Coastal monitoring and the use of lightweight drones (UAVs)

By Roman Sorgenfrei

1. Surveying the Mekong Delta coast
The Mekong Delta is one of the most vulnerable deltas in the world. Climate change impacts such as rising sea level, land subsidence, erosion, in combination with upstream development threaten the existence of the region and the local people. The coastal mangrove forests which protect the hinterlands from flooding and storms are declining dramatically. The problems along the coast are quickly worsening and the resident communities are at threat. The monitoring and surveying of the current state of the coastal area as well as the surveying of the effectiveness of coastal protection measures such as dykes, mangrove plantations and breakwater has high priority. Furthermore, the complex dynamics of the shoreline – accretion and erosion - can only be understood if the changes can be recorded. Well established methods for collecting data in the coastal zone typically involve two-dimensional profiling using traditional survey techniques like GPS. Limitations of these in situ survey methods include the fact that they are labour-intensive, physically restrictive (e.g. due to the presence of dense vegetation, fragile ecosystems, quagmire etc. preventing access) and simply unfeasible given the areal extent of the terrain required to be surveyed within a limited timeframe.

There are several coastal monitoring methods which were used in the Mekong Delta. Water-based video monitoring techniques were used in the provinces of Kien Giang and Ca Mau and resulted in a GIS enabled map of mangrove density, erosion intensity and human impacts (see library). Airborne methods such as LiDAR mounted to an airplane overcome many of the limitations of in situ techniques by remotely sensing topographic data over large spatial areas and at very fine resolutions. LiDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the earth. These light pulses - combined with other data recorded by the airborne system - generate precise, three-dimensional information about the shape of the earth and its surface features. This technique is for instance used along the coasts of Germany. The significant costs involved in undertaking LiDAR surveys, in large part due to the considerable logistical efforts required to deploy a piloted airplane, put this approach for routinely monitoring coastal areas beyond the scope of most projects at province level. As a result, where repeated LiDAR surveys of the coastal zone do exist, they are typically confined to intermittent sampling every few years and lack a consistent sampling strategy. Another option is the analysis of high resolution satellite imagery. To use these for a systematic monitoring of the coastal areas they need to be accurate, recent, regular, and without cloud cover in the relevant spectral bands. Imagery with the described specifications is usually very cost intensive and is therefore also difficult to be used, to process and to interpret. For regular overall observations of changes on large Delta wide scale, the Remote Sensing using satellite images is still the best choice.

What is needed in the coastal area of the Mekong Delta is a survey technique serving multiple purposes and stakeholder. Disaster risk management, science, forest coverage and many more purposes can be monitored by a relative new instrument, the Unmanned Aerial
Vehicle (UAV), commonly known also as lightweight drone and “Flycams” in Vietnam. The UAV is an aircraft without a human pilot aboard. UAVs are a component of an Unmanned Aircraft System (UAS); which include an UAV, a ground-based controller, and a system of communications between the two. There are several model lines in use and in the following these drones are presented as suitable cost-efficient tool for coastal surveys.

Figure 1. UAV (lightweight drone) in use

2. The capacity and potential of UAVs for mapping, surveying, and monitoring in the coastal zone

In recent years there has been a rapid increase in the use of Unmanned Aerial Vehicles (UAVs or “drones”) for commercial and recreational applications worldwide. One such field in which UAVs have been found to be particularly beneficial is as a tool for environmental surveying, mapping and monitoring (see Table 1 for examples of UAV applications).
Erosion monitoring, assessing cliff stability, monitoring coastal vegetation and changes in land volume or coastline state are only a few examples of the applications of UAVs in coastal areas collecting data at high-accuracy and with very high spatial resolution. They play an increasingly important role in the systematic monitoring of coastal areas and forest rehabilitation around the world. The technology is evolving very fast and both the navigation as well as the data processing of visual results are becoming more sophisticated and user-friendly. Current UAV applications in the coastal engineering sector in Vietnam include: mapping and surveying coastal waterworks and environment. At the same time, the videos improve communication and broader understanding through data visualization. In future it can be expected that new applications are being developed in parallel with advancements in data acquisition and processing technologies which broaden the scope of UAVs even more.

**Table 1: Examples for UAV applications for environmental monitoring.**

<table>
<thead>
<tr>
<th>Forestry</th>
<th>Change monitoring</th>
<th>Terrain modelling</th>
<th>Coastal management</th>
<th>River &amp; flood assessment</th>
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<tr>
<td>Vegetation health analysis</td>
<td>Environmental Pollution</td>
<td>Morphology</td>
<td>Erosion monitoring</td>
<td>River mapping &amp; modelling</td>
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<td>Biomass estimation</td>
<td>Glacial dynamics</td>
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<td>Fire detection &amp; tracking</td>
<td>Coastal / soil erosion</td>
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<td>Storm damage assessment</td>
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<td>Planting / re-planting campaign planning</td>
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<td>Deforestation / illegal logging / farming / incursion monitoring</td>
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<td>Forest mapping</td>
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<td>Forest classification</td>
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UAV technology offers the ability to access previously unreachable areas or points of view, providing the user with still photos and video images that can greatly enhance communications and documentation. Sites that would normally be too dangerous to visit by field personnel such as breakwaters, steep cliffs or loose terrain, and areas with dense vegetation. Examples for
videos taken from aerial points of view (bird’s-eye view) showing such sites can be found on the online Coastal Protection Tool (CPMD). Within few weeks the entire provincial coastlines can be recorded repeatedly.

The result is not only impressive picture but equipped with an on-board sensor such as a high-resolution camera in the visible or near infrared light bands, and making use of state-of-the-art image processing algorithms, UAV have the potential to rapidly sample large areas of terrain at very high resolution and accuracy. The availability of different camera sensors allows UAVs to provide even more information than what the human eye can observe. Sensors collecting light beyond the for human visible spectrum, like near infrared light, can be used to compute vegetation indices. For example, the Normalized Difference Vegetation Index (NDVI) is a simple graphical indicator that can be used to analyse and assess whether the target being observed contains live green vegetation or not. It shows the difference between red light reflected from plants, and near-infrared light. Healthy leaves with an active photosynthesis process absorb red light, and strongly reflect near infrared light. Dead, or unhealthy leaves reflect both wavelengths of light. This property can be used to measure the health of vegetation or also to identify plant species.

The following sensors are currently available:

- RGB (red, green, blue): for plant counting, elevation modeling, and visual inspection
- NIR (near infrared): for water management, erosion analysis, plant counting, soil moisture analysis, and crop health
- RE (red edge): plant counting, water management, and crop health
- Thermal Infrared: irrigation scheduling, plant physiology, and yield forecasting

Within the next years further small and light sensors, such as LiDAR, for lightweight drones, will be developed, expanding the potential usage of this technology even further.

### 3. Technical background and UAV basics

A basic UAV system is composed of an aircraft frame, propulsion system, onboard autopilot, and ground control station. The two most common platforms are multirotors (usually consisting of 4, 6, or 8 fixed-pitch propellers), and fixed-wing aircraft. Multirotors are more manoeuvrable than fixed wing platforms but generally have shorter flight times.

A UAV may be remotely piloted using a radio control device (ground control station) or flown autonomously using an onboard autopilot. The autopilot is able to follow a pre-planned flight path by processing positional and attitude data from a global navigation and satellite system (GNSS) receiver and inertial measurement unit (IMU). The ground control station receives flight data such as aircraft location, elevation, speed, and battery status via a telemetry radio link. The operator monitors the flight data while the UAV is in flight and may assume manual control of the UAV at any time.

Safety measures are built into most multirotor UAVs to reduce the likelihood of crashes resulting from low battery power or loss of communications with the ground control station. For example, a UAV may return to the launch location or automatically land itself if the telemetry link is lost or if the battery life drops below a pre-set level. Additional safety measures such as object
detection and avoidance are improved and will broaden applications for UAVs and presumably encourage greater adoption of this technology to engineering studies.

4. Aerial mapping and surveying using UAVs

Aerial photographs taken from a UAV platform can be processed using commercial Structure-from-Motion (SfM) photogrammetry software to obtain high-resolution orthomosaic photographs and elevation data that is comparable to land-based surveys. Structure-from-Motion describes the process of 3D surface calculation using 2D image information from different perspectives. In order to be able to calculate 3D points from 2D image data it is first necessary to align the set of images. This is done by a combination of photogrammetric algorithms. In particular, these are feature point detection and extraction, correlation of similar pairs of points, relative orientation of image pairs, robust outlier detection estimators and bundle block adjustment. In general, the technique involves flying the UAV in a lawn mower pattern to acquire overlapping photographs. Specialized flight planning software is used to develop an optimum flight path based on the flight altitude, camera lens properties, and desired photo overlap (influences the results resolution). These parameters are adjusted to fly most economically (maximum area per battery charge).

The flight path with waypoints is uploaded to the drone which automatically starts the engines, takes off, flights to the correct altitude and the starting point of the monitoring track, then follows the flight path while automatically taking the images (orthophotos). After completing the path, or in case of low battery values, it flies back to the starting point where it descends and lands. The operator just needs to observe the flight parameters on the ground control station to check if all goes well and must take care that the landing area is free of obstacles (e.g. exited kids coming to see the UAV). If issues occur the operator can take manual control at any time to ensure safe landing.

The orthophotos are automatically georeferenced using the onboard GNSS and can be used as is or processed to obtain mapping products. GNSS stands for Global Navigation Satellite System and is the standard generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. This term includes e.g. the GPS, GLONASS, Galileo, Beidou and other regional systems. The advantage to having access to multiple satellites is accuracy, redundancy, and availability at all times. Pre-established ground control points (GCP) may also be distributed around the project site to increase the positional accuracy. The accuracy of the resulting data products is generally less than 0.1 m, which is adequate for many coastal engineering studies. Concluding, the described procedure is most effective for sites where a traditional land survey would be too labour intensive and where manned aerial flights would be too expensive.

An example for the data processing result can be seen in the figure below. A software for photogrammetry was used to process sets of orthophotos into a 3D point cloud. These points were then used to generate a georeferenced orthomosaic and digital surface model (DSM) (Figure 2). The processing results can be further analysed topic related using geographical information systems (GIS). In case multispectral sensors were used for data collection (e.g. NIR), remote sensing algorithms like NDVI can also be applied.
5. **Examples of application in Mekong Delta provinces**

In the following, a collection of images made recently along the coast of the Mekong Delta is illustrating the unique perspective and options of UVA.
6. Comparison with other methods and future applications

In Ca Mau province the Shoreline Video Assessment Method (SVAM) was used to assess the following parameters:

- Shoreline Physical Condition,
- Shoreline Mangrove Forest Type,
- Extent and Condition,
- Mangrove Resource Use,
- Creation of Biomass classes,
- Creation of extreme erosion class,
- Creation of Human Influence classes.

This classification is based on continuous video filming along the coastline followed by an interpretation of the resulting georeferenced images. The biggest limitation of this method is the dimensional limitation of obtaining information only from the seaward side of the coastline. Using UAVs this method could become airborne and provide much needed “depth” information about the more landward mangrove forest belt (e.g. width, density, human influence, …).

Currently several datasets collected by UAV over the coastal area of Soc Trang province are piloted to be used for calculation of forest biomass as well as mangrove species identification.
7. Challenges of environmental monitoring using UAV in Vietnam

The current legislation for any usage of UAV, meaning for professional monitoring and mapping and recreational purposes alike, is regulated by the decrees:

- 36/2008/ND-CP Decree on management of unmanned aircraft and ultralight aircraft (link)
- 79/2011/ND-CP Decree amending and supplementing of a number of articles of the government decree no. 36/2008/ND-CP (link)

**Summary of regulations:**
Organizations and individuals that use unmanned aircraft to make flights for economic, social, cultural, sport and scientific purposes have to submit applications for a flight license. The Operations Bureau of the General Command Post licenses or refuses to license flights of unmanned aircraft. At least 7 working days before the planned date of organization of their flights, organizations and individuals shall submit applications for flight licenses to the Operations Bureau of the General Command Post (Ministry of Defense). Within 5 working days after receiving complete dossiers as prescribed in the decrees, the Operations Bureau of the General Command Post grants licenses for organizing flights.

Due to security reason the application of UAVs in Vietnam is monitored, and flights are often restricted both in time and area permitted to be flown over. But in emergency situations (e.g. forest fires, comparison of pre- and post-storm damage assessments, acute danger from proceeding river erosion) a flexible deployment of UAV teams is necessary. Therefore, the legal status of UAV usage for environmental monitoring needs to be clarified. This can make the continued application of this innovative technology possible throughout all relevant sectors. At the same time, such legislation should include the necessity to protect individual’s privacy and private information.

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**Experience with UAVs in the province: voice from the ground**

“In the past, field surveys using GPS took several hours and provided data only for the area observable from the ground around the walking track. Using drones at heights up to 200 metres, it is possible for us to stay on the dyke for video filming as well as aerial mapping. It saves time and workload. Photos for up to 100 hectares can be taken in less than 15 minutes. And back in the office, software is used to process and analyse the collected sets of photos. It supports us in our decision-making process. Such innovative technology should be used in the long term and sustainably” (Mr. Nguyễn Đức Hoàng, head of Forest Management and Protection Section, Forest Protection Sub-department in Soc Trang province).
8. Conclusion

Drones are the perfect tool for regular coastal surveying, monitoring and mapping. They are saving time and costs, make remote areas observable, and provide accurate data of the current situation, thereby supporting information-based decision making. Filming and photogrammetry are used to support forest management and planning, classification of forests, mapping, coastline management, management of water resources and the inspection of coastal protection measures. Information gathered can be used in conjunction with historical data, satellite imagery and models created in 3-D to ensure an accurate compilation of current conditions.

With the application of lightweight drones, the coastal provinces of the Mekong Delta and regional planning institutions are already now at the front line of coastal protection techniques. Applied together by several authorities which work together on cooperative monitoring and joint planning. The expected added value is a strengthened information-based intersectoral planning for coastal management through up to date expressive analyses and monitoring results. In future, further fields of application might be explored, such as agriculture and irrigation. The outlook of this technology is excellent as it enables cost-efficient planning and management of coastal zones in the Mekong Delta.

In addition, further lightweight multispectral and hyperspectral sensors for UAVs will be available in near future. Already now first appliances of LiDAR (Light Detection and Ranging) and Near Infrared Sensors (NIR for vegetation indices like NDVI) are available. This development increases the array of topics which can be addressed within the next years and lowers the costs of standard surveys nowadays only possible with huge, heavy systems on piloted planes or satellite-based systems, enabling coastal provinces to cost efficiently plan and manage the coastal zone.

Climate change can cause unpredictable events and it is more important than ever to keep an eye on the development of the coastline. Drones will continue to take an ever-increasing role in the monitoring and assessment of coastal erosion and assist in effective decision making for local planners and environmental bodies.

References


**Legal documents**

- Decree 36/2008/ND-CP on management of unmanned aircraft and ultralight aircraft (<link>link</link>)
- Decree 79/2011/ND-CP amending and supplementing of a number of articles of the government decree no. 36/2008/ND-CP (<link>link</link>).