework.

Conclusion

Aerial mapping continues to be a highly relevant, efficient and effective means to capture high-quality, highly accurate data for GIS and mapping applications. The range of sensors and derived products continues to expand, whilst the range of applications appears almost limitless. When considering aerial mapping as a method for capturing geospatial data, the user should keep in mind the primary purpose for the data capture exercise. Ideally, resist specifying the type of aircraft or aerial sensor and consult with specialist aerial mapping companies instead. These experts will be able to advise on the best approaches and options available to achieve the project outcomes required, whilst balancing operational logistics such as air traffic control, accuracy, quality, timeliness and cost of the survey.

More information:

www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/

www.youtube.com/watch?v=GbJ9xPf0gwg (for an overview of airborne Lidar systems)

www.faa.gov/news/fact_sheets/news_story.cfm?newsId=20516 (USA Federal Aviation (Part 107) Regulations)

www.opengeospatial.org/standards/citygml

www.youtube.com/watch?v=3HNjU5pT5Ck