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An easy and low-cost method for preprocessing and matching small-scale amateur aerial photography for assessing agricultural land use in Burkina Faso

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ABSTRACT

In recent decades, the Kou watershed in south-western Burkina Faso has suffered from poor water management. Despite the abundance of water, most water users regularly face water shortages because of the increase in the amount of land under irrigation. To help them achieve a more equitable allocation of irrigated land, local stakeholders need an easily managed low-cost tool for monitoring and mapping these irrigated zones. The aim of this study was to develop a fast and low-cost procedure for mosaicing and geo referencing amateur small-scale aerial photographs for land-use surveys. Sets of tens (2009) and hundreds (2007) of low-altitude aerial photographs, with a resolution of 0.4 m and 0.8 m, respectively, were used to create a detailed land-cover map of typical African small-scale irrigated agriculture. A commercially available stitching tool and GIS allowed geo referenced 'mono-images' to be constructed; both mosaics were warped on a high-resolution SPOT image with a horizontal root mean square error (RMSE) of about 11 m. The RMSE between the two image datasets was 2 m. This approach is less sensitive to atmospheric conditions that are non-predictable in programming satellite imagery.

1. Introduction

Irrigated land in sub-Saharan Africa it is predicted to increase by a further 28% by 2030 (FAO, 2002). In sub-Saharan Africa rapid population growth, coupled with recurring droughts and the continuing decline in per capita food production, has led to a renewed call for irrigation development (Urama, 2005). In south-western Burkina Faso this intensification has led to increased pressure on available land and water, accompanied by environmental degradation and the onset of water-related conflicts. Local stakeholders (i.e., decentralized State agencies responsible for agriculture and the environment) therefore need an easily manageable, low-cost tool for monitoring and mapping the irrigated zones.

On a regional scale, land-use and land-cover maps are typically produced from satellite image analysis. Although there are continental and national mapping programs (e.g., Jaffrain et al., 2005; FAO, 2011), the remote sensors are designed to cover large spatial areas and therefore might not provide enough detail. Irrigated agriculture in Burkina Faso is characterized by a highly heterogeneous patchwork of small plots with an average size of 0.5 ha, and seldom exceeding 1 ha. When standard satellite imagery is used, its spatial resolution of 10–90 m/pixel could be too coarse for mapping the sub-pixel complexity (Foody, 2000). The size of objects should be at least 3–4 times greater than the pixel size (resolution) of the satellite image (Lillesand et al., 2004). The availability of high-resolution (SPOT) to very high-resolution (Ikonos, QuickBird) images could provide a solution, but they are expensive and therefore not within everyone's reach. In addition, unforeseen unfavorable climatic conditions, such as clouds and dust, can degrade image quality and considerably reduce their usefulness. The cluster of points in Fig. 1 shows the variation in daily hours of insolation during the irrigation season (January–May) in Burkina Faso. From one day to the next, the hours of insolation can drop from 10 h to 5 or less. In such climatic conditions it is a financial risk to program a satellite image several months in advance.

Wentz et al. (2006) concluded that for mapping complex land-use configurations, aerial photographs are needed, thus resolving the problem of sub-pixel heterogeneity with classical satellite images. For monitoring vegetation over large areas, aerial photographs can be mosaiced (Baker et al., 1995). Thurston (2002) differentiated three types of mosaics: controlled, semi-controlled and uncontrolled. All aerial photographs are subject to distortions and displacements caused by the relief of the photographed area and by the 'tilting' of the aircraft (i.e., not being perfectly horizontal at the moment of exposure) (Warner et al., 1996). In controlled mosaics, the photos are corrected for tilt and relief

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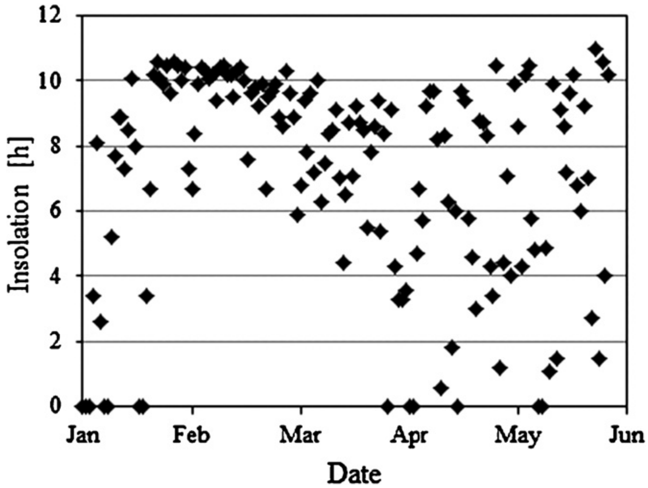

Fig. 1. Variation in daily hours of insolation during the irrigation season in Burkina Faso.

displacement, and then georeferenced using specific software (e.g., ENVI, ERDAS-OrthoBase, PCI), giving an 'ortho-photo mosaic'. All distances, angles and positions can be accurately measured using an ortho-photo. This approach is the most accurate, but it requires the input of auxiliary data that are often not available: ground control point data; digital terrain models (DTMs); camera calibration reports; and 'exterior orientation', defining the position and angle of the camera for each photo (ERDAS, 2002). At the other end of the spectrum is the uncontrolled mosaic, which can be produced quickly; the user simply orients the image until a larger one is formed. A semi-controlled mosaic is an enhanced uncontrolled mosaic, where image edges are properly aligned using common image 'matchers' for the creation of photo mosaics. Thematic maps or satellite imagery can provide the ground control points for georeferencing.

Rocchini and Di Rita (2005) showed that for flat regions such as alluvial plains, as in the case of the study area, DTM resampling did not improve the rectification method. The use of just polynomial functions confirmed their power in the rectification process in case of flat areas.

In the literature there are many studies on the photo-interpretation or image processing of high-quality commercial aerial photography for detailed land-use mapping. Most of them deal with estuarine (e.g., Zharikov et al., 2005; Raal and Burns, 1996), urban (e.g., Wentz et al., 2006; Cleve et al., 2008) or forested (e.g., Carreiras et al., 2006) environments. In the field of agriculture, aerial photography with mostly state-of-the-art devices tends to be used for monitoring crops in research plots or under commercial management (Oberthür et al., 2007; Peña-Barragán et al., 2004; Rabatel et al., 2008). One of the few studies on the use of aerial photography for mapping agricultural land in Africa was conducted by Rembold et al. (2000).

In the case of Burkina Faso, the absence of high-quality commercial aerial imagery or aircraft equipped with 'kinematic GPS airborne control' for registering exterior orientation has restricted the ability to conduct detailed land-use surveys. The aim of this study was therefore to develop a fast and low-cost procedure for the semi-controlled mosaicing and georeferencing of amateur small-scale aerial photography for surveying and monitoring land use. Two sets of tens (2009) and hundreds (2007) of low-altitude aerial photographs, with a resolution of 0.4 m and 0.8 m, respectively, were used for the detailed mapping of small-scale irrigated agriculture. A commercially available stitching tool and GIS software enabled a single georeferenced image to be constructed. For further classification studies (outside the scope of this study), it was also considered that the photographs should be uniformly color-balanced.

2. Study area

The study was carried out in the agricultural zone of the Kou watershed (11.3°N, 4.4°W) in south-western Burkina Faso. Being mainly a floodplain, the study area is characterized by a topographically homogeneous area of ±200 km^2.

In recent decades, the Kou watershed has suffered from poor water management. Despite the abundance of water, most water users regularly face water shortages because of the increase in the amount of land under irrigated agriculture. In recent years, local stakeholders have acquired decision-support tools to help them effectively monitor the water resources and their use (Wellens, 2011).

3. Materials and methods

3.1. Image acquisition

A camera operator, accompanying the pilot, obtained true-color digital images using a standard commercial digital camera with a remote control mounted on a small plane: a MoraneSaulnier 180 GT in 2007 and a Cessna 117 in 2009. In 2007, a Sony DSC-P92 digital camera, equipped with a 1/1.8 in. (7.18 mm × 5.32 mm) CCD data capture producing 2048 *cols* × 1536 *rows* images, was used. The integrated lens was set to a fixed focal length of 8 mm. For the survey in 2009, a Canon EOS 450 D, with a 22.2 mm × 12.4 mm CMOS image sensor giving 4272 *cols* × 2848 *rows* images, was used with the focal length of 19 mm.

A flight plan was calculated, taking into account such parameters as focal length of the camera (f; in mm), size of the digital sensor ($S'_l \times S'_h$, in mm × mm), flying speed (V_g, in km/h), height above mean ground level (H_g, in m), forward overlap (p, in %) and side lap (q, in %) (Warner et al., 1996), whereby:

- ground distance (S, in m):

$$S = \frac{S' \times H_g}{f} \quad (1)$$

- length of base (B, in m) with p forward overlap:

$$B = S\left(1 - \frac{p}{100}\right) \quad (2)$$

- distance between flight lines (A, in m) with q side lap:

$$A = S\left(1 - \frac{q}{100}\right) \quad (3)$$

- exposure interval in seconds (ΔT):

$$\Delta T = \left(\frac{B}{V_g}\right) \quad (4)$$

- ground resolution (R, in m):

$$R = \frac{S'_l \times H_g}{Col \times f} \quad (5)$$

The results, presented in Table 1, were drawn in ArcGIS (ESRI) on an archived Landsat TM image. The resulting flight lines, with locations indicating the moments of exposure, were exported to a GPS (Garmin GPS-92) for pilot and camera operator guidance. If atmospheric conditions were found not to be optimal, the flight was postponed until the following day, avoiding harmful effects on the quality of the aerial imagery. Early morning flights were preferred because at that time there is less turbulence caused by the thermal radiation of the Earth's surface.