Application development supporting orthophoto documentation

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Abstract— **We have developed a GIS algorithm that can support the project application processes with automatic and accurate GIS results that can be used for the planning and post-flight implementation documentation of orthophoto projects. The tools aim at easing the documentation of orthophotography projects both in the planning phase and after the completion of data acquisition, by providing qualitative information within the form of maps.**

The flight planning software available on the market have limited output capacities -they can output the photo footprints with correction based on terrain elevation- but they do not offer the capacity to extensively document photogrammetry project as it is expected in some state level applications. To cover this gap we have developed the three different following tools: 1) a tool issuing tables with the percentage of overlap between adjacent images; 2) A tool generating a map of the effective resolution where the variation of the resolution can be appreciated and 3) a tool targeting the buildings inclination that issues a map with the leaning percentage at each location. The two last solutions include corrections made from the terrain elevation.

In this paper we aim to present our solutions for these practical problems.

Keywords—orthophoto, photogrammetry, GIS, application development, maps

I. INTRODUCTION

In parallel with the constant increase with the accuracy requirements, there is a growing need with the documentation of the quality of photogrammetry projects. New descriptors are requested to characterize the advanced products at the diverse phase of a project (planning and acquisition).

Flight planning software that are in use today cover the most common requirements, but they do not offer advanced options to meet some of the newest requirements. So, there are areas of application where such advanced software features do not yet exist.

A photogrammetry project starts with an appropriate planning. and many aspects need to be considered in order to properly prepare a flight plan.

In order to obtain the proper results, in addition to technical requirements, it is necessary to know the accuracy and method of the subsequent processing procedure, as well as the expected conditions of the flight. A computational error made at this stage can make processing difficult or even completely impossible. To create a proper flight plan, it has to be considered:

1. Aircraft performance specifications
2. Measuring camera parameters
3. The type of product to be manufactured
4. Terrain conditions
5. Accuracy requirements
6. Processing software features

All but one of the above parameters can be determined relatively accurately before flight for the entire project. We know the technical parameters of the aircraft and the camera, the processing software background is also given, and the accuracy requirements and the final product to be made are included in the technical specification of the order. There is one thing that is typically not available or may not be available with sufficient accuracy for the area in question or just from an earlier date, and that is the topography model. The flight plan definitely requires some DTM from the area, which in most cases means an SRTM terrain model created as a result of satellite remote sensing. [5]

The well-known disadvantage of these types of topographical models is that their resolution is typically only around 20-30 meters or worse.

For the preparation of a flight plan, which can typically cover, hundreds, even thousands of square kilometers, such an accuracy of 20-30 meters may be sufficient, with the help of which in-line and between-line overlaps can be planned with good approximation.

However, as the hardware and software technologies used for aerial photography evolve (including camera compensation systems, higher resolution cameras, processing software backgrounds), and the accuracy and resolution of aerial photographs become better, there has been a demand from customers to improve the documentation of the following descriptors: field resolution within a given photograph, perspective tilt (1. Fig.), degree of exact overlap between images. They should described with high accuracy

(up to 10-15 meters resolution for the entire area) and already in the design phase.

The team of Envirosense Hungary Ltd dealing with orthophoto processing and related developments has been commissioned to develop a software solution to these problems and documentation needs; the results of which are presented in this article.
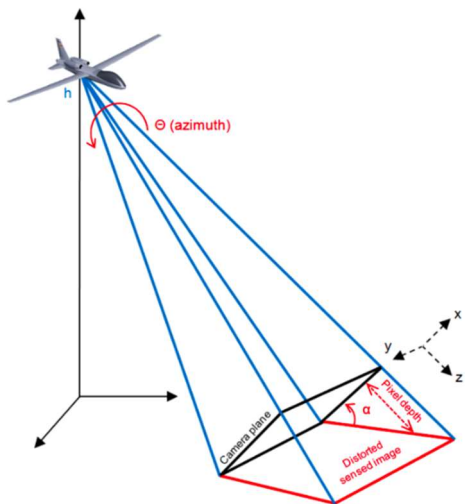
1. Figure Perspective distortion and correction

II. DETAILED ALGORITHM DESCRIPTIONS

A. Generating overlap statistics for adjacent images

For flight planning software, the input parameter is usually a SRTM terrain model or an area-specific average terrain height. In addition, the boundary of the area to be surveyed, the desired overlap values, and the camera parameters (sensor size, pixel size, lens type) must be specified [11].

For the given sample an Ultracam Eagle M3 large format camera was used, whith 120mm focal and 17004x26460 pixels sensor size (pixel sizes are 4.000 x 4.000 microns)

Using this data, the program calculates the coordinates of flight lines and shooting locations.

It is important to note that the set overlaps represent minimum overlap values for the software. Even at this design stage, the actual result may differ from image pair to image pair even due to terrain, as planning programs determine the flight altitude for each line, but in many cases as a uniform value for the whole block.

It is important for the customer to know the exact overlap percentage per image, taking into account the planned flight parameters, as well as the actual recording locations (GNSS) and aircraft tilt (IMU) based on the flight.

The algorithm we created was developed for the following specific layout conditions:

- *The overlay on line must be greater than or equal to 72%, so that each point of the terrain is visible on at least 3 successive images of the same strip. A hole in the tri-stereoscopic cover will be considered a blocking anomaly.*
- *The overlay cross lines may in no case be less than 55%, so that every detail of the land is visible on at least 2 adjacent strips. A hole in the side stereoscopic cover will be considered a blocking anomaly.*

- *These draft flight plans will be delivered in shapefile format, accompanied by tables describing the recoveries (expressed in %). The table of recoveries (expressed in %) for each pair of photographs*

Because geometric data is available, we chose QGIS to implement the task from the options offered by the customer for application development. [3]

QGIS is a free, open source GIS software that allows users to edit, analyze, and map spatial data [1].

The program is suitable for handling raster and vector data in various formats and projections. Own applications can be developed with graphical programming on the interface, using Python or C ++ programming language [1] [2].

The procedure we propose starts from the assumption that the geometry of the footprint file serving as input data, already contains the effects of the terrain. Otherwise, it would be necessary to project the footprint polygons onto real terrain for further steps.

The planned result would be a table consisting of three columns: the first column shows the image currently being examined, the second column contains its neighbors below each other, and the third column the percentage overlap of the two (2. Fig.).

Source Image	Paired Image	Overlap %
cap_00001	cap_00002	76.5
cap_00001	cap_00123	62.91
cap_00002	cap_00001	76.28
cap_00002	cap_00003	76.71
cap_00002	cap_00124	62.57
cap_00003	cap_00002	76.46
cap_00003	cap_00004	75.88
cap_00003	cap_00125	62.46
cap_00004	cap_00003	76.14
cap_00004	cap_00005	75.96
cap_00004	cap_00126	62.14
cap_00005	cap_00004	76.13
cap_00005	cap_00006	75.97
cap_00005	cap_00127	62.15
cap_00006	cap_00005	76.95
cap_00006	cap_00007	76.2
cap_00006	cap_00128	62.69
cap_00007	cap_00006	76.4
cap_00007	cap_00008	76.55
cap_00007	cap_00129	62.82
cap_00008	cap_00007	77.17
cap_00008	cap_00009	76.76
cap_00008	cap_00130	63.01
cap_00009	cap_00008	77.33
cap_00009	cap_00010	76.78
cap_00009	cap_00131	63.33
cap_00010	cap_00009	77.26
cap_00010	cap_00011	77.08
cap_00010	cap_00132	63.36
cap_00011	cap_00010	77.09
cap_00011	cap_00012	77.05
cap_00011	cap_00133	63.4
cap_00012	cap_00011	77.21
cap_00012	cap_00013	77.1
cap_00012	cap_00134	63.25
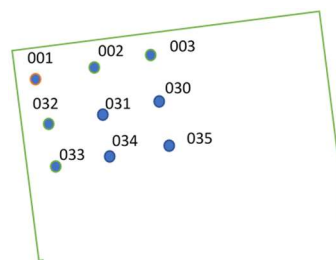
2. Figure The structure of the table

In terms of their location, we can talk about three cases:
- corner image with two neighbors, one in row and one in a neighboring row next to it
- border image, in which we can talk about three neighbors, two within the row and one on the side in the row next to it
- image inside a block, when it has two neighbors in a row, and two other ones from the strip next to it

Based on the above list and the previously described overlap minima that only the immediate neighbors of an image need to be considered, although the number of overlaps, including three-, four- and even five-times overlaps, is significantly higher than the above, so a method had to be found to eliminate them. [4]

It is common for flights to require a cross line perpendicular to the flight lines to improve aerial triangulation accuracy, but such cross lines no longer needed in the mosaicing phase of orthophoto making.

Therefore, for proper results, it is expected that these cross lines on the footprint map to be removed in advance.

1) How the algorithm works:

As a first step, we need the size of the area in square meters defined by the field boundaries of each image. This can be defined with a simple basic GIS operation and stored as an attribute according to each polygon.

Because there are no identifiers for polygons in the footprint file to be used by default, we need to create them so that each area can be identified later. This is done in the second step.

With the following subroutine, an overlap operation is performed to map the intersection of each polygon. From now on, the result layer contains all the combinations of possible overlaps, associated IDs, and the area of the original polygons.

In order to obtain the percentage overlap values, we also need the area of each of the previously created intersections. We calculate these in a similar way as described in the first step.

Once both the original and the overlapping areas are known, their percentages can be calculated with a simple division operation, which is also stored as an attribute within the layer.

In the last step, we create the result table with an SQL query. To be able to filter out multiple overlaps, we examined the percentage of overlap that single-overlapping (direct) neighbors present. Based on these, we concluded that if we exclude elements smaller than 55% and greater than 95%, the resulting polygons 2-3 and 4, respectively, are obtained, which categories have been described above.

Elements around 100% should be excluded because overlapping polygons with themselves may result in elements with the same ID as the original or overlapping shape, resulting in elements greater than 95% overlap.

2) Advantages and disadvantages of the algorithm

It is a prerequisite that footprints are created using a terrain model and available as input.

It is important to remove any crosslines before running the algorithm. Because, overlaps in the classical sense can only be interpreted in the case of parallel flight lines.

If the flight block were to be composed of sub-blocks, their processing should be done separately by the discussed program. This is because, in the case of sub-block flight, at least two frame overlaps must be provided under flight planning rules, so that in the case of joint processing at these locations, the number of overlaps would be twice as normal.

Before running, the path and file name of the table to be created must also be specified.

A disadvantage is that the removal of cross lines is not an automatic process. Also, since the identification generation is universal and automatic, its use requires attention especially in cases when working with actual post-flight data, since there will be image identifiers among the attributes.

The main advantage of our program is that it offers a general solution for determining the degree of overlap between adjacent images.

The tool can be used to process pre-flight, planned data; or using a realized post-flight map.

B. GSD calculation algorithm
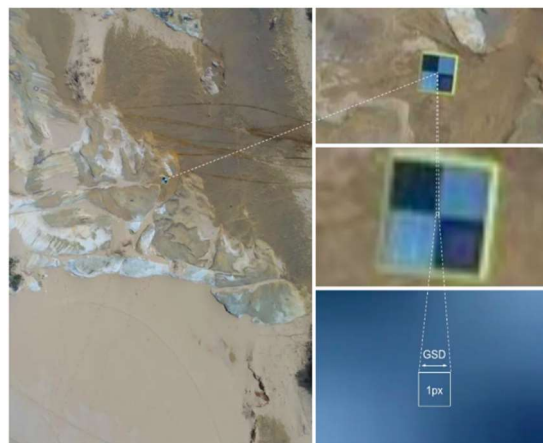
3. Figure What do we mean by GSD?
Size of a pixel on an aerial photo

In order to be able to meet the project order specifications for resolution, it is important to enter a parameter in the flight plan as to what resolution end product we need to make. Knowing this, the camera parameters and the terrain, the maximum flight altitude can be determined.

GSD (Ground Sample Distance) (3. Fig) is a measure of the pixel resolution of aerial photographs. Its calculation requires information on the focal length, the distance of the camera from the subject, and the resolution of the camera sensor. [8] (4. Fig)
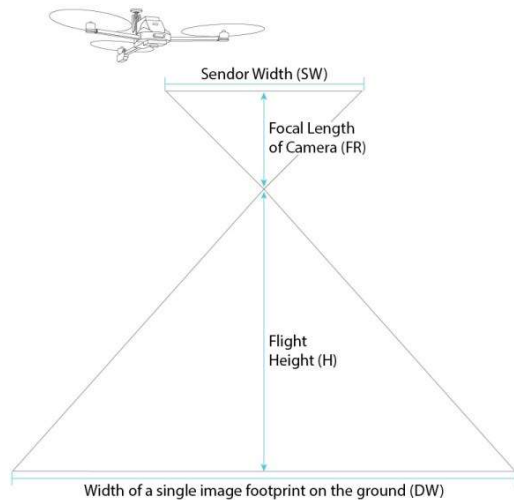
4. Figure Components of GSD

Usually characterized by cm / pixel, it describes the distance that can be measured on the ground between the centers of two adjacent pixels. For example, a 12 cm / pix GSD covers a square with an area of 12 cm x 12 cm (144 cm^2) on the ground.[9][10]

$$GSD = pixel\ size * \frac{H}{FR}$$

GSD values within images are not constant because they also depend on the distance from the center of the image and on the topography.

Even on a flat area within an image, it is easy to see that the maximum value of the resolution will be directly below the shooting location, and moving away from this, the value will continuously deteriorate, so the resolution will be lower. In addition to the location within the image, the topography can also have a significant effect on the GSD, as the terrain protrusions will be inherently closer to the camera than the deeper valleys, so the relative flight altitude can vary from point to point, bringing with it a change in resolution.

So, if we want to get a detail-rich orthophoto, it is advantageous to work with a small GSD. [7]

As we stated above, it can be seen that field resolution in aerial photography is a complex and variable value, which is why our customer needed to find a solution so that we can also map these changes on a map. One of the most interesting challenges in this was how to handle the excess information caused by overlapping images and how to select the boundaries of each image from which the resolution map can be composed.

The customer formulated the requirements as follows:

- *These flight plan projects will be delivered in shapefile format, accompanied by a map showing the planned resolutions (expressed in mm).*
- *"The useful part of an image is defined as the area for which the details of the terrain are closer tothe center of the image considered than to the center of the neighboring images".*

Similar to the previous algorithm, we created the solution in QGIS and Python environments.

The layer containing the geometry of the shooting locations, with attribute data for the absolute flight altitude, must be provided as input data. This altitude value is interpreted to the focus point of the camera. As in the first application, the data for any cross lines must be removed beforehand.

The layer containing the footprints must be available to run the program, but this also without cross lines as we discussed the reasons before.

In order the change in resolution due to the topography appears in the final result, a data layer showing the topography of the area is also essential. It can be a STRM topography model or Lidar data.

Using this data, we also obtain the resolution map in territorial unit that can also be specified as a parameter.

1) How the algorithm works:

During development, the biggest difficulty was that during aerial photography, a given area appears in multiple photographs since they overlap, while the resulting map where ground resolution should be represented on a layer is without overlap and gap.

The value which has the smallest GSD value (smaller is better) in a given area is the one which have the closest distance to the camera, the closest to the centroid of any given footprint centroid. The areas which contain points that are closer to a given point than to any other are the Thiessen areas, their borders are the Thiessen polygons (also known as Voronoi polygons), and by its nature it is a polygon network without any overlap [13]. Technically the lines of the Thiessen polygons are oversimplified seam-lines. We used this Thiessen polygon calculation tool to simplify the dataset and get free of the overlays. (5. Fig.)

Each step of the algorithm, since its structure is significantly the same as the program developed for the third problem, will be described in detail in that chapter.
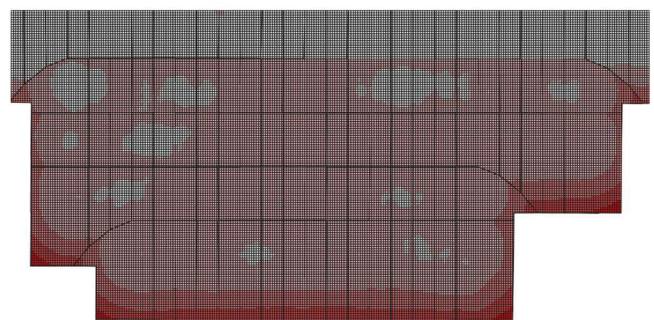
5. Figure GSD map White patches caused by DTM (white is smaller GSD, red is bigger GSD, smaller is better)

2) Advantages and disadvantages of the algorithm:

The program created to solve the problem can be used to process the data of both planned and implemented flights, to create the field resolution map.

The sampling distance of the GSD must be adjusted to the resolution of the terrain model, since increasing the resolution

beyond this limit will only increase the running time, the accuracy of the map will not increase.

C. Perspective tilt map of buildings

The presence of perspective distortions is a natural phenomenon in aerial photography end products. The only exceptions to this are the so-called true orthophotos. [8] This effect should be taken into account when producing traditional orthophotos. Our client's documentation obligation extends to this phenomenon as well, when applying and after the completion of the flight, they must show a map with the percentage of the apparent tilt of the buildings caused by the perspective mapping. [6]

According to the regulations:

- *These draft flight plans will be delivered in shapefile format, accompanied by a map showing the tiltings (in %). The map of the tilting (in %)*

It is easy to see that the amount of tilt increases concentrically away from the center of the given image, reaching its maximum at the edges of the frame.

Our developed algorithm expects similar input data as the one created by the GSD map, so it is necessary to specify a point file containing the shooting locations with altitude data, a footprint polygon file that takes into account the terrain, and an SRTM or Lidar terrain model available for the whole area.

The result is a map that can be used to thematically display tilt categories. These categories can be generated automatically in a GIS program or by the user. Typical category limits: 0-5-10-15-20%

1) Operation of Tilt- and GSD calculation program

The first step here is to calculate the area of the footprint polygons in square meters.

Since these polygons do not yet have a unique identifier at the time of design, this must be created so that we can later establish a connection between the polygons and the shooting locations.

In order to determine the boundaries of the areas close to the center of each image, their centroids need to be calculated.

With the knowledge of the centroids, Thiessen polygons can be made, so from here we have the validity limits within each image.

In the next step, based on the identifiers created earlier, we connect the shooting coordinates with the polygons of the corresponding images in order to find the data of the two data levels within one layer.

An important step is to create a regular grid with terrain data, which will also determine the detail of the final tilt or resolution map.

Intersecting this and the previous derived Thiessen polygons yields a layer that also contains topographic data, flight altitude, and image center coordinates.

In the above result layer, all the data can already be found, on the basis of which the field resolution and the building tilt can be calculated by trigonometry. (6. Fig.)
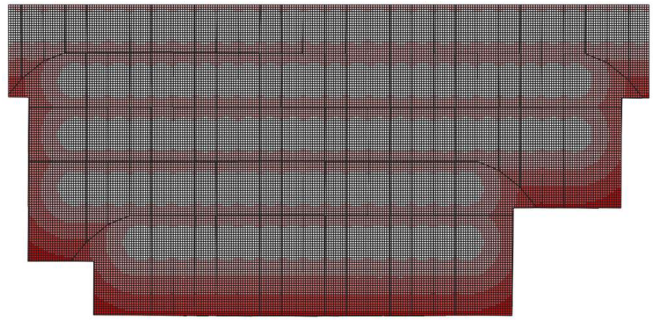
6. Figure Perspective tilt map of buildings (white is smaller tilt, red is bigger tilt, smaller is better)

2) Advantages and disadvantages of the algorithm:

As before, it is important that footprints are made using a terrain model.

Any crosslines should be removed before running, this step is not automatic.

It is recommended to process the subblocks separately. The program works without it, but anomalies should be expected in the areas affected by the overlap.

The image ID of the footprints and the ID of the shooting positions must match. Due to the automatic generation, it is advisable to pay attention to checking these.

If we are working with a large area and small sampling cells, we should expect increased system memory usage. To mitigate this problem, the application was created to automatically delete unnecessary attribute properties.

The advantage of the applications we create is that it provides a general solution for creating GSD and perspective tilt maps using such specific input data. It is also suitable for use with data showing the planned and realized status.

III. CONCLUSIONS

Nowadays, the technological accuracy of aerial photography has reached the level that it can be realistically expected from the customers that already in the tender phase the plans are prepared in such depth and accuracy for the expected end product that certain technical characteristics are known with centimeter accuracy.

We have been commissioned to map such features, as the state customer already sets them as a requirement.

We had to find a GIS solution for three problems:

1. to determine the exact percentage of overlap with the images in the immediate vicinity of each image;
2. to show on a map the field resolution of the aerial photographs (GSD) to be taken for the whole flight area, taking into account the topography;
3. to make a map also on the basis of the topographical conditions of the extent to which we can expect perspective building tilts at any given point of the AOI.

Based on QGIS and Python, our three-person team has developed applications that offer solutions in such a way that they can be used in a universal way among others to be able to use for in-flight states compared to the planned versions.

Results will be verified in the coming weeks, when we can compare the planned data with the actual flights, and also the calculated results with the actual ones.

The development of our programs, like all other applications, is not over yet it is an iterative process, based on the first experiences of the customer, their further development is currently underway, and we have even been commissioned to prepare documentation solutions for Lidar data also.

IV. ACKNOWLEDGEMENT

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