Rapid Environmental Assessment (REA) from small Unmanned Aerial Vehicle (UAV).

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BACKGROUND: The nearshore is a highly dynamic area where hydrodynamic and morphodynamic processes may change on a wide range of spatial and temporal scales .The information regarding these variations (estimation of waves, currents and bathymetry) can be used to assist in performing **Rapid Environmental Assessment (REA)**. The **standard *in situ* methodologies** (ship-board echo-soundings, or amphibious vehicle) may not be possible in denied environments and are typically expensive and dangerous.
In recent years, video imaging from fixed land based station has been used extensively for studying the surf zone. The signals from the camera are processed to provide standard products in helping REA. The most common tool is the time exposed image, as presented in figure 1.

Figure 1: this type of image highlights regions of consistent **wave breaking** as seen in these white stripes here. This information provides the location of long shore bars and other bathymetric features as well as circulation patterns such as rip currents.

OBJECTIVES: The main goal was the development of a novel technique for creating time averaged surf zone imagery from a small Unmanned Aerial Vehicle (UAV) platform.
In particular the project objectives are:
- ✓ To test the geolocation capabilities of such a platform;
- ✓ To make basic improvements to geolocation and image collection methods;
- ✓ To assess the oceanographic potential of such sensor.

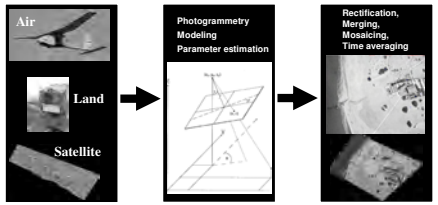


Figure 2: flow chart of the work performed during the Airborne Forward Eyes project. The first step involved the data acquisitions (many data sources were available); the second was the data processing (the acquisitions were processed and analyzed to make improvement on the final products); and last step was the products generation (many different types of products were created, such as georectified images and movies, mosaics and time expose images.

THE SENSOR:

In a decision based largely on market penetration, the AeroVironment (AV) UAV Raven was chosen. Physically it has a wingspan of 1.4 m and a weight of 1.9 kg. It's composed of three main parts:
1. the wings;
2. the nose (that is interchangeable allowing the selection of camera type, (optical or IR), and camera orientation (Forward, Side or down camera);
3. the body (that contains the sensors which include GPS receivers, rate sensors and pressure sensors).

THE GROUND STATION:

Imagery is collected using standard 640 x 480 NTSC format video at 29.97 frames per seconds while the metadata is updated at 4 Hz. Both the video signal and metadata are transmitted to the system GCU – Ground Control Unit (see the figure below) in real time.

CAMERA MODEL[1]: The ability to associate scenes and objects visible in video imagery with their corresponding ground location is a prerequisite to all imaging methods. Sensor orientation, also called image georeferencing, is defined by a transformation between the image coordinates specified in the camera frame and ground coordinates, specified in a mapping reference frame. The transformation from world coordinates (X,Y,Z), to image coordinates (U,V) (and *vice-versa*) was performed in homogeneous coordinates using the camera model: $\mathbf{P}(X,Y,Z,1)^T = (U,V,1)^T$

The camera matrix P can be decomposed as $\mathbf{P} = \mathbf{K} \cdot \mathbf{R} \cdot \mathbf{T}$, where:

Camera calibration matrix:
depends on the intrinsic parameters of the camera (focal length and center point of the image plane).

$$\mathbf{K} = \begin{pmatrix} \alpha & 0 & u_0 \\ 0 & \beta & v_0 \\ 0 & 0 & 1 \end{pmatrix}$$

Camera rotation matrix:
depends on the orientation angles and can be represented as the result of:

- three rigid rotations that describing the effective center of view (COV) of the camera to respect the world reference system;
- six rigid rotation of two sets of six Euler angles. One describing the airframe attitude (in blue) and the other describing the orientation of the camera relative to the airframe (in red).

$$\mathbf{R} = \mathbf{R}_{COV_Roll} \cdot \mathbf{R}_{COV_Tilt} \cdot \mathbf{R}_{Azimuth}$$

$$\mathbf{R} = \mathbf{R}_{Roll} \cdot \mathbf{R}_{Tilt} \cdot \mathbf{R}_{Pan} \cdot \mathbf{R}_{Bank} \cdot \mathbf{R}_{Pitch} \cdot \mathbf{R}_{Head}$$

Camera translation matrix:
depends on the position of the camera imaging plane in the world coordinate reference system:

$$\mathbf{T} = \begin{pmatrix} 1 & 0 & 0 & -X_{CAM} \\ 0 & 1 & 0 & -Y_{CAM} \\ 0 & 0 & 1 & -Z_{CAM} \end{pmatrix}$$

FIELD EXPERIMENTS: Two field experiments were performed in order to collect data. The sites were chosen on the basis of likelihood of observing significant surf conditions.

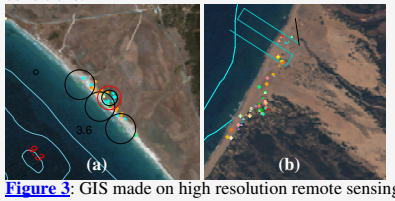


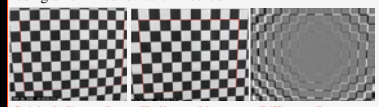
Figure 3: GIS made on high resolution remote sensing imagery (acquired by Quickbird satellite) of the field sites: (a) Playa el Retin (Spain), (b) Piscinas di Ingurtosu (Sardinia, Italy).

WORK ORGANIZATION:
- ✓ Inspection of the area and identification of appropriate instrument deployment locations;
- ✓ Placement of a target farm of artificial (of plastic) and natural Ground Control Points (e.g. rocks, and bushes) to be used as reference points with a known geographic location;
- ✓ Survey all GCPs and instrument location with the high resolution differential GPS;
- ✓ Assembly and calibration of the sensors;
- ✓ Development of a set of flight tests at varying altitudes and with varying image acquisition methods;
- ✓ Data processing, and statistical analysis to improve the metadata information;
- ✓ Generation of final products.

CAMERA CALIBRATION procedures: prior to the Raven launch there is a need to estimate the camera model parameters :

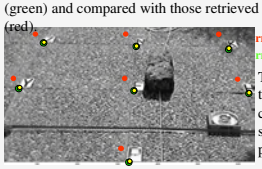
1. Lens distortion: one source of systematic error involves the lens distortions (intrinsic parameters).

Accurate lens calibration was based on analysis of multiple images of a standard checkerboard pattern at varying orientations[2]. The corner points of this series are automatically located and the parameters are estimated using a non linear solution method.



Original (distorted) Image (A) | Undistorted image (B) | Difference Image (A-B)

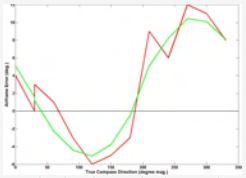
2. Ground test (for the camera) : the orientation of the camera relative to the Raven was provided by AV. However it can differ by several degrees and may change after multiple landing impacts. The test was to fix the Raven on a tripod at known location and orientation. The COV angles were estimated on the basis of known GCPs (yellow). The resulting projection were then determined (green) and compared with those retrieved using the nominal angles (red).



These results show that the use of calibrated camera mounting angles significantly reduces projection error.

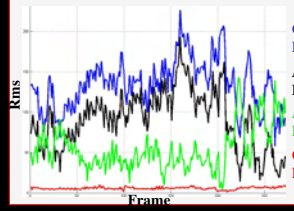
Error in camera mounting angles: Pan error = 1.1885 [deg]
Tilt error = 1.6828 [deg], Roll error = 0.96821 [deg]

3. Ground test: additional tests were made to quantify the stability, noise level and bias of navigation sensors. The results indicate that pitch and bank are stable but there is high (systematic) error in the compass heading. It has been found that this error can be well approximated (by a sinusoid) and corrected.

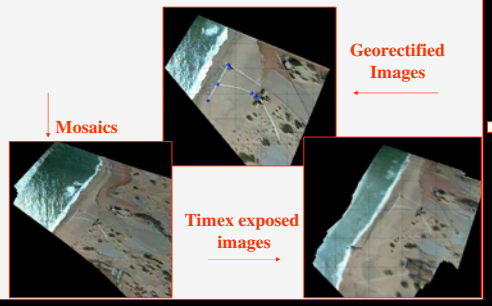


Metadata location results show random error with std deviation of 5 m in lat/lon 15 m in altitude.

DATA PROCESSING: To project images we must have camera position and orientation (attitude) information. Because the metadata accuracy was not acceptable for our proposes, NURC algorithm and estimations was used to estimate and correct the metadata information. The results show that the use of the NURC algorithm metadata corrections provide a dramatic increase in image projection



PRODUCTS: using the NURC algorithms and estimations, it was possible to make several mapping products, such as:



CONCLUSION and WORK IN PROGRESS: we have presented an approach to analyze surf zone imagery from a non stationary platform, noting some of the problems specific to UAVs for the conduct of REA operations. On the basis of the results from camera calibrations, and ground and flight tests, package accuracy has been assessed and the errors minimized using the NURC estimations. In particular, we found that the errors in ground target locations (that typically exceed 50 m for 300 m of airframe altitude) can be reduced to less that 5 m using GCPs and improved NURC calibration methodologies. Automatic procedures to determine image location and methods to generate products are currently under study. In particular we are working on a method[2] that used the satellite image to georectify the UAV acquisitions. This technique uses object recognition procedures to find matches (red lines) between the satellite image and the Raven acquisitions. As you can see from the figure only some matches are correct (green lines). After the GCPs were identified, the corresponding geographic information of these points in the satellite base image can be used to solve the camera model (the P matrix) and to make georectified image. The results retrieved using this methods are comparable with those retrieved using the ground GCPs:

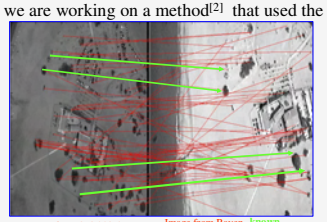


Image from Quickbird (pixels with know lat/lon) | Image from Raven (pixels with unknown lat/lon)

Rms with GCPs at ground = 3.7 pixels
Rms with automatic procedure = 13.6 pixels

This method is very powerful because doesn't require of *in-situ* measurements that are time consuming procedures.

[1] Hartley, R. & Zisserman, A. Multiple View Geometry in Computer Vision, Second Edition, Cambridge University Press., 2006; [2] http://www.cs.ubc.ca/~lowe/keypoints/)