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DRELIO: An Unmanned Helicopter for Imaging Coastal Areas

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ABSTRACT

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Very high spatial resolution remote sensing images and Digital Elevation Models (DEM) are widely used in coastal management applications. For example, they are used for the quantification of morphosedimentary changes of the coastal fringe, including cross-shore and longshore sediment transport. They are also used as input in hydrodynamics numerical modelling . Spatial resolution, precision and accuracy are critical parameters of the DEM. Presently, most of DEM are built using aerial or satellite images with a spatial resolution coarser than 50cm is not accurate enough for most of applications. An unmanned photogrammetric helicopter (DRELIO) has been developed. It is equipped with an autopilot system. After loading the flight plan, no ground communications are needed from take off to landing. The fly altitude can reach 100m above the ground. DRELIO can operate in windy conditions up to 50km/h and it is able to make stationary flights. A reflex camera with high quality interchangeable optics is onboard. Depending on the focal length and flying altitude, the resolution of the images varies from 1 to 5cm with a ground coverage of 50 by 75m up to 250 by 375m. Due to specific flight conditions and image acquisitions, a photogrammetric toolbox has been developed. Using stereoscopic images and GPS positioning of reference points on the images, it allows building DEM and an orthorectified image with a spatial resolution better than 5cm. In this study, we present an example of an acquisition realzed on the beach of Porsmillin (French Brittany) and we discuss the precision and accuracy obtained by this method. The DRELIO system, which produces DEM concurrent to LIDARs, appears now to be more flexible and efficient than UAV (Unmanned Aerial Vehicle) helicopters equipped with electric engines, UAV planes and less expensive than LIDAR.

ADITIONAL INDEX WORDS: *DEM, Photogrammetry*

INTRODUCTION

Coastal monitoring is considered as a major challenge to anticipate the response of coastal hazards on coastal risks (Ruggiero *et al.,* 2000; Rieb and Walker, 2001). Moreover, survey of coasts provides a useful help for management regarding of coastal defence, land use and planning (Hamm *et al.,* 2002; Meur-Férec *et al.,* 2008). Furthermore, to be fully successful, Integrated Coastal Management (ICM) programs, must explicitly incorporate a realistic range of coastal processes and responses based on a physical environment understanding by the use of surveys (Solomon and Forbes, 1999). Remote sensing is widely used in coastal studies. In oceanic and coastal domains, remote sensing techniques are the only practical methods able to cover large areas (Dekker *et al.,* 2001). Until now, most of the remote sensing studies on such areas are based on satellite images. However, coastal monitoring needs some requirements which can actually not be obtained from optical satellite data. In cloudy areas, ground and water surface cannot be observed. Despite recent improvements in spatial resolution, this resolution remains too low for some phenomena (for example hydrologic phenomena) that would require a spatial resolution better than 50 cm. At last, time revisit is totally dependant on satellite orbits. These limitations can be partly overcome using aerial platforms that could supply data with a spatial resolution better than 50cm (Casson *et al.,* 2005). Another advantage of the aerial technique is the stereoscopic acquisition which can supply DEM with submetric accuracy. Additionally to multitemporal aerial images, which allow to determine 2D coastal evolution, multitemporal DEMs can be used for 3D monitoring of beach morphology. However, the cost in time and money of a dedicated mission can be prohibitive. Furthermore such a mission requires several days to be organized. To overcome these various constraints, new techniques are prospected. Platforms such as kites, microlights and drones, already used for surveying landslides and erosion slopes (Casson *et al.,* 2005), rivers (Lejot *et al.,* 2007), as well as agriculture (Sugiura *et al.,* 2005) are very promising tools. Such remotely operated platforms are flexible in term of use and can provide repeated surveys over a short period of time. They allow to observe coastal change and to quantify the motions of local features. The new technical challenges include how to increase the resolution of the images and the accuracy of the DEM to allow the survey of smaller geomorphic features (centimetric to decimetric resolution), but also how to repeat image acquisitions over shorter periods of time (weekly to annually) to analyze channel changes, particularly within monitoring surveys of restoration and management projects. Here we present the potential and limitation of an unmanned helicopter developed by our team, called DRELIO for imaging coastal area. An example of acquisition is also presented.

DRELIO

DRELIO system consists in 4 main parts (Figure 1) a) the helicopter, b) payload for scientific sensors (camera, video-camera), c) onboard flight control system (FCS, Autopilot, GPS, magnetometer), d) ground control system (GCS) for mission planning and control (computer, ground air data link, joystick, joypad).

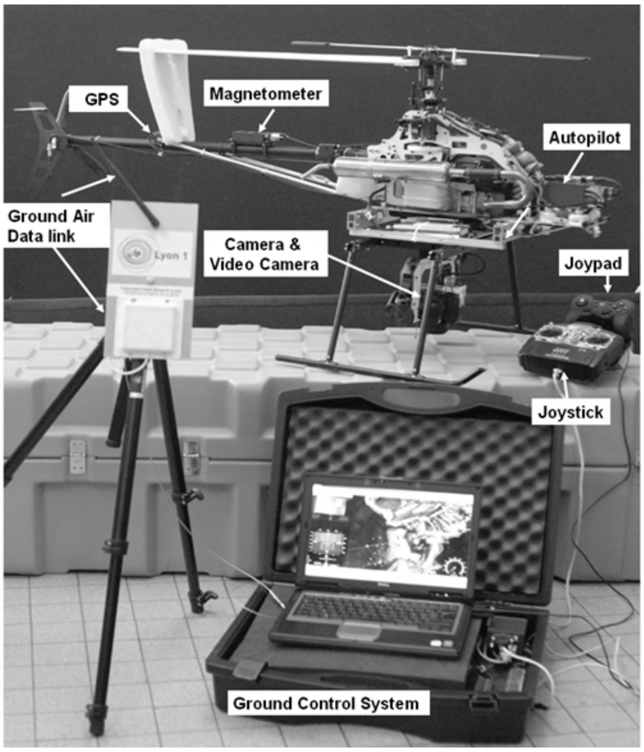

Figure 1: Technical configuration of DRELIO

The helicopter is a Vario rigidified acrobatic thermic model. Rotation speed of blades has been reduced in order to limit vibrations and to increase flight stability. Despite this limitation, the maximum speed reaches 70km.h^{-1}. The total weight is 11kg with an additional payload of 6kg. In order to protect DRELIO from the corrosive salted water, all wires have been isolated. Under the helicopter a 3D rotation platine is installed. The motion of the platine is either controlled in real time from the ground but it can also be programmed before the mission. As it is linked to a GPS, series of specific photographs can be programmed in order to realize multitemporal comparisons from exactly the same point and angle of view. A video camera transfers in real time the images that are acquired with a very high resolution camera. This video is low resolution but is used only to control the swath coverage during the acquisition. An autopilot is installed. It is connected to a atmospheric pressure sensor, an inertial sensor, a geomagnetic direction sensor and a GPS. DRELIO is thus able of fully automatic takeoff, hovering flight plan following, and landing. Its integrated radio link allows data communication up to 60km. Once a flight plan is loaded, no ground communications is needed. This extends the range of operation beyond radio reach. Depending on the mode of the autopilot (manual, hoovering or planned flight), manual (Joystick) or semi manual (Joypad) remote controls can be used.

TYPICAL DRELIO MISSION

The missions are planned early in the morning or late in the evening when the sun is just under the horizon. In that case, the light is homogeneous and the lack of shadows allows a good correlation of the stereo-images. Moreover, the period of dawn and twilight are characterized by low wind. If several missions are planned over the same area, they will be done in the same illumination conditions. 0.5 by 0.5m red targets with a 10cm wide cross in their center are disposed on the ground. The target density is adjusted in such a way that 8 targets at least will be visible on the images. The exact location of the center of targets is measured by DGPS with a centimetric precision.

The flight plan of DRELIO is then programmed in the autopilot software. The flight plan is made up of the position of the image acquisition points, the DRELIO landing location, the velocity of DRELIO between two points, the emergency landing site in case of link break-off between the station and the Helicopter. DRELIO flight altitude usually ranges from 50 to 200m above the ground. Therefore with 50mm focus zoom, pixel size is around 2cm.

DELIO is verified according a check list. Both mechanical, electronic and image systems are checked and verified. Then, the engine is started up. After the heating of the engine, the mission is launched by a start up order given to the software. At every moment, the flight can be controlled from a manned remote control if a problem is detected.

After the flight, the images are transferred from the camera to a computer in order to be inspected. If the quality of the images is sufficient, the mission is over.

DEM PROCESSING STEPS

Digital Elevation Models (DEMs) can be derived using photogrammetric techniques applied on two images, called a stereoscopic pair, that are acquired over the same area from different view angles. This technique requires knowledge of the optical characteristics of the camera, which are called “internal parameters”, and knowledge of the position and orientation of the camera at the time of acquisition, called “external parameters”. The internal parameters of the camera are known either from the camera manufacturer or by measuring them before the mission. These parameters are the focal distance of the lens (c), the principal point coordinates in the image system (η_0, ξ_0), which is the projection of the optical axis on the image, and the distortion parameters of the lens (Kasser and Egels, 2002). The external parameters of the camera are defined for each image. They are (a) the coordinates (X_0, Y_0, Z_0) of the principal point of the camera and (b) the orientations (ω, ϕ, κ) of the line of sight of the camera (Figure 2). These parameters can be defined in either a projected or geographic reference frame.

Deriving a DEM from stereoscopic images acquired by DRELIO is realized using the methods that are similar to those used to derive DEM from classical airborne missions, even if the calculation is more difficult. The first problem is to control and obtain precise image acquisition parameters. In terms of altitude and orientation, the flight of DRELIO is not as stable as that of a plane. Moreover, the technical constraints in these cases do not permit the drone to be equipped with precise positioning equipment. As a result, the external parameters of each image are poorly defined. The precision on these parameters can be increased using the ground control points (GCP). These points are identified by the red targets lying on the ground during acquisitions. They are geo-located by differential GPS with a precision of few centimeters. Using the absolute locations of these points and their positions on the images, minimization methods have been developed to increase the accuracy of the external parameters. This accuracy is fundamental because it determines the quality of the DEM in the absolute reference frame.

Only commercial digital reflex camera is used on DRELIO due to cost and weight. To optimize the missions and to reduce the number of images necessary to cover a given zone, lenses with a focal length smaller than or equal to 35mm are used. These lenses maximize the swath coverage. However they are affected by optical distortions larger than those from photogrammetric cameras, which tend to use lenses with a focal length larger than 135mm (Kasser and Egels, 2002). The distortion, which is the difference of geometry between a perfect lens and a real one, can reach more than 5 pixels on the camera onboard the drone.

The computation chain of a DEM starts by a rough first estimation of the exterior parameters (X_0, Y_0, Z_0, ω, φ, κ) of the camera for two stereoscopic images by a direct linear transformation (DLT) (Mikhail *et al.*, 2001). If necessary, the focal length and the principal point of the camera can be also specified during this step. These parameters are used to project the two images in neighbouring geometries. The GCPs of which image position has been determined are used to constrain the external parameters using mean squares minimization (Kraus and Waldhäusl, 1994).

In the following step, the position of each point on the first image is associated with the position of the analogous point in the second image. A pair of points that represents an unique object on the two images is called a pair of homologous points. The correspondence between the pixels of the two images is calculated by maximizing a correlation function (Baratoux *et al.*, 2001; Delacourt *et al.*, 2004). For each point of the first image, we obtain three arrays of the same size: the first one contains the shift in *X* for each pixel between the two images, the second one the shift in *Y* and the last one the correlation coefficient. Correlation is accepted or rejected according to the correlation coefficient value. If the threshold is too high, the number of accepted correlated points is low but the points are well correlated. If the value of the threshold is too low, the number of correlated points is high but some pairs can be wrong.

At least, the photogrammetric equations are applied to each pair of homologous points to determine their 3D coordinates (Kraus and Waldhäusl, 1994). A last minimization step is applied to determine the 3D coordinates that reduce the distance between the lines of sight of each pixel. The minimized distance between the lines of sight, which should be zero in a perfect case, is a measurement of the DEM precision. Using the resulting DEM, two orthophotos can be computed.

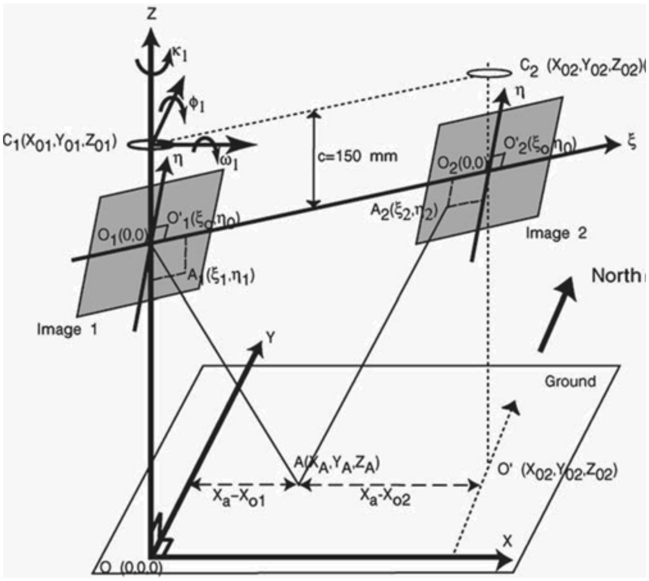

Figure 2: Reference systems and geometric characteristics of a stereoscopic pair (after Kraus *et al.*, 1979; Jensen, 2000; Casson *et al.*, 2003), where (X, Y, Z) is the absolute reference system with O as its origin; C1 (X_{01}, Y_{01}, Z_{01}) and C2 (X_{02}, Y_{02}, Z_{02}) are the positions of cameras in the absolute reference system; O_2 is the vertical projection of the second camera on the ground; η and ξ are the axes of the image reference systems; O_1 (0, 0) and O_2 (0, 0) are the centers of the images; O_1' (η_0, ξ_0) and O_2' (η_0, ξ_0) are the real intersections between optic axis and film, which are referred to as the principal points; A (X_A, Y_A, Z_A) is a ground point and A_1 (η_1, ξ_1) and A_2 (η_2, ξ_2) are the corresponding image points; ($X_a - X_{01}$) is the distance between the A point and the first camera along the X-axis; ($X_a - X_{02}$) is the distance between the A point and the second camera along the X-axis; c is the focal length of the camera and (ω_1, ϕ_1, κ_1) are the rotation angles of the first camera.

RESULTS AND DISCUSSION

An example of the products realized using stereo-images is shown on figure 3. These results have been obtained from a mission realized on the Porsmillin beach located in French Brittany. The flight altitude was close to 100m and the focal distance of the camera was 35mm. The swath of the images is 90m with a resolution of 2cm. A stereo pair of images has been selected. The common covering of the images is close to 60%. A 3cm of resolution DEM has been computed. One image has been draped on this DEM (Figure 3a). The general trend of the topography of the beach is visible on the DEM. The upper part of the beach is flat. The middle part displays a constant slope to the swatch zone which slope is lower. The last part of the profile displays a slope that is similar to the one of the middle part of the profile. Moreover, the DEM has captured small details of the topography. For example a 1m in diameter, 10cm deep hole is visible on the profiles (Figure 3 and 4). The validity of these profiles has been estimated comparing them with a profile acquired by DGPS. The deviation between the DGPS data and the DEM computed from the image is less than 3cm. .

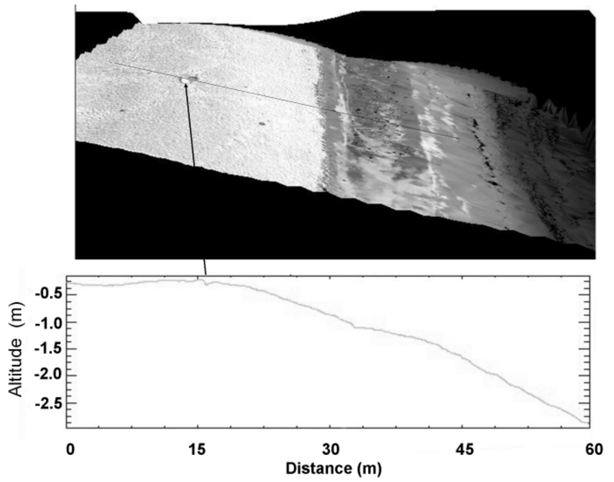

Figure 3: Top (3a): orthorectified image acquired by DRELIO and draped on the DEM derived from 2 stereoscopic images. The black line over the image corresponds to the topographic profile across the beach shown below (3b).

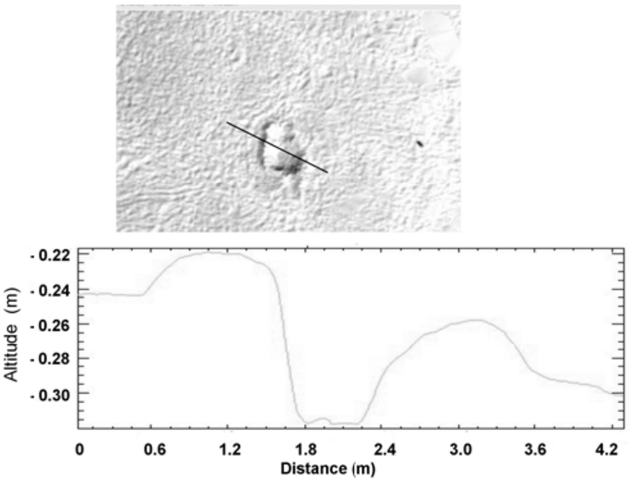

Figure 4: Top: orthorectified image acquired by DRELIO on a sand hole. Footsteps are observed around the hole. The black line over the image corresponds to the topographic profile across the beach presented below.

These results show that the DRELIO system has demonstrated his capabilities for coastal research. The images obtained from DRELIO can be used to derive DEM with a resolution of 3cm and a precision better than 3cm on 100m by 100m surfaces. The advantage of DRELIO is that it is a very flexible system. Missions can be planned and performed in less than 1 day and results can be then obtained within a few hours. DRELIO is less sensitive to weather conditions than conventional paramotors drones and can therefore be used almost all the year long.

The main limitation of DRELIO is its positioning that is not accurate enough to derive directly DEM from the flight data. Geo-located targets are needed on the ground. Their installation and the measurement of their position is the most time consuming step of a mission. An upcoming improvement will be to control the flight, setting up an inertial sensor with a sufficient angular and positioning precision to release us from ground target position measurements.

The others UAV (Unmanned Aerial Vehicle) systems which could be competitive with DRELIO are generally helicopters sustained by electric engines or planes equipped with thermal engines. The power of electric systems is not sufficient to carry heavy charges such as the high resolution cameras that are abroad DRELIO. More over electric engines are not able to maintain a programmed way if the wind speed exceeds 20km/h. DRELIO has been tested in wind speeds exceeding 50km/h. The UAV planes can fly in windy condition and can support heavy charges. However they must fly at velocities above 50km/h. In such conditions, it is quite impossible to obtain sharp images of the ground. The DRELIO velocity flight is variable and it is also able to make stationary flight. The classical velocity used during a mission is around 5km/h. Thus, the pictures taken by DRELIO are always sharp.

The DEM obtained from the data of DRELIO data have a resolution which is around some centimeters for a precision which is better than 5 centimeters. The properties of these DEM are thus similar to those obtained by LIDAR. But a LIDAR mission is expensive. It requires the rental of an helicopter and of a LIDAR. DRELIO missions are less expensive and are more flexible. A DRELIO mission can be realized by two engineers and programmed in one day with a simple logistics.

CONCLUSION

Our team has developed DRELIO, an integrated system for the acquisition and the processing of high resolution images of coastal domains. This flexible system can acquire high resolution images, which, after accurate processing, allow obtaining 3cm resolution DEM with accuracy better than 3cm. The potential of the system has not been fully exploited yet. Indeed, the potential of DRELIO is very large. The images delivered with this system are also used to derive DEM of immerged areas where water is transparent enough to observe the ground. The DEM can be derived by classical photogrammetry and also from water color (Lejot *et al.,* 2007). The results from repeated mission will also be used to derive successive DEM of an area affected by processes modifying the topography such as a storm. Such results will be important to quantify the transfer of sediments in coastal domains. The DRELIO system, which produces DEM concurrent to LIDARs, appears now to be more flexible and efficient than UAV helicopters equipped with electric engines, UAV planes and less expensive than LIDAR.

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