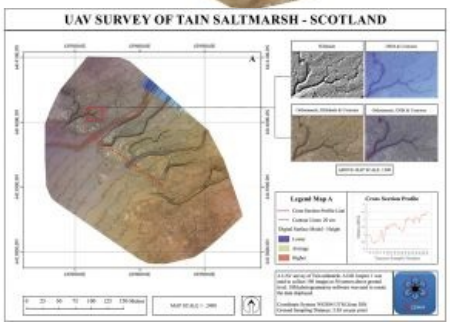
THE UAV WAY

Monitoring, Mapping, and Modelling Saltmarsh



Coastal and estuarine saltmarsh has long been recognised as having key physical, ecological, and recreational value, acting as sediment and nutrient traps and as natural coastal protection structures functioning as protective buffers between the land and sea. Additionally, they are important areas for shelter, feeding and breeding of diverse forms of wildlife (Doody, 2007).

Recent work suggests that saltmarshes are particularly good for demonstrating how the coast can change in response to environmental influences, including relative sea level rise. The pace of current Scottish relative sea level rise (Rennie and Hansom, 2011) may lead to inundation of coastal saltmarsh, with the potential for rapid change and loss, and so it is critical to be able to monitor the response of saltmarsh to sea level rise, map saltmarsh topography, and to model rates of marsh elevation change on a real-time basis. However, changes in saltmarsh vegetation differ according to local circumstances, and can be very difficult to map from the land; and even if there is enough survey time to walk vegetation community boundaries using GPS, some areas are so soft and muddy that they cannot be surveyed safely on foot.

This is where aerial imagery comes into its own. Not only does it provide an overview of the saltmarsh that cannot be obtained from the ground, but with geo-rectified photography it becomes possible (with more than one survey) to map both area and volumetric changes accurately. In contrast to conventional vegetation mapping, aerial imagery is non-selective in its data capture and multispectral and hyperspectral imagery adds even more information about these changes for scientists who are attempting to interpret coastal change from a variety of perspectives.

Remote Sensing and Saltmarsh

The Saltmarsh Survey of Scotland (SSS) (Haynes, 2016) identified key areas relevant to the study of saltmarsh including: the value of remote sensing (past, present and future) to provide valuable insight into sediment movement, its interrelationship with saltmarsh vegetation, and changes to saltmarsh communities; the need to collect time-series high-resolution topographic data (e.g. Lidar) to provide real-time accurate information about the location and rates of saltmarsh erosion and accretion; the need to investigate the decline in the

extent of saltmarsh pioneer communities; the potential for saltmarsh surveys to inform management practices and policy in Scotland and improve the conservation and management of saltmarsh.

Saltmarshes can be difficult to access and ground monitoring and inventory is problematic and time-consuming. Collection of data from remote sensing platforms therefore has considerable potential. Numerous studies of saltmarshes have been undertaken using both airborne and satellite remote sensing platforms and sensors (Klemas, 2013), including studies using multispectral, thermal, CASI hyperspectral (Kumar and Sinha, 2014) and Lidar sensors (Rosso et al., 2006). Many different types of satellite imagery and data (including Landsat TM (Hobbs and Shennan, 1986); ROSIS, CASI (Wang et al., 2007; Silvestri et al., 2003; Sadro et al., 2007), MIVIS, IKONOS, QuickBird (Belluco et al., 2006), AVIRIS, and MODIS (Mishra and Gosh, 2013) have all been used in various studies to monitor and map saltmarsh environments and characteristics.

Classification of remotely sensed data has been shown to provide a means to help accurately monitor the spatial structure and evolution of saltmarsh vegetation over time; for accurate vegetation mapping and quantitative characterisation of the spatial distribution of saltmarsh plants; for understanding saltmarsh soil elevation and its dynamics; monitoring biophysical characteristics, photosynthetic capacity, nitrogen content, blue carbon storage, and the physiological status of saltmarsh vegetation; to infer overall condition and productivity; and allow for the development of effective management strategies in high priority areas. In addition, other studies have shown the value of remote sensing to characterise saltmarsh topography at a scale relevant to ecological processes; for evaluating changes in saltmarsh morphometry and community structure over long time scales; to quantify and map the dynamics of saltmarshes, specifically to wetland topography and vegetation structure; and to integrate plant community mapping and local tidal hydrodynamics with fine scale topographic analysis.

Remote sensing has been shown to offer considerable potential for the long-term study, monitoring and mapping of coastal saltmarsh at different spatial, temporal and radiometric resolutions to provide information that is not always accessible through field observations. There are now opportunities to acquire, process and integrate high-resolution datasets derived from miniaturised remote sensing platforms (UAVs or drones) with the aid of image processing software, soft-copy photogrammetry, and GIS into multi-dimensional geo-visual representations of saltmarsh for analysis, interpretation and communication.

Effective management of our coasts in a time of rapid climate change and uncertainty requires the availability of multi-temporal, high-resolution spatial data. Coastal saltmarshes are a vital part of a functioning coast and provide a significant coastal protection function (SNH, 2016). The research reported here seeks to take advantage of an emerging new area of remote sensing technology to acquire high-resolution aerial photography and imagery from small-scale UAV platforms and sensors as a basis for: (a) providing new data and information about the physical and ecological characteristics of coastal saltmarsh; (b) mapping saltmarsh vegetation communities; (c) identifying areas of erosion and accretion; (d) providing a high resolution topographic model of the saltmarsh; and (d) utilising geo-visualisation tools and techniques to communicate key results to the public as a novel way to raise awareness and educate about saltmarsh as living natural coastal protection structures.

UAVs

UAVs can provide very high-resolution maps and models of changes in the saltmarsh environment in virtually real-time. A number of recent studies have highlighted the potential of small drone platforms to acquire high-resolution aerial photography and the use of Structure from Motion (SfM) to construct 3D models of the surface. Such studies have focused on the role of remote sensing, and information extraction. The aims and objectives of this article are to demonstrate the practical potential of using UAV-based remote sensing platforms and sensors to monitor, map, and model coastal and estuarine saltmarsh.

UAV sensors can: (a) offer comprehensive (i.e. non-selective) high-resolution, spatio-temporal data capture over inaccessible areas of saltmarsh; (b) create 3D models of saltmarsh micro-topography, soil and vegetation; and (c) enhance knowledge and understanding of saltmarsh functioning and the spatial extent of vegetation composition and habitat change over time that affects ecosystem functioning. Such data can inform: (a) coastal policy for improved and sustainable coastal management; and (b) raise awareness and educate the public about the importance of saltmarsh, the benefits of natural coastal protection, and adaptation management.

Research

The research we report here is currently exploratory in nature and sets out to test the viability of using UAV platforms and sensors to monitor and map saltmarsh. More specifically the questions we wish to address are:

- How practical are UAV remote sensing platforms and miniaturised sensors for collecting remotely sensed data and imagery of coastal saltmarsh?
- How easy is it to acquire high-resolution data and information from UAV remote sensing?
- Is the spatial and temporal resolution of UAV data and imagery useful for the monitoring and mapping of coastal saltmarsh?
- Can a high-resolution 3D terrain and surface model of a saltmarsh be acquired via SfM to inform saltmarsh functioning (such as interrelationships between vegetation patterns, distribution and micro-topography), and better understand saltmarsh dynamics (such as sediment erosion and accretion processes)?
- Can the integration of remote sensing, soft-copy photogrammetry, GIS and geo-visualisation tools and techniques be used to help communicate detailed information about saltmarsh morphology and ecology to a wider audience to aid in raising awareness and to educate?

The primary purpose of the work is to develop a robust methodology for the practical use of low-cost UAV-based platforms and sensors to acquire aerial data and imagery. The study is being conducted at a number of selected saltmarsh sites around the Scottish coastline based upon the Saltmarsh Survey of Scotland, and following consultation with saltmarsh experts to optimise the identification of different types of saltmarsh *hotspots* where information is needed.

UAV overflights of the selected saltmarsh sites are being conducted at regular intervals using a small commercial, off-the-shelf, drone carrying a number of small colour cameras and a number of other miniaturised sensors e.g. an NDVI camera and a thermal camera to

acquire colour stereo-photography and imagery. The flights are undertaken at a low-altitude e.g. <50m in order to maximise the spatial resolution of the photography and imagery. Ground Control Points (GCPs) are surveyed in at each site using a ground-based RTK GPS unit, or a small RTK GPS unit mounted on the UAV platform to ensure accuracy of the subsequent geo/ortho-correction of the imagery and mosaics. Pix4D softcopy photogrammetric SfM software is used to generate high-resolution DTMs and DSMs, and ortho-mosaics of the selected saltmarsh sites. Single-date imagery, DTMs and DEMs of Difference (DOD) will be interpreted to create vegetation maps, and establish where sediment has been eroded, where there is no change, and where accretion has taken place. On-screen digitising, image interpretation and digital image processing (e.g. classification techniques) will be used to prepare maps of the vegetation types and communities in the saltmarsh. Reference documentation and co-incident ground-truthing (where access is possible) is used to ground-truth the saltmarsh vegetation. Pix4D soft-copy photogrammetric software will be used to develop 3D models of the saltmarsh micro-topography (a DSM and DTM) and will be used to provide: (a) insight into the saltmarsh surface characteristics; (b) identify surface geomorphological features of the saltmarsh; (c) identify areas of erosion and accretion within the saltmarsh; and (d) correlate vegetation patterns and distribution with the geomorphology and topography of the saltmarsh. The imagery and 3D model will form the basis for developing geo-visualisations of each saltmarsh site. Integrating the vegetation map and topographic surfaces within a GIS will allow us to develop novel ways to communicate information about saltmarsh functioning to the general public in order to raise awareness about the nature and value of saltmarsh as a key element in coastal protection and management.

Novel

This is a novel, practical and integrated data collection, processing, analysis, modelling and communication approach to the acquisition of high-resolution spatial and temporal information about coastal saltmarsh. At its core is the goal to develop an inherently low-cost and practical solution to the acquisition of information about the functioning of coastal and estuarine saltmarshes, their utility and management, together with communication with the public**.**

Ultimately outputs from the UAV-acquired aerial data will provide input to a GIS and offer the potential to explore new ways to raise awareness and engage stakeholders in understanding the importance of safeguarding the roles and functions of saltmarshes via coastal management. The use of geo-visualisation tools and techniques to communicate information will provide a novel way to promote greater awareness and understanding of saltmarshes, and engage the public in understanding the ecosystem services provided. The use of 3D models and Virtual Reality (VR) tools and technologies will be used to communicate information to coastal managers, in planning and informing decision-making, and to drive scenario discussion with policy and community stakeholders (e.g. the in-combination impacts of sea level rise, flood risk management and coastal reclamation and their effect on saltmarshes and management responses).

Summary and Conclusions

Saltmarshes are recognised to be a key feature of our coast, offering not only important habitat for wildlife and vegetation, but also a major part of our current and future climate change mitigation and adaptation responses at the coast, helping to safeguard our homes and activities. They can be, for example, low-cost, carbon-storing, self-repairing, coastal flood protection features that have the ability to keep pace with sea-level rise. Low-cost UAVs now provide a practical means to provide high-resolution, small-area multi-temporal aerial surveys of coastal and estuarine saltmarsh with the potential to collect data more cheaply and quickly, and to present it in novel ways that can significantly enhance our understanding of their characteristics, form and function over both space and time. Such information will be very relevant to the scientist and policymaker in managing this resource, and also in an educational and awareness capacity for the public to perceive and better understand the importance of managing this area of the coast.

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