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Short communication

UAVs for coastal surveying

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ABSTRACT

UAVs (Unmanned Aerial Vehicles or "drones") for routine survey applications at the coast have come of age, and are no longer 'the latest thing' more suited to the specialist researcher or amateur enthusiast. Off-the-shelf, survey-grade UAV equipment, data processing and analysis tools are now readily available to practicing coastal engineers, managers and researchers. Within the regulatory constraints that determine their use in many countries, UAVs provide an efficient and cost-effective survey tool for topographic mapping and measurement in the coastal zone. At the practical level, the specialist training required to operate off-the-shelf UAV suited to coastal surveying is now comparable in time and degree of difficulty to learning how to use the equivalent survey capabilities of professional hand-held RTK-GPS equipment. While incremental improvements to both the flight technology and data processing will no doubt continue to occur, from the coastal practitioner's perspective, no more step changes in UAV technology or ease of useability are required. In particular, survey-grade UAVs that incorporate internal RTK-GPS for high accuracy positioning and requiring a single operator only to safely deploy in the field, remove the need for separate and time-consuming on-ground surveying of ground control points (GCPs), previously required during post-deployment data processing. A coastal engineering application of UAV is used here to exemplify the practical use and potential benefits of this now mature survey technology. Over the past 2 years, rapid post-storm deployment of UAV surveying has been successfully integrated into an established coastal monitoring program spanning 4 decades at Narrabeen Beach, Australia. This has extended the scope of this program to include detailed measurements of dune and beachface erosion spanning the full 3.5 km long embayment at a spatial scale and temporal resolution that were previously unfeasible. For both the researcher and practicing coastal engineer, UAVs now provide a practical option for routine coastal surveying.

1. Introduction

Variously referred to in different contexts and aviation jurisdictions as UAS (Unmanned Aerial Systems), RPAS (Remotely-Piloted Aerial Systems), "Aerial Robots" or simply "drones", the practical application of UAVs (Unmanned Aerial Vehicles) for surveying at the coast has come of age. No longer 'the latest thing' more suited to the technical specialist or amateur enthusiast, off-the-shelf (i.e., commercially supplied) UAV survey equipment and data processing methods are now readily available and suitable for use by coastal engineers, managers and scientists. At its core, UAVs use autonomous flight technology combined with recent advances in computer vision techniques, to extend the very familiar and already extensive use of aerial photogrammetry applied to coastal surveying.

In this short communication we provide the coastal practitioner more interested in the survey product (i.e., wide-coverage, high-resolution coastal topography and imagery) than the specific survey equipment used to obtain it, a practical overview of current UAV survey capabilities and requirements. The rapid-response deployment of an off-the-shelf, survey-grade UAV is described, that is being used to extend the scope of a long-term coastal monitoring program underway in southeast Australia, to now include detailed post-storm coastal erosion assessment spanning a full coastal embayment.

2. Brief overview of UAV technology and regulations

For a comprehensive overview of UAV historical development, country-specific regulations and their broader applications to photogrammetry and remote sensing, the reader is referred to the recent review of Colomina and Molina (2014). The current range of civil UAV surveying and mapping applications is diverse, for example: geological resource mapping (Johnson et al., 2014); agricultural watershed analysis (Ouédraogo et al., 2014); mining (Nex and Remondino 2014); archaeology (Rinaudo et al. 2012); fire-fighting (Rufino and Moccia, 2005); forestry (Puliti et al. 2015) as well as a range of more conventional cadastral mapping tasks (Cramer et al. 2013). Published reports of UAV applied to coastal surveying are relatively limited: Mancini et al. (2013) described the trial of a multi-rotor hexacopter UAV to measure the topography of a 200 m section of beach and dune in northeast Italy; while Gonçalves and Henriques (2015) outlined the trial of an earlier generation fixed-wing and very light-weight UAV used to obtain

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a digital surface model at two test areas located on the northwest coast of Portugal. The use of a manually-piloted octocopter UAV to evaluate storm and engineered topographic changes along a 500 m section of beach of the Liguria Region in the northwest of Italy is presented in Casella et al. (2016). In Europe, the USA and Australia, the authors are aware of a number of coastal research groups who are currently exploring the use of UAVs to compliment and extend their coastal measurement programs. Drummond et al. (2015) recently described a range of practical coastal engineering and coastal management UAV applications, including: coastal structure armour volume and damage analysis; beach surveying; as well as estuary and coastal wetland mapping and management. Provided below is a very brief overview of a current off-the-shelf UAV technology that is particularly well suited to topographic surveying at the coast.

2.1. UAV airframes, flight planning & control

A modern, survey-grade UAV contains within the lightweight airframe integrated autopilot and navigation systems, a motor and battery for propulsion, and a digital camera for image capture. For applications extending beyond the specific topographic survey capability that is the focus here, an ever-expanding range of additional ground and atmospheric sensors is also available. The surveyor uses a tablet or laptop to plan, monitor and if necessary alter the survey plan during flight, and a radio link to maintain communication with the aerial vehicle. Extensive description of each of these components (and their various subcomponents) is provided in several recent review articles, including Colomina and Molina (2014) and Nex and Remondino (2014).

Fundamentally, there are two types of UAV airframes: multi-rotor (e.g., 'quadcopters', 'hexacopters' and 'octocopters'.) or fixed-wing. While each system has their particular advantages for specific applications, fixed-wing UAVs are well suited to routine topographic surveying along the coastline, as their naturally 'linear' flight path typically matches the geometry of what is commonly a long (longshore) but relatively narrow (cross-shore) survey region. Where more 'square' than 'strip' surveys of coastal regions are needed, the fixed-wing flight plan comprises a grid pattern spanning the required survey extent. Off-the-shelf fixed-wing UAVs targeted at survey applications can typically weigh of the order of a kilogram (including the camera and battery), and with a total wingspan of around a metre (that is often in two parts and can be additionally separated from the aircraft body), they are very easily transportable to and between survey sites.

Crucially, UAVs developed for the professional surveying market do not require the operator to have any specialist skills to 'fly' the airframe. Instead, a single operator determines the extent of the ground region to be surveyed and the spatial resolution required, and then automated flight-planning software calculates the required movement of the UAV in the air and at what positions to take the multiple aerial images, which is then passed to the airframe's internal autopilot and navigation systems prior to commencing the flight. The operator monitors rather than controls the UAV during flight, but for safety reasons also has the ability via the radio link to initiate several alternative actions mid-flight. These actions can include a temporary return to one or more pre-determined 'safe' waypoints and altitude (for example, if another low-flying aircraft appears unexpectedly), or initiation of automated landing prior to the completion of the full survey. Survey navigation and landing at a specified approach angle and location are all fully automated, and other than the ability to initiate an emergency abort, require no input from the operator. Many earlier generation fixed-wing UAVs relied upon a spiralling approach to the designated landing point, which on a beach of restricted width and/or relatively steep slope can be problematic. The current generation of UAVs describe below now enables a range of automated landing options to be selected, including the ability to precisely align the final approach of the UAV to the local orientation of the shore/dune-line.

2.2. RTK-GPS survey positioning and image data post-processing

The recent major advance in UAV technology that is of particular benefit to the coastal practitioner, is the availability over the past ~2 years of off-the-shelf UAV survey systems that now integrate high-precision RTK-GPS positioning. [Note: while it is recognised that 'RTK-GNSS' is more strictly the correct generic term to use here as it encompasses all global satellite navigation systems, the term 'RTK-GPS' continues to be the most commonly used in this context]. The practical advantage of UAVs with on-board precision positioning is the resulting step change in their practical useability. The RTK-GPS positioning of the camera, combined with the large redundancy of image overlaps, removes the need for any additional ground surveys.

Prior to the availability of RTK-GPS UAVs, it was necessary to separately and independently establish the precise position of a number of ground control points (GCPs) spanning the survey region, in order to proceed with the post-processing of image data to derive topographic information relative to a real-world coordinate system. Temporary GCPs typically comprised marked carpet tiles or other ground targets that were readily identifiable in aerial images. Determining the accurate location of GCPs necessitated additional hand-held RTK-GPS survey equipment and an on-ground survey team.

Removing the need for GCPs has two distinct advantages. First, the time taken to complete individual UAV surveys is substantially reduced. Second, less accessible coastal areas (e.g., wetlands or coastal cliffs) are now as straightforward to survey as an open beach. For earlier users of UAVs where this capability was not available, by far the most time-consuming (and sometime impractical) aspect of completing a UAV survey over larger areas of interest was the pre-flight laying out, accurate surveying, then post-flight collection of temporary GCPs.

A concurrent and similarly time-saving advance in satellite navigation that survey-grade UAVs now incorporate is automatic and seamless access to CORS (Continuously Operating Reference Station) networks via a standard SIM card. Networks of permanent RTK base stations that broadcast corrections over the internet in real-time are increasingly available to surveyors in the field. Whether used in real time or by accessing archived corrections during post-processing, for the coastal surveyor the proliferation of national- and state-based permanent RTK base stations provides the very real benefit that it is no longer necessary to own and deploy at each survey site a base station to achieve RTK calculation and correction.

2.3. Structure from Motion (SfM) — 3-D topography from multiple 2-D images

As noted earlier, the general principles underpinning UAV topographic surveying are very familiar to the coastal practitioner. Stereo-photogrammetry applied to aerial imagery at the coast has been in common use for more than half a century. Recent and significant developments in digital photogrammetry and computer vision have now rapidly advanced the field.

Structure from Motion (*SfM*) is a practical photogrammetric technique that has emerged in the last decade or so, used to derive three-dimensional surface reconstructions from a series of overlapping photographs. First developed in the 1990′s within the computer vision industry, the emergence of *SfM* at that time benefitted from new advances in both motion perception (e.g., Spetsakis and Aloimonos, 1991) and automated feature-matching algorithms (e.g., Lowe, 1999). *SfM* is best suited to a set of images where there is a high degree of overlap that capture the region to be surveyed from a wide number of different positions and orientations, for which a moving camera platform relative to a stationary survey target (hence the name) is particularly well suited. For topographic survey applications, many thousands of matching object and textural features are automatically detected in multiple, overlapping images of the ground surface, from which a high-density point cloud of 3-D positions is then derived. For further technical