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Large Image Formation using Harris-Plessey Corner Detection Algorithm

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Introduction

There are cases, when large images must be created by stitching several smaller ones because of the imperfection of the technical equipment. Such methods are used to scan large format documents [1], to register long X-ray images in medicine [2, 3], to create panoramic images with usual camera in photography [4], to create photomaps [5], and other applications. The most important prerequisite to make such technique work is the information about fragment order and exact disposition.

When stitching is performed basing only on the photo detector's parameters during image registration – stitched image contains seams [6]. To avoid this effect, registered images must have overlapping regions. Information from overlapping regions must be used for revise of overlapping fragment superposition. Complexity of the processing and reliability of the superposition strongly depends on the image content. Images containing small dimension objects can be precisely superposed using artificially added markers [2, 3]. Problems arise when it is required to stitch images with unknown, variable content and means for adding artificial markers do not exist, like in aerial imaging.

Superposition in aerial images is possible only when matched points in the both image fragments are identified using information from the real content (without any artificial items) of the images. Content in such images is changeable and unpredictable. To make superposition accurate and reliable both the matched points and the specifics of the image registration process must be employed.

In this paper there are presented the analysis of the photomap image acquire process with accentuated specifics. Investigated feasibility of the Harris-Plessey corner detection algorithm for photomap image stitching. Proposed the method for automatic photomap image stitching based on corner points detected by the modified Harris-Plessey algorithm.

Automated Stitching Method

The procedure for merging several smaller photomap image fragments into one big image can be described like this:

1) Selection of the detector's position.
2) Image acquire.
3) Determination of the image parameters.
4) Parameter adjustment and image stitching.

The position of the detector depends on its movement trajectory, speed and time moment. Images must be superposed before stitching. Superposition requires having overlapping area in both images. The size of the overlapping area depends on the length of the surface area fitting into image and the speed of the photo detector. The length of the area covered by photo detector is described by the following equation:

$$l = 2h \cdot \tan\frac{\alpha}{2}, \quad (1)$$

where l – the length of the area covered by photo detector, h its altitude of the photo detector and α the view angle of the photo detector objective's lens.

Two registered images will have overlapping area when photo detector will be shifted shorter than "l". For example, images will have 20 % overlapping when photo detectors shift will be calculated according to this equation:

$$l_{shift} = 0.8l, \quad (2)$$

where l_{shift} – length of the photo detector's shift before acquiring next image.

The time period required for aircraft carrying photo detector to travel distance l_{shift} according to $l = vt$ (where v is photo detector's speed and t the movement time) is defined by equation (3):

$$T = \frac{0.8l}{v} = \frac{1.6h \cdot \tan\frac{\alpha}{2}}{v}, \quad (3)$$

where T – the time period between registering images and v – speed of photo detector's movement.

The easiest way to explain this equation is an example. If images are being acquired with photo detector having 10 mega pixels, aspect ratio 4:3 matrix and required image resolution is 3 pixels per meter then the length of the area covered by the image will have length approximately 900 meters. Such length can be easily defined by changing altitude and view angle parameters in equation (1). Moving photo detector with speed 100 m/s (what corresponds to 360 km/h) and demanding 20 % overlap, time period between registrations according to (3) will be ~7.2 s.

The example shows, that time period between image acquire is quite long, and it can be even prolonged by slowing down aircraft's speed. Modern photo detectors registers image faster than one second [7]. And this consideration allows much higher than 20% overlap. Bigger overlapping area allows more precise and reliable.

When overlapping area in the images reaches 50 % – every single point in the image is registered twice. When this percent is bigger, overlapping becomes multiple. This means that the same point in the image is registered in three, four or even more images. During photomap image acquire there is no possibility to use artificial markers which allow 100 % reliable stitching, but the analyzed example shows, that because of the relatively slow speed of photo detector's movement there is a possibility to register images with multiple overlapping.

Multiple overlapping allows analyzing the same interest point in several overlapping images, comparing them, rejecting distorted ones and etc. One more very important consideration is that registering images as fast as they can be analyzed makes them very similar each to other. Small details in the aerial image, in the reality are huge objects. Little changes in the image correspond to large displacements in reality which simply cannot happen in a part of the second. Discussed aerial image registration specifics allow to raise stitching reliability to level required for executing it fully automatically.

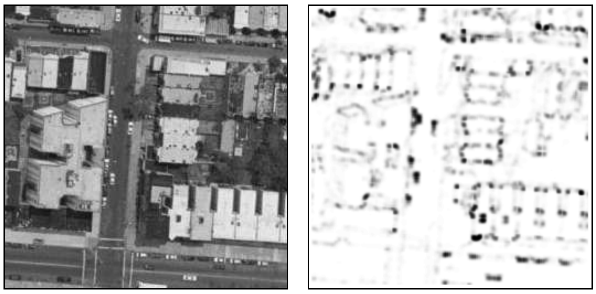
Feature Point Detection

Photomap images do not contain objects which presence in their content could be predicted. Such images are very miscellaneous, they do not contain objects with a priori known form or parameters, and there are no means to complement them with such information. Feature points in such images can be based only on the most general image characteristics. When it is required to identify feature points in two-dimensional space the most appropriate are corner detection algorithms. Lots of modifications of such algorithms exist in our days. They differ in accuracy, detection rate, localization, repeatability rate, robustness to noise, speed and etc.

According to the comparison of corner detection algorithms [8], the best in most of detection criteria currently is algorithm named CSS, but it also has some certainly negative attributes – it is hardly adoptable and its implementation is complicated. When an adoptable algorithm is required Harris-Plessey is the correct one [9]. This algorithm is slower than CSS, but in other parameters it is very similar. The essential qualities of Harris-Plessey are: simple realization, excellent repeatability of detected corner points, Fair robustness to noise (because of the Gaussian filtering which is used in one of algorithms steps) and good localization.

When corner detection is implemented according to Harris-Plessey method, the whole process can be divided into these stages [8]:

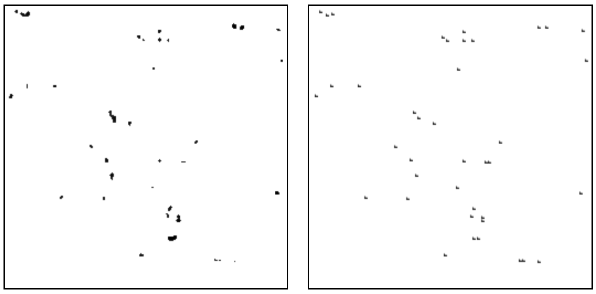
1. Calculate the cornerness map K for the image. The result of this calculation is an image where corner areas are having brighter than the flat areas intensity. In the Fig. 1b it is represented visually. Fig. 1a represents the original image.



a) b)

Fig. 1. Examples of image (a) and its cornerness map (b)

2. Apply a threshold function on the cornerness map. After this, corner areas are separated into isolated regions. The result of threshold function is presented in the Fig. 2a:



a) b)

Fig. 2. Examples of cornerness map after threshold function (a) and detected corner points (b)

3. Calculate local maximums in the isolated corner regions obtained in the stage two. These maximum points will be the searched corner points. The map of the detected corner points is presented in the Fig. 2b.

The stages of corner detection require parameters to do their job. These parameters have a great impact on the detected set of corner points and can be used to control the detection process in a wanted manner. Parameters with the biggest contribution are these: the size of the Gaussian filter's window (1-st stage), the value of the threshold's function (2-nd stage) and the size of the window for searching identical local maxima points (3-rd stage).

The size of Gaussian filter window determines noise filtering, however choosing this size too large decreases corner detection accuracy, because smallest image details are also filtered. The size of window for searching identical regional maxima points determines minimal distance between detected corner points with identical corner response. Sometimes local maxima are described by group of pixels. Such groups make identification of corner point impossible, because corner point must be one pixel. Problem can be avoided by eliminating such point groups. This parameter defines the scope of elimination. Usually images do not have much corner points with identical corner response, so the size of this window does not make big impact on the quantity of detected corner points.

The biggest impact on the number of detected in the image corner points is made by the value of threshold function, during second corner detection stage. This means it must be selected carefully.

Corner Point Quantity Control

Threshold function applied on the cornerness map, rejects image regions, where corner measure is smaller than the threshold value. How many regions will be rejected depends on the chosen value and the content of the image. It is most important to avoid two extremities:

1. If chosen threshold value will be too high most of image regions with good corner response will be eliminated and there will be too less corner points detected.
2. Choosing too low threshold will result detection of false (having weak corner response) corner points. In this case it would be hard to match the same corner points in two image fragments.

Objective is to choose threshold value allowing corner point detection algorithm to detecting only these corner points which can be easily matched. This means that corner detection process must be controlled.

High threshold value is appropriate for images with low details when low threshold value is more suitable for high detail images. Fig. 3 shows how the number of detected corner points changes in different test images when fixed threshold value is used. Seven overlapping test images were used for this purpose. Images are created using multiple clipping of one long aerial image, which begins with townscape (lots of buildings, cars) and ends by woodland. Clipping is performed using 80 % overlap. When test images are created in such way, their content gradually changes from high level of details to low. Fig. 3 proves how the number of detected corner points changes when level of details in the image content changes from high to low (moving from 1 to 7 sample).

The result of corner point detection should be the set of corner points which can be easily and unambiguously matched. In this example threshold value was chosen experimentally by repeating corner point detection on the 7 sample, trying to detect only the most important points. Later on, the same threshold value was used during corner detection in all other samples. Experiment shows that the count of the detected corner points differs more than twice.

The answer of choosing correct threshold value is in the cornerness map histogram (Fig. 4). Histogram shows that most of pixels in the corner map usually have low intensity values. The best illustration of this trend can be given by example: setting threshold value to the half of the maximum possible pixel intensity results that only 0,22 % of image pixels will remain not rejected by the threshold. Changing threshold to the 1/10 of the maximum possible

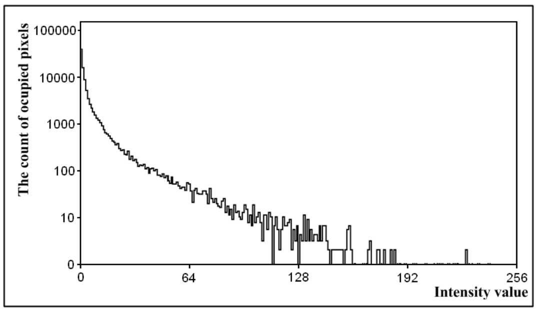


Fig. 4. Histogram of the image cornerness map (presented in the logarithmic scale)

pixel intensity results 6,11 % of unaltered pixels.

Histogram allows calculating image area which will be left unaltered after threshold operation. Fig. 5 shows that the number of detected corner points depends on the image area unaltered by the threshold operation. Ordinate axis in Fig. 5 represents the number of detected corner points and abscissa – the relative area of image pixels unaltered by threshold function expressed percents. Relative area of unaltered pixels is not the indicator which directly determines the number of corner points identified in the image when it is processed by Harris-Plessey algorithm, but it shows that connection between these two parameters is linear and strong: The differences in the numbers of detected corner points in the sample images now is less than 20 %, when fixed threshold value gave differences larger than 100 %. This means that calculating threshold‘s value from image‘s histogram allows to control the number of detected corner points.

Even when means to control the number of detected corner points are defined and corner point quantities in two images are identical, there is no assurance that matching will pass correctly. Different thresholds give different corner points. The problem does not exist if threshold value is the same for both images. The solution is in the Fig. 3. The biggest difference of detected corner points is between second and seventh images, but in the neighbouring images this difference is admissible. This is because of the nature of the test images. They are created by multiple clipping of one long aerial image, which begins with townscape and ends by woodland. In the real images, their content does not change immediately – changes are in process step by step. This is why the neighbouring images have similar level of details. The same threshold for both images should be used, and it should be calculated for the image with lower details.

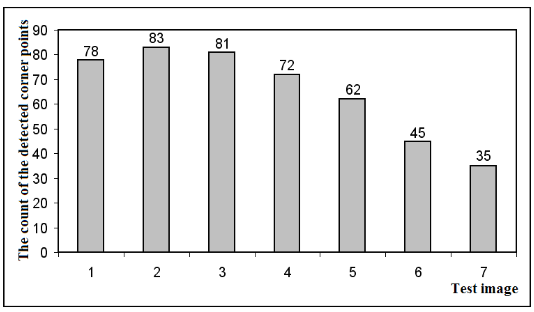


Fig. 3. The counts of the detected corner points in test images when threshold for all of them had fixed value

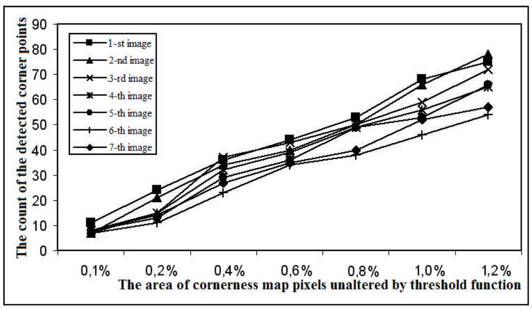


Fig. 5. The counts of detected corner points when threshold values were calculated for every image individually

When two images have very vivid detail border, what requires to choose different threshold values for each of them, multiple overlapping allows performing stitching in the further image fragments (which do no have such border) to avoid the problem.

Summarising all considerations stitching of two image fragments should be performed like this: threshold values should be calculated for both of them; thresholds should be calculated according to area of cornerness map pixels unaltered by the threshold operation; from two calculated threshold values the higher should be chose, because even in the image with lower details number of detected corner points must be sufficient; if the count of detected corner points in the images is too high or too low, stitching should be repeated with other pair of images.

Conclusions

1. Analysis of the general features in the overlapping image fragment areas allows merging them into one big image.
2. If the content of the image fragments does not contain predictable objects, accurate and reliable stitching is possible only when fragment overlapping is multiple.
3. In this case, fragments must be searched for the corner points. The count of corner points must be controlled.
4. Harris-Plessey corner detection method supplemented with the predictive value of the threshold function is well suitable for corner detection in such images.

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Creation of the big aerial images out of several smaller fragments is investigated in this paper. Proposed technique for the fully automated stitching of the overlapping two-dimensional photomap images. Technique is based on the detection of the general features in the overlapping image areas. Suggested to perform feature detection when overlapping is bigger than 50%. Proven that accurate and reliable stitching of images with unknown content is possible only when fragment overlapping is multiple. In this case it is mandatory to detect image's corner points. Corner point quantity must be controlled by changing the value of the threshold function. Corner points in the images can be detected using Harris-Plessey method supplemented with the predictive threshold function. Feasibility of the proposed method is proven by experiment. Ill. 5, bibl. 9 (in English; summaries in English, Russian and Lithuanian).

Д. Матейка, Р. Мартавичюс. Использование алгоритма Harris-Plessey для образования больших изображений // Электроника и электротехника. – Каунас: Технология, 2008. – № 5(85) – С. 21–24.

Решаются проблемы образования больших изображений из нескольких небольших фрагментов. Предложена методика полного автоматического образования двухмерных фотокарт из небольших фрагментов. Методика основана на определении общих параметров, накладывающихся друг на друга обединяемых изображений. Определение общих параметров возможно только при более чем 50 % наложении изображений. Доказывается, что точное и надёжное объединение неизвестного содержания изображений возможно только при многократном их наложении. В этом случае необходимо определить уголки в изображениях и, изменяя уровень пороговой функции, подобрать количество совмещаемых углов. Для определения в изображении имеющихся углов пригоден Harris-Plessey метод с использованием прогнозируемой пороговой функции. Экспериментами доказана пригодность предлагаемого метода. Ил. 5, библ. 9 (на английском языке; рефераты английском, русском и литовском яз.).

D. Mateika, R. Martavičius. Harris'o ir Plessey'jaus kampų aptikimo algoritmo naudojimas dideliems vaizdams sudaryti // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 5(85). – P. 21–24.

Sprendžiamos didelių vaizdų sudarymo iš kelių mažesnių jų fragmentų problemos. Siūloma visiškai automatizuoto dvimačių fotožemėlapių vaizdų sudarymo, sujungiant nedidelius sutampančius fragmentus, metodika, pagrįsta sutampančiųjų vaizdų sričių bendrųjų savybių nustatymu. Bendrosioms savybėms nustatyti siūloma sujungiamus fragmentus fiksuoti didesne negu 50 % sanklota. Įrodyta, kad nežinomo turinio vaizdai patikimai ir tiksliai sujungiami į vieną didelį vaizdą tik esant daugkartinei jų fragmentų sanklotai. Šiuo atveju būtina surasti juose esančius kampus ir jų skaičių reguliuoti keičiant slenksčio funkcijos vertę. Vaizde esantiems kampams surasti tinka Harris'o ir Plessey'jaus metodas, papildytas prognozuojama slenksčio funkcija. Eksperimentiškai įrodytas siūlomo metodo tinkamumas.Il. 5, bibl. 9 (anglų kalba, santraukos anglų, rusų ir lietuvių k.).