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Carrivick, JL, Smith, MW, Quincey, DJ et al. (1 more author) (2013) Developments in budget remote sensing for the geosciences. Geology Today, 29 (4). 138 - 143. ISSN 0266-6979

https://doi.org/10.1111/gto.12015

Developments in budget remote sensing for the geosciences

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Acquiring outcrop, landform or other surface topography data in the field for the geosciences has always been challenging. Accessibility is often a problem, time is usually limited and an ideal spatial and temporal coverage often has to be compromised to be more manageable. However, emerging technologies, and some re-inventions of rather older ones, can overcome many of these constraints in a very exciting and budget-friendly manner. This article briefly introduces and reviews four major recent developments in budget remote sensing; specifically 1. the use of blimps, 2. kites, 3. drones or UAVs including quadcopters, and 4. structure from motion (SFM) software. Both scientific and applied case studies are given and some possibilities for future studies are highlighted. Overall, the potential for these technologies to revolutionise the geosciences is clear and should be opportunistically embraced by scientists, resource and hazard managers and educators alike.

INTRODUCTION

The ability to acquire topographic data is fundamental to the geosciences. Geologists, earth scientists, geographers and those in related disciplines have always required field data focussed on outcrops, landforms and other surface parameters. These data comprise a number of surface attributes, such as lithology, grain size or elevation, for example, all tied together by a measurement of geospatial location. Commonly, information on changes at that location is also required, so surveys have to be repeated. However, many field surveys are far from straight-forward. Limitations centred around accessibility, time and money often conflict with ideals of coverage; both extent and resolution in space, and repeat interval or temporal resolution. Traditional surveying techniques based on triangulation, usually using theodolites and similar equipment (Fig. 1A), are very resource intensive, have a maximum acquisition rate of a few hundred points per day, and are limited to directly-visited sites and to local coordinate systems. However, from the mid-1990s Global Positioning Systems (GPS) changed surveying entirely. GPS still requires a surveyor to visit a site directly (Fig. 1B), but, on continuous or 'kinematic' mode, has increased the achievable acquisition rate to thousands of points per day, with each point georeferenced in a global coordinate system. Furthermore, GPS produces digital data that are both easily captured by a non-specialist and easily and accurately manipulated, to a different coordinate system, for example.

LASER SCANNING

From the year 2000, a cutting edge method for indirect or remote sensing surface measurement became available with the capability of unprecedented (dense) coverage and incredibly fast capture of millions of surface point measurements per day, possibly even per hour. Laser scanning instruments, or 'laser scanners' look similar to traditional surveying instruments, especially when mounted upon a tripod (Fig. 2A), but they emit a laser pulse and record the time it takes for that pulse to return to the scanner. They do this many thousands of times per second. Lasers travel at a constant speed, the speed of light, and because the scanner 'knows' in which direction the laser went out it can calculate not only the distance of the surface from the scanner, but also the remote coordinates of that point on that surface. This process is generally termed Light Detection and Ranging, or 'LiDAR'. In this manner 'point clouds' are compiled in just a few minutes. Indeed many scanners have the ability to also record a RGB value to add colour to the point cloud, or have an integral camera. The intensity of the laser received back at the scanner can give insight to the material properties of the remote surface, but the intensity also depends on the distance of the surface and the angle of incidence of the laser with that surface. Recent generations of laser scanners have 'full waveform' capability, whereby the entire backscattered signal is recorded, providing more information of complex surface structures (e.g. tree canopies) and more user-control in the interpretation of returned signals. Some scanners operate in a part of the electromagnetic spectrum to enable some through-water capability while others can measure the precise location of points on a surface that is as much as several kilometres from the scan position. For greater spatial extent, for improved spatial coverage (i.e. to avoid 'blind spots' behind obstacles for example), and for increased speed, laser scanners can be mounted on vehicles and on aircraft (Fig. 2B), both of which also require simultaneous data feeds from GPS and probably from an inertial measurement unit (IMU) and are often of a lower spatial resolution. But there are several drawbacks. Laser scanners are financially very expensive (of the order of £50-100,000 to purchase). Laser scan data are quite difficult to process and interrogate, not least due the voluminous nature of the data but also due to problems of visualising and analysing three-dimensional data on screen. It is therefore with considerable interest that this article briefly reviews a number of emerging budget-friendly technologies and new applications of some older ones!

BLIMPS

Blimps have been consistently in use by the geosciences for the last decade (Fig. 3). Blimps are lighter-than-air balloons and are usually in the shape of a Zeppelin for directional control and stability. The simplest balloons are physically pulled around via a length of cord, whilst the more sophisticated blimps have on-board propulsion, usually a propeller, remote control or a semi-autonomous flight control system. Blimp usage is limited by payload and by wind speed, and in the case of powered models by flight duration as well. However, blimps are low cost (of the order of £1000), low maintenance, have considerable ease of deployment and minimal personnel requirements. Blimps of up to 10 m in length can have payloads for aerial photography, altimetry, synthetic aperture radar (SAR), and scatterometry. Typical applications could be to use; an altimeter to scan landslide prone areas whilst the blimp flies at a constant altitude; a Synthetic Aperture Radar to produce images for archaeological and geological studies; a scatterometer to quantify surface complex surface characteristics, such as material properties.

In more detail a blimp system comprises the balloon/body/envelope, a burner system or a Helium supply, a payload or sensor system, remote control hardware (optional) and electronics and tether ropes. Blimp payloads are usually photographic cameras; perhaps two single-lens reflex cameras with motor drives mounted against each other with parallel camera bases on a 360° electronic turntable, which ensures a vertical optical axis at any time. With focal distance set at infinity and a fast shutter speed, photographs are taken in automatic aperture mode preferably using an electronic trigger connected to a remotely controlled switch. A twin camera system allows photographs to be taken simultaneously with different film types (normal or infrared colour) or with different focal lengths.

Whilst the burner/Helium and camera functions are often remotely controlled, a blimp as a passive unmanned airship has to be steered with tether ropes from the ground. As wind pressure against the rope and blimp as well as slant rope angles have to be taken into account, 500-m long tether ropes are required for a maximum flying height of approximately 350 m. A third rope, suspended from the rear of the blimp near the sensor system and marked in 5-m intervals, serves as a plumb line indicating ground position and flying height. Maximum altitude is limited by the length of the tether ropes but there is practically no lower limit to flying height. Depending on the altitude and focal length, photographs will vary in scale between approximately 1:200 and 1:10,000, covering areas from 35 m^2 up to 20,000 m^2. A blimp can be positioned with the tether ropes fairly precisely so stereoscopic coverage; for extraction of digital elevation models from photographs, can be accomplished by towing the blimp along a straight line.

KITES

To create a kite system capable of aerial photography it is necessary to combine a kite(s), line, reel (spool), camera and a cradle or rig capable of holding the camera on the kite line. Kites used for aerial photography are usually of a delta or airfoil style. The size of the kite determines what wind speed it should be flown in. Larger kites (2 m x 2 m) should be used in light winds, whilst smaller kites (1 m x 1 m) are used in stronger winds. A line should be heavyweight and able to handle the weight of the camera and kite and a camera should be small and lightweight because the lift capability of a kite can vary greatly dependent upon wind velocity. In higher wind speeds, a kite will lift more weight; in lower wind speeds, a kite will not lift as much. Traditional kites are notoriously difficult to direct and position, but modern advances in material technology and kite aerodynamics mean that kites similar to those used for kite-surfing are cheap (several hundred GBP), powerful and very controllable; they can even be made to ‘hover’ with very little user-input.

Kites can be used almost anywhere, especially in remote regions. Additionally, minimal training is required for users. Thus kites have been successfully used in research studies to observe and document forest canopy and cover, and for characterisation of wetlands, geological and archaeological mapping and stream channel characteristics, for example. Additional uses can be found in the literature on determining growing crop status, delineating flood extent, recognizing rock types, pinpointing areas of deforestation, identifying agricultural land damage and mapping erosion.

DRONES or UAVs

Drones, 'unmanned aircraft systems' (UAS), 'unmanned aerial vehicles' (UAVs) or 'remotely piloted aircraft' (RPA), actually pre-date manned-flight, but presently span a whole range of platforms with differing size, shape, power and capability; Watts et al., 2012 give a useful review that includes fixed wing, helicopter, multi-rotor and glider systems. These systems combine sensor and sampling quality typically found in larger aircraft with portability, cost and survey coverage and speed advantages provided by smaller platforms (Fig. 4). The most common smaller drones provide rapid surveys at low cost and crucially from nearly any viewpoint. Furthermore, there is presently a niche in aviation regulations that allow such platforms utility within certain flight constraints and conditions. The recent resurgence of use of drones has to be partly attributed to: (i) vastly improved and affordable autopilots; and (ii) vertical take off and landing (VTOL) capability. Autopilots not only help with stability but also offer several flight modes and 'fail-safe' options. For example, on-board GPS enables a 'home' point to be established and a position to be maintained without user-input on manual controls; to compensate for cross-winds for example. It also permits 'home' to be sought by the drone, if battery power drops below a threshold or if radio signal from the manual user is lost. Extra features of some systems include a live-feed from the on-board camera to the user, whether via a headset or a laptop, and autopilot software that permits interactive flight path programming; for example overlaying a route on GoogleEarth.

VTOL drones e.g. helicopters, quadcopters, are usually quite small, and thus offer great portability, obviously without the need for runways. Current VTOL drones are powered by electric motors from rechargeable batteries and this limits flights to less than one hour and limits sensor payload capabilities. VTOL drones are presently used in the USA and in the UK as support for the police where low-altitude and hovering capability with image data capture is exceptionally useful. Many scientific research applications also require hovering capability over a fixed survey plot and re-visits over a known point. Alongside photographing and mapping e.g. for quantification of dynamic landscapes, terrain stability assessments, surface and vegetation characterisation, natural hazard analysis and geoarchaeology, and attempts at precision agriculture, future applications of drones in the geosciences could include bathymetry mapping and gathering gas samples from hazardous localities, for example.

STRUCTURE FROM MOTION

If blimps, kites or drones are used for aerial photography, it is still necessary to use photogrammetry to produce high-resolution topographic digital elevation models (DEMs) because the altimetry method as described above with blimps is not precise or high-resolution. DEMS are three-dimensional models of a landscape, landform or other surface and are crucial data for the geosciences. Photogrammetry requires a lot of personnel time, expensive hardware and/or software. However, 'structure from motion' (SfM) is an image-based method which could deliver a methodological leap if transferred to geological and geomorphological applications because it requires little training and is extremely inexpensive. The basic product of the SfM process is a point cloud, like that obtained from laser-scanning, but in this case of identifiable features present in the input photographs rather than of pseudo-random points on any surface. This point cloud can be georeferenced from a small number of ground control points collected in the field or from measurements of camera positions at the time of image acquisition. SfM and ground-based or low-altitude platforms can produce point clouds with point densities comparable to airborne laser-scanning and with centimetre horizontal and vertical precision.

In more detail, SfM uses images acquired from multiple viewpoints in order to determine the three dimensional geometry of a surface. However, SfM diverges significantly from traditional photogrammetry by firstly using a new generation of image matching algorithms which allow for unstructured image acquisition. Whilst classic photogrammetric methods typically rely on strips of overlapping images acquired in parallel flight lines, SfM was designed to utilise randomly acquired images. This is a significant advance when compared to the kernel-based image correlation approaches used in classic photogrammetry. SfM determines points present in multiple images based on multiscale image brightness and colour gradients and this approach is novel in its ability to accommodate large changes in image scale (i.e. resolution) and large changes in view point. Secondly, SfM introduces ground control points (GCPs) after image matching and projection onto a planimetrically correct surface, i.e. 'orthorectification', which is in contrast to photogrammetry that requires GCPs to be input first.

In traditional photogrammetry the final quality of a DEM relies on few highly accurate and precise GCPs and/or camera positions but these points allow for camera calibration and for a high quality 3D geometry. In contrast, in SfM the final quality of camera calibration and of the DEM relies on a very large number of automatically generated points that have varying degrees of error that are hidden from the user and are a function of image properties. Using an iterative bundle adjustment procedure camera positions and orientations are solved simultaneously with surface geometry utilising the high level of redundancy afforded by a large overlapping image set. There is therefore an assumption in SfM that the automated image matching process yields precise and accurate results with little non-linear deformation. This is a crucial assumption that still needs rigorous testing and verification but the initial experience of a range of users and their results are very encouraging. The SfM workflow has significantly more automation and thus is perceived by users as being much more straightforward and simple than photogrammetry. This ease of use has been greatly enhanced in recent years by the development of freely available software such as Microsoft Photosynth and Bundler, for example.

BRIEF DISCUSSION AND CONCLUSIONS

Traditional ground-based surveying is resource intensive. Mainstream remote sensing from high altitude; i.e. satellite or aircraft platforms, is often expensive and generally of relatively coarse scale. Laser scanners are revolutionary in terms of resolution, precision and accuracy and speed, but are very expensive in terms of hardware costs and data processing.

Blimps, kites and drones are cheaper alternative platforms for gathering a range of data for the geosciences and are outstanding at generating “snapshot” views of sites. However, if a study requires spatial analysis of imagery, including import into Geographic Information System (GIS), then collection of positional data is required for image georeferencing. Some positioning capability is increasingly common within the smallest Drone autopilot systems, but overall it is absolutely essential to collect ground control points (GCPs). GCPs are identifiable points on a surface and in an image and are geo-located precisely using GPS. Some laser-scanner software can automatically merge scans and georeference them given knowledge of the scan position and SfM-type automation, and some high-end UAV systems can add precise attitudinal data to imagery allowing for direct image georeferencing.

Rapid technological development and commercial providers of blimps, kites and drones and of SfM methods make estimations of platform and per-hour survey costs difficult. Potential users should consider options based on sensor/payload capabilities. Sensors that produce visible and near-infrared images tend to be among the lightest and can be accommodated on all platforms. This has been enabled in no small part by considerable advancements in consumer-grade imaging products during the past decade. Thermal-infrared imaging is less common. Multispectral and LiDAR payloads (and more exotic payloads such as RADAR) each weigh several kilogrammes and are therefore limited to the very largest drones where high operational costs can be balanced by long flight durations and large coverage areas.

In conclusion, several recent developments in remote sensing hardware and software technologies offer to revolutionise the geosciences by offering a cost-effective ability to survey outcrops, landforms and other surface properties remotely, quickly and cheaply and at high spatial and temporal resolution. Low altitude remote sensing means that multi-scale surveys are now possible, and characterising spatial heterogeneity, or ‘spatial diversity’ as well as measuring rapid landscape changes is now very possible.

ACKNOWLEDGEMENTS

Martin Geilhausen is thanked for his laser scanning data acquisition and processing. EUFAR is thanked for a laser scanning overflight and data processing. The School of Geography at the University of Leeds is thanked for its contribution towards purchase of a laser scanner, for purchase of a quadcopter and for travel and subsistence costs for fieldwork in western Greenland.

Suggested reading

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Figure 1. Traditional survey methods are resource intensive. Using a theodolite, or total station or geodimeter (A: left) must have a reflector or 'prism' that is usually mounted on a survey staff, positioned exactly on the point of interest; in this case to determine river bathymetry (A: right). Differential GPS requires a local base station that is usually mounted on a tripod (B: left), as well as a 'rover' antenna-receiver system to be positioned exactly on the point of interest; in this example at a stake on the Ödenwinkelkees glacier in central Austria, to measure surface elevation and velocity (B: centre) and river gravel bar form in west Greenland (B: right).

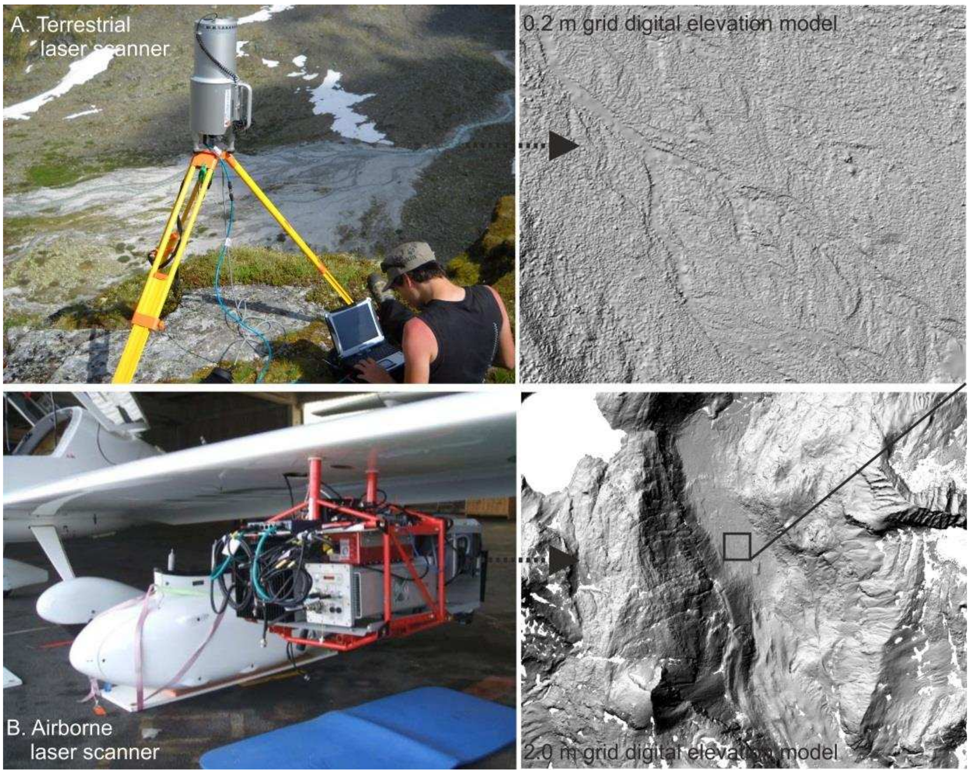

Figure 2. Terrestrial laser scanning (A) in the Ödenwinkelkees catchment, central Austria, to produce valley-floor digital elevation models at 0.2 m resolution, and Airborne laser scanning (B) achieved by mounting hardware within an under-wing pod to produce landscape-scale 2m grid elevation models.

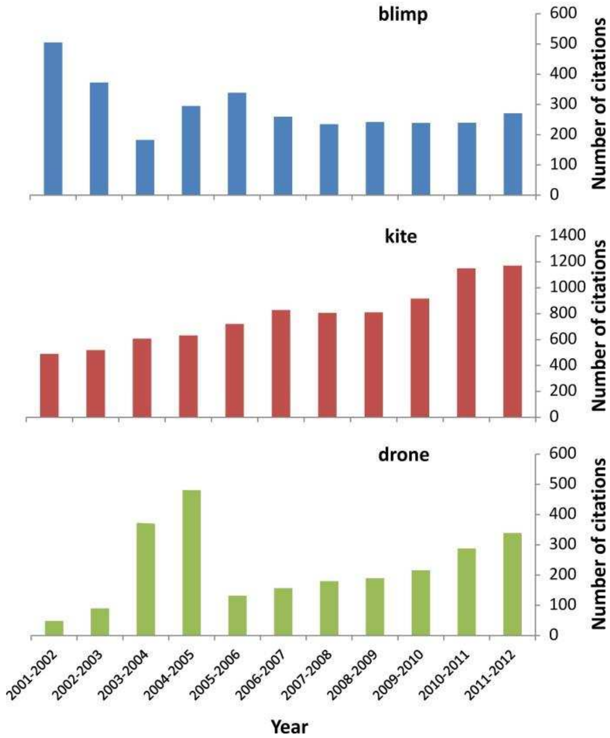

Figure 3. Google Scholar citations containing the text 'blimp remote sensing', 'kite remote sensing' or 'drone' or 'UAV' and 'remote sensing'. Both kites and drones are apparently having year-on-year increased usage, whereas apparent usage of blimps is more steady. Note differing vertical scales

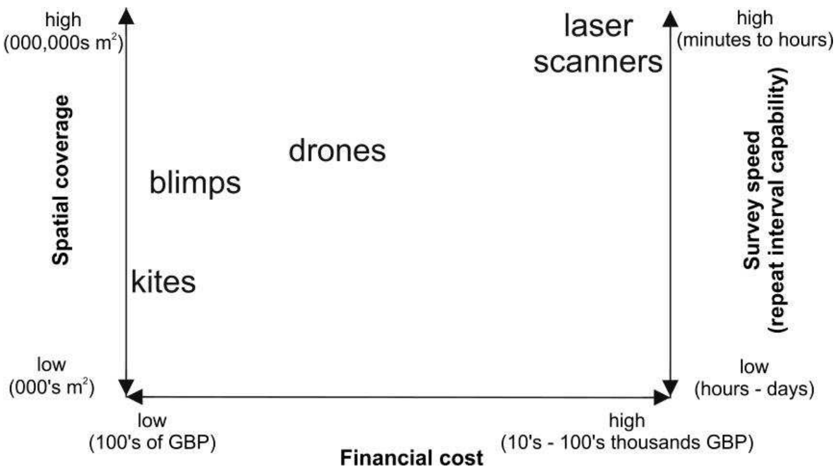

Figure 4. Schematic discrimination of the place of budget remote sensing methods in terms of cost, spatial and temporal coverage and in relation to cutting edge laser scanning systems

Figure 5. Examples of a blimp (A), kite: image credit: Matt Westoby (B) and a drone/U.A.V; in this case a quadcopter (C) all supporting camera equipment payloads

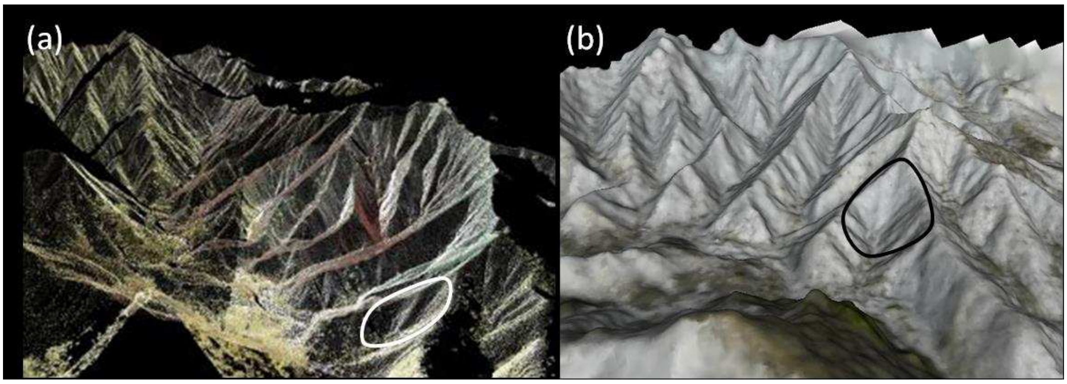

Figure 6. Example of a point cloud representing terrain; image credit: Damià Vericat (A) and an interpolated surface using structure-from-motion; image credit: Matt Westoby (B)