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artigo

Environmental Monitoring using Small Format Aerial Image Mosaics

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Abstract. In the cartographic process, images are usually acquired using controlled techniques that employ special cameras and airplanes, resulting in an expensive environment for acquisition. We propose a technique that uses small format aerial images, or SFAI, considered as not controlled, and stereo-photogrammetry techniques to construct georeferenced mosaics. A mosaic is a composition of adjacent images that are put together in order to provide a larger view of a scene. A georeferenced mosaic is characterized by the definition and adoption of a scale and a reference system. Images are obtained using a simple digital camera coupled to a radio controlled (RC) helicopter. Techniques for removing common distortions are applied and the relative orientation of the models are recovered using perspective geometry. Ground truth points are used to get absolute orientation, plus a definition of scale and a coordinate system which relates image measures to the ground. The mosaic is read into a GIS system, providing useful information to different types of users, such as researchers, government officers, fishers and tourism enterprises. Results are reported, illustrating the applicability of the system. The main contribution is the generation of georeferenced mosaics using SFAIs, what has not been widely explored previously in cartography projects. The proposed architecture presents a viable and much less expensive solution, when compared to systems using controlled pictures.

Keywords: Georeferenced Mosaics, Small Format Aerial Images, Radio Controlled Helicopter ..

1. Introduction

Traditional cartography techniques basically involve the acquisition of analogical images (photographs) in a controlled form, using cameras on airplanes, followed by the application of techniques based on projective geometry for determining the position and orientation of models determined by each pair of images. This is done using an analogical three-dimensional (3D) reconstruction, followed by the creation of maps using drawing techniques specific to cartography. The introduction of digital image processing techniques in the cartography process allows the fast creation of high quality, georeferenced mosaics, what was not possible with the earlier process.

A mosaic is a composition of adjacent images that are put together in order to provide a larger view of a scene. A georeferenced mosaic is characterized by the definition and adoption of a scale and a reference system. This is obtained by relating the final composition to a coordinate system, after removing distortions and other errors caused by the acquisition process, in such a way that measures in the georeferenced mosaic are related to measures in the scene by some affine mapping (usually only a scale factor). Transformations are applied in order to reconstruct the positions and relative orientation of each image to the other images and to ground truth points. In the cartographic process, images are usually acquired using controlled techniques that employ special cameras and airplanes, resulting in an expensive environment for acquisition. A cheaper alternative is the use of satellite images. However, this results in less accurate sharp relief reconstruction. In this work, we propose a new approach for generating georeferenced mosaics, that fits into the the category mentioned above.

We use small format aerial images (SFAIs) acquired by a digital camera connected to a small radio-controlled helicopter (shown in Figure 2 (a)). This setting allows the acquisition of images with large scales, i.e., with the acquisition system closer to the surface, and low-cost common digital cameras. We can also compute 3D mappings of a desirable region with the use of homologous points in pairs of stereo images, thus producing depth and height information. As mentioned above, the acquisition process using a simple digital camera coupled in a radio controlled (RC) helicopter is much cheaper than the traditional acquisition processes that use satellites or aero-photogrammetric cameras connected to airplanes. However, since the SFAIs are acquired with less control in position and orientation, it is necessary to readjust and/or to create methodologies that are specific for this kind of application. There are systems, such as the ArcView of ESRI, the ERDAS of Leica Geosystem and the Regeemy and SPRING of INPE that allow the generation of high quality mosaics using registration techniques that are applied to big format aerial images (BFAIs). It is important to note that, by definition, BFAIs have a high control level. The images do not present distortions like the ones created by using common digital cameras on a RC helicopter, specially when taking low-altitude (higher resolution images of the terrain) pictures. Moreover, BFAI acquisition systems can use the knowledge acquired in previous acquisitions, such as when, how and where a picture was taken. Thus, such systems acquire images with little if any distortion, being georeferenced in some cases, making the task of producing mosaics from such images much easier than when using SFAIs. Besides the aforementioned systems, there are other systems (LHUILLIER et al., 2001; HSU, 2001), that use registration techniques to correct the geometry of the images prior to the step of mosaicing (the step where the images are composed in the mosaic). By using registration techniques, these systems allow the creation of mosaics with high resolution and low distortion levels. The registration techniques used vary in complexity and number of control points needed.

The method of Feldman (FELDMAN; ZOMET, 2004) proposes a new method that corrects geometric distortions based on the perspective transformation of the camera, thus allowing the recovery of reliable distance measures. There are a few other approaches that make use of RC helicopters for a variety of applications, such as the one proposed by Syuhei (SYUHEI; YUE; TAKAHITO, 2007), which uses autonomous helicopters that navigate autonomously by using information gathered by a GPS (Global Positioning System), IMU (Inertial Measurement Unit) sensors and images from a camera. In this case, points are detected, matched and used to perform the autonomous navigation, the goal of the system.

2. Construction of georeferenced mosaics using SFAIs

The process of construction of georeferenced mosaics becomes more challenging when SFAIs are used. Furthermore, the environment where we are testing our system (a coastal sea region) is highly dynamic, with changes in the images due to wind, tides and reflections from the sun light, increasing the occurrence of errors in matching points in the images. Moreover, there are variations of positions and orientations of the support of the helicopter during the flight, that incur in other sources of acquisition problems, as well as variations of the intrinsic parameters of the digital camera used, that can cause radial and radiometric distortions. In order to obtain high quality mosaics, we have to apply a series of techniques, as to perform camera calibration, radial and radiometric distortion corrections, reconstruction using stereo-photogrammetry. These techniques are described next.

2.1. Calibration of camera and correction of the radial and radiometric distortion

In order to obtain 3D information about an imaged scene, we first have to model the camera used to acquire the image. This is done through a calibration process, that determines the intrinsic and extrinsic camera parameters (TSAI, 1986). These parameters are then used to correct the acquired images. In this work, we use the calibration process proposed by Tsai (TSAI, 1986), that is based on a pin-hole camera, and models for perspective projection and radial distortion corrections. After performing the calibration process, we can correct the radial distortion using

$$\begin{aligned} x &= x_d(1 + k_1 r^2 + k_2 r^4), \\ y &= y_d(1 + k_1 r^2 + k_2 r^4), \\ r &= \sqrt{x_d^2 + y_d^2}, \end{aligned} \tag{1}$$

where x_d and y_d are the points in the distorted image, r is the distance of the center of the image to the pixel and k_1 and k_2 are distortion coefficients. By using Equation 2, radiometric distortion can be removed (TRUCCO; VERRI, 1998).

$$E(p) = L(P)\left[\frac{\pi}{4}\left(\frac{d}{\hat{z}}\right)^2 cos^4\alpha\right]. \tag{2}$$

Illumination in the image P decreases as a function of the distance (d) at the rate of the fourth power of the cosine of the angle formed by the main ray that arrives in P with the optical axis ($\hat{z}$). In the case of a small opening, this effect can be neglected. Then the radiance in the image can be understood as uniformly proportional to the radiance of the scene on all points of the image (TRUCCO; VERRI, 1998), what is not the case in our work.

2.2. Stereo-Photogrammetry

Our acquisition system guarantees longitudinal and lateral recovering of about 70% and 30%, respectively, between the images. Thus, each point of the mosaic is made up by values of at least two images. The main problem of stereo reconstruction is to discover pairs of points in both images that correspond to the projections of a same point of the scene. This problem is known as $matching$ (BALLARD; BROWN, 1982) or the correspondence problem, and it is the most expensive stage of the stereo process.

After the correspondence is determined for all pixels of the images, this information can be used in the mosaic reconstruction. The depth for each pixel can be determined relative to a reference fixed in the image center by using simple triangulation. This depth can help to differentiate the characteristics or attributes of data pixels, since it appears in more than one image. We notice that, in the worst case, an average between the attributes can help to minimize errors in the images. The correspondences between the images can be determined using area-based or feature-based techniques (MARR; POGGIO, 1979). In general, this involves the application of operators such as normalized cross correlation (NCC) or sum of squared differences (SSD) (TRUCCO; VERRI, 1998). The SSD is faster than correlation, but it is not immune to variations of illumination and brightness in the images, problems that do not affect the NCC, shown in Equation 3:

$$r_{x,y} = \frac{n\sum(x_i y_i) - \sum(x_i)\sum(y_i)}{\sqrt{n\sum(x_i^2) - (\sum x_i)^2}\sqrt{n\sum(y_i^2) - (\sum y_i)^2}}, \tag{3}$$

where n is the number of samples in each signal. For $matching$, correlation is restricted to a region (comparison window) of each image, with n being the area of this window.

2.2.1. Relative Orientation

In order to simplify the process, some stereo-photogrammetry principles can be used in the step of determination of the relative orientation of the models produced for each pair of consecutive images. In this phase, the goal is to estimate the spatial positioning of the helicopter at the moment each image is acquired, given by the on-board GPS.

This problem is currently well-defined in the photogrammetry literature and its formalization can be found in many references, such as the work of Wolf (WOLF, 1983). Due to the simplification, only 6 pairs of points known in each model (between each pair of images) are necessary in the current work for obtaining a good estimate in the determination of the transformation coefficients. The coefficients are then used to reconstruct the spatial positioning and orientation of the helicopter in each frame.

2.2.2. Absolute Orientation

For georeferencing the mosaic (determining the scale and referencing it to a known coordinate system), we determine terrain coordinates of the control points previously chosen in the study area using a GPS. By using aerial-triangulation techniques (WOLF, 1983), these known coordinates are extended to the points determined in the relative orientation phase. Note that, in the case of having an irregular terrain model, these coordinates could be extended to all other points of all images, thus, generating coordinates that are referenced to a system for all points in the mosaic (GONÇALVES, 1995).

We notice that each pair of adjacent models has a common image, from which errors can be minimized and estimated, in order to compute point coordinates. The technique for aerial-triangulation adopted in this work uses least squared differences (LSD) to minimize errors in the process of computing coordinates for the corresponding points of each model. Finally, we perform a block adjustment for determining the georeferenced coordinates of all the points. The resulting coefficients are used to compute the transformations that are applied in each image for the generation of the final mosaic.

2.3. Implementation

The system was developed in C++, using QT's libraries for creating the graphical user interfaces. The overall system organization is shown in Figure 1.

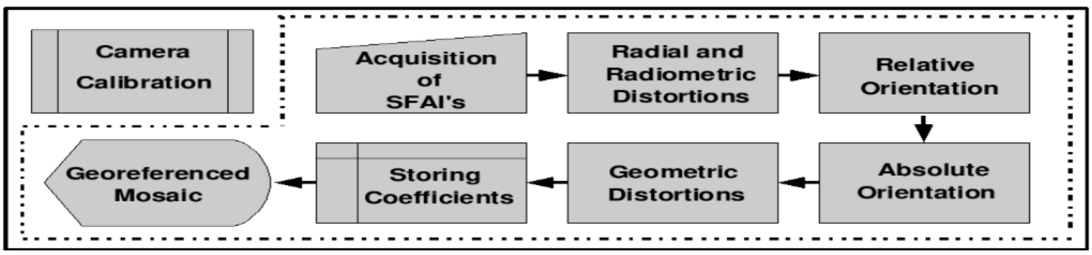


Figure 1: Structure of the system.

Note that the calibration module is located outside the internal system area defined by the dotted lines. This happens because the calibration process is performed only once to determine the intrinsic paramters and the radial and radiometric distortions. In the calibration phase, we compute all parameters needed using Tsai's method, thus, relating world coordinates with frame coordinates. Then, the radial and radiometric corrections are performed by applying Equations

1 and Equation 2, followed by the interpolation of pixels, resulting in the corrected image. After the radial and radiometric corrections, the relative orientations are determined. To compute those, we define homologous points between stereo pairs and compute the transformations mapping one image to the other using the least squares method. The transformations, containing translation, rotation and scale information are then used to map pixels to their correspondents on different images, so they are aligned in the final mosaic. To generate the final georeferenced mosaic, we need to compute the absolute orientation coefficients by performing an aerial-triangulation process and aligning the mosaic with real world coordinates. In the geometric correction module, affine (Equation 4) or projective (Equation 5) transformations are applied (using bilinear or bicubic interpolation). The affine transformation is given by (Equation 4):

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} A_0 + A_1 X" + A_2 Y" \\ B_0 + B_1 X" + B_2 Y" \end{bmatrix}, \tag{4}$$

where A_0, A_1, A_2, B_0, B_1, B_2 are parameters corresponding to factors of scale, rotation, and shear, respectively, and X and Y are coordinates in the adjustment coordinate system; $X"$ and $Y"$ are coordinates in the reference coordinate system (NOGUEIRA,). The perspective transformation is given by

$$X^* = \left[\frac{a_{11}X + a_{12}Y + a_{13}}{a_{31}X + a_{32}Y + 1}\right],\ Y^* = \left[\frac{a_{21}X + a_{22}Y + a_{23}}{a_{31}X + a_{32}Y + 1}\right], \tag{5}$$

where a_{ij} are parameters of the transformation, with i and j= 1, 2 or 3; X and Y are the values measured in the reference system; and X^* and Y^* are values calculated for the corrected system (NOGUEIRA,).

The method used to compute the coefficients for the projective transformation is similar to the one used for the affine transformation. The difference between the two methods is how the points of the adjustment image in the matrix are stored, which must respect the positions in the matrix. Both transformations modify the positions, scales and forms, trying to match the coordinate systems. However, the projective transformation is more efficient than the affine transformation in some occasions, when there is significant foreshortening in the images. One of these transformations will be applied when constructing the mosaic, using the coefficients supplied by the processes of relative and absolute orientations, as described above in the text.

3. Experiments and results

In order to verify our methodology, we first perform tests to validate some modules of the developed system, step by step. Figure 2 shows the result of Tsai's calibration process of implemented with radial and radiometric corrections using different coefficients. For this test, the same, common digital camera coupled in the helicopter was used for both calibration and aerial images acquisition (Figure 2 (a)). Figure 2 (b) below shows distorted using a barrel transformation, resulting in Figure 2 (c). Then, the corrected image shown in Figure 2 (d) was obtained using the correction module and the pincushion distortion.

Several tests were performed using both transformations (affine, projective), and we observed visually that the projective transformation produced mosaics with higher quality. This difference in the quality can be observed specially in geographical coordinates of points that are farther away from the camera, since the affine transformation does not take into account the foreshortening. Figure 3 shows the application of projective transformations for the geometric correction and relative orientation estimation of small format aerial images, while Figure 3 (e) shows one example of mosaic produced using the same transformations.

Finally, Figure 4 shows the resulting mosaic produced by the whole process using known

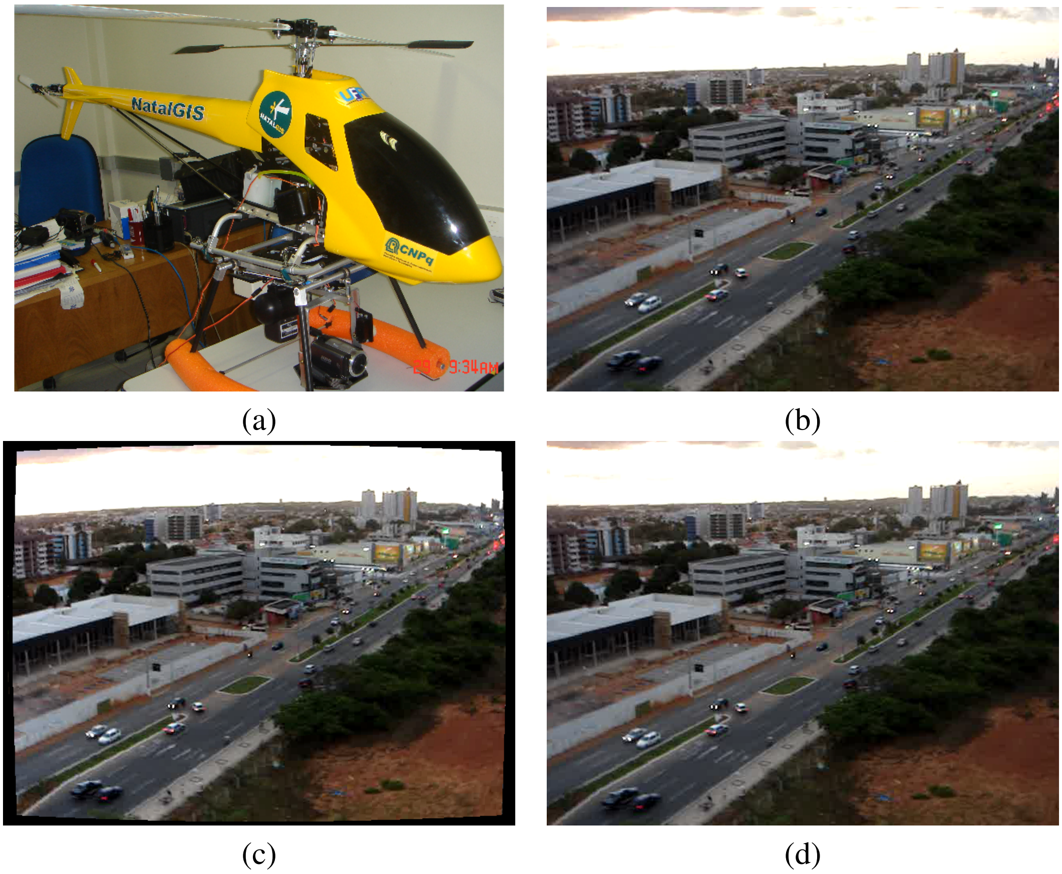


Figure 2: Small radio controlled helicopter (a), Original Image (b), Distorted Image "Barrel" κ_1 = +2.5 (c), and Correct Image with Distorted "Pincushion" κ_1 = -2, κ_2 = -0.025 and α = 0.45 (d)

control points positioned using GPS. To produce this final mosaic, the geographical coordinates of some points in the terrain shown in the mosaic are needed. The user, through the graphical interface, inputs this information, by clicking points in the mosaic and associating the corresponding geographical coordinates. These reference points are visible to the user until the last transformations are computed.

4. Conclusion

In this paper we propose a system that generates georeferenced mosaics with stereo-photogrammetry techniques, using small format aerial images (SFAIs) that are acquired using a common digital camera connected to a RC helicopter. The main contribution is the generation of georeferenced mosaics using SFAIs, something that has not been widely explored in cartography projects. The proposed system presents a viable and much less expensive solution, when compared to systems using BFAIs. Our system is being developed to work in a variety of settings, but is was initially devised to be used in the management of a protected coastal sea area, that needs to be constantly monitored, thus requiring routine flights. The techniques described here can be used to obtain reliable information about the imaged area, thus, gathering information that can be used in the management of areas with small details. Systems that use satellite acquired images cannot operate at the same level of scale, i.e. , close to the land, and systems that use aerial photogrammetry professional equipment are very expensive.

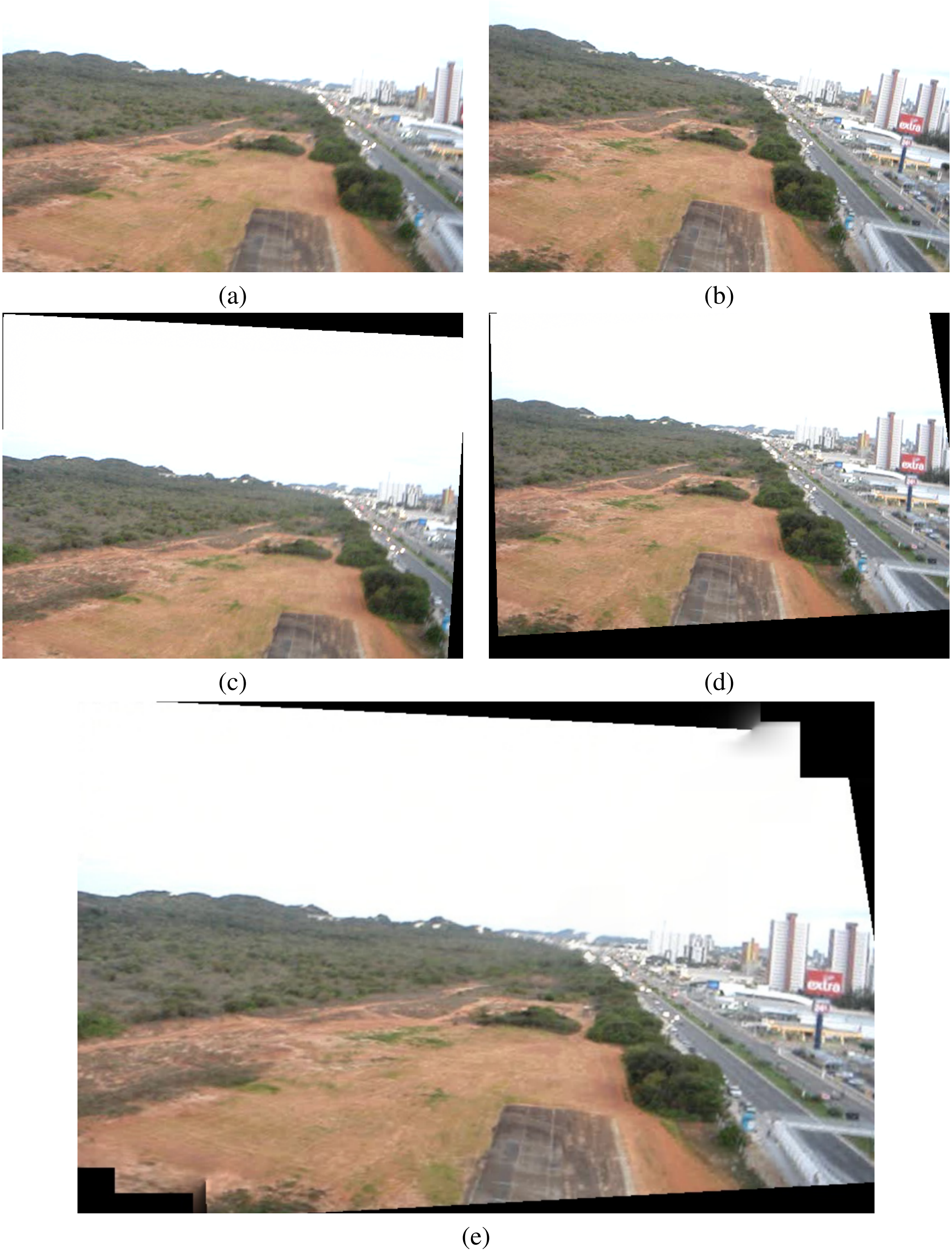
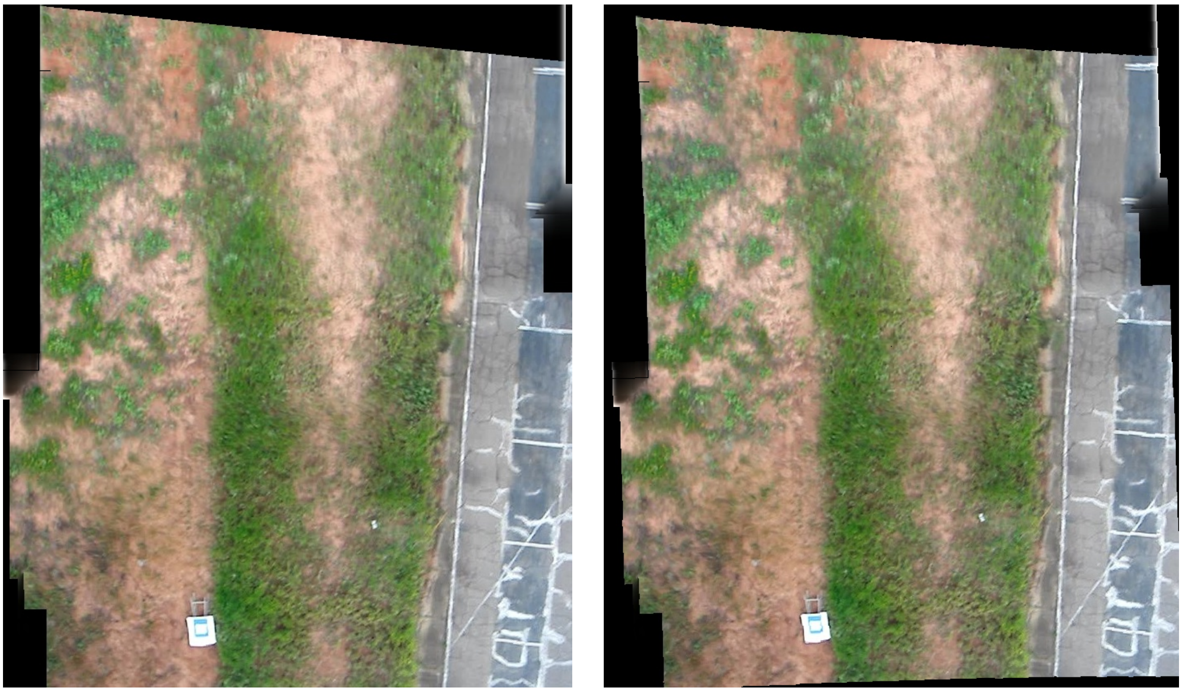


Figure 3: Original SFAI (First) (a), Original SFAI (Second) (b), Correct SFAI (First) with projective transformation (c), Correct SFAI (Second) with projective transformation (d), Mosaic with three SFAI's.



(a) (b)

Figure 4: Example of Mosaic with five SFAI's (a), Mosaic of Figure (a) georeferenced with estimated points given by GPS (Geographical Coordinates) (b).

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