# Efficient Aerial Image Matching Algorithm for Autonomous Navigation of Aerial Vehicle

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Abstract-- ***Guidance of aerial systems is generally based upon inertial navigation sensors and Global Positioning System. Inertial navigation sensors are assumed accurate and reliable for short duration of flights. Error of inertial navigation sensors accumulates and ultimately drifts from actual position increases with flight duration. On the other hand, Global Positioning System (GPS) is independent of flight durations. So errors of inertial sensors are corrected by information of GPS. There is another way to correct errors of inertial navigation sensors. This is based upon image matching techniques. Waypoints are defined along flight path of aerial vehicle. These way points are stored in aerial system as satellite images. When aerial vehicle reaches pre-stored area, it captures image of small geographic area (aerial image). Now image matching algorithm locates aerial image in pre-stored satellite image. Design of these algorithms is a challenging task. Image matching algorithms are computationally very expansive. A number of matching algorithms are evaluated and finally a computationally efficient algorithm is proposed.***

Keywords-- **Image matching, Aerial Vehicle, Efficient, Hashing, Chamfer matching, realtime.**

## 1. INTRODUCTION TO PROBLEM

Our algorithm has to deal with two images: satellite image and aerial image. Images are affected by number of parameters: lighting conditions, weather conditions, sensor resolution, optical system specifications, flight altitude and direction of image viewing. Our particular problem has no exception and experiences all these difficulties. Lighting and weather conditions of satellite image may be different from aerial image. Similarly sensor resolution and optical specifications of imaging system mounted on satellite may be different than imaging system upon aerial system.

Altitude of satellite is usually constant while altitude of aerial system may be varying number of times. Also, satellite image may be captured by certain orientation while aerial system may be entering the same area with different heading direction.

Algorithm development process for image matching can be divided in two broader tasks: pre-processing and matching. Satellite image is used as reference while aerial image is used as template. Successful matching is possible if satellite and aerial images are same in perspective of above defined parameters. Pre-processing modified aerial image according to satellite image. Then matching process locates position of aerial image in satellite image.

### 1.1 PRE-PROCESSING

Lighting and weather conditions affect the amount of feature. So a restoration process is required to correct lighting and weather conditions of aerial image according to satellite image. Optical specifications and sensor resolution of both images also affect the performance of matching process. Since imaging system of aerial vehicle and satellite lie in category of aerospace, so specifications of aerial vehicle imaging system are chosen according to satellite image. Traditionally satellite imaging systems are CCIR video system and having 2/3” optics. So it is easier to maintain these specifications. Flight altitude of aerial vehicle can vary tremendously. Then systems are designed with multiple fields of views (FOV). Flight altitude is divided in ranges equivalent to no. of steps in FOV. Scale corrections are applied only for smaller variations. Finally, aerial image has to be aligned according to satellite image. This alignment requires some reference directions. Aerial vehicles are equipped with magnetic sensors indicating north direction. Position of north of satellite image is pre-stored and direction of north for aerial image is acquired by magnetic sensor. A rotation algorithm rotates aerial image in desired amount and finally both images are in very much similar conditions and ready for matching process to be performed.

## 2. MATCHING TECHNIQUES

Following image matching techniques were evaluated: binary correlation [1], sum of absolute differences [2], truncated sum of absolute differences, chamfer matching [3],[4], truncated chamfer matching, hierarchical discrete correlation [4].

Binary correlation is performed in two stages: edge extraction of both images and XOR operation b/w aerial image and all possible locations of satellite image. Aerial image can be used in two forms: whole image or cropped imaged of aerial image. Computational analysis showed tremendous processing requirements consuming enough time prohibiting real time operation. An optimization process was adopted described later on in the next section.
Sum of absolute differences is similar to binary correlation in sense that template is searched over all possible locations of searched image. But essentially the difference is that there is subtraction operation b/w corresponding pixel locations rather than multiplication for binary correlation. Also, the gray values of both images are directly used rather edge extracted images for binary correlation.

Chamfer matching uses shape information for correspondence. It compares shapes of aerial image at all possible locations of satellite image. Chamfer matching treats aerial image and satellite image separately. Edges are extracted from aerial image. Satellite image is processed by two steps: edge extraction and distance transform.

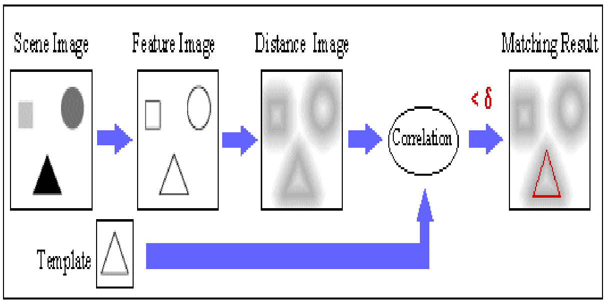


**Fig. 1**

## 3. EFFICIENT ALGORITHM

Computation requirements of binary correlation can be reduced by considering the multiplication process of binary digits. Binary digits result into one whenever both numbers are 1. So, there were two possible optimizations for binary correlation. First optimization is that location of edge points are known in satellite image. Now we multiply edge points of aerial image to pre-stored locations of satellite image. This arrangement required a lot of memory requirements. Second optimization is that edge points of aerial image are used. Then only these locations are compared to corresponding satellite image locations. This process requires fewer additional memory requirements. Also computational requirements are reduced considerably. Consider aerial image is cropped into template of 100*100 and this is used for matching in satellite image. For matching at one location, we require 10,000 operations. Consider the size of satellite image is 1000*1000 pixels. For aerial image of size 100*100, there are 811801 (901*901)

possible locations in satellite image where this aerial image may possibly exist. Roughly speaking we require 8GOPS (giga operations) for just comparison and data access from memory and other processing requirements are additional. Consider the case when we compare only edge points of aerial image to corresponding locations of satellite image. This computation depends upon number of edge points in aerial image. More the number of edge points in aerial image, more are the computation requirements. Generally 5% of total number of pixels is considered as enough for useful information extraction from aerial image. Now practically speaking, we compare 500 (for aerial image of 100*100 pixels) edge points of aerial image to find best match in satellite image. Now computation requirements for comparison process are reduced from 10,000 to 500. This is a reduction in processing requirements by 20 times.

Computation requirement of Sum of absolute differences is reduced by using truncation process. This reduces computation requirement by two times generally.
Similar optimization is performed for chamfer matching. Chamfer matching is a process which considers minima as best match (similar to SAD but different than binary correlation as it considers maxima as best match). It sums the values of distance transformed image of satellite image according to edge point (shape) in aerial image. Generally, as I mentioned above, 5% of edge points are considered enough for shape information [6]. Automatically we have reduced information to deal with. So this matching process is straight away less computationally expansive and we may consider it equivalent to binary correlation. But there is one more point that since it is minima based process, we can apply truncation process to reduce processing requirements further by twice. So ultimately we achieve a reduction by 40 times in computation requirements for matching process.

### 3.1. DESIGN OF REAL TIME IMAGE MATCHING ALGORITHM

Till now, we have achieved most computationally efficient algorithm by restricting maximum number of edge points to 5% and introducing concept of truncation for minima calculation. As I claimed in above section, that we have reduced computation requirements by 40 times i.e. computation requirements are decreased from a total of 8 GOPS to 200 MOPS (mega operations). These are the requirements for comparison only. But practically speaking, there are additional processes required to carry the computation. Data fetching, address incrementing and looping requirements add tremendous processing burden. If

we include all these processing requirements, then processing requirements are roughly around 1 GOPS range.

All these algorithms were experimented upon C6711 DSP processor of Texas Instruments. This is a floating point DSP processor capable of 1 GOPS per second. Calculations are good up to this point. There is one more point that matching algorithms require that both aerial image and satellite image should have the same imaging conditions. This is practically impossible. However image processing techniques are used to bring both images to same imaging conditions. This correction requires image rotation and image restoration processes. These processes add processing burden. Image rotation algorithm is computationally more expansive than image restoration algorithm. We experimented with Weiner process to correct lighting conditions of aerial image.

100*100 pixels cropped from aerial image is fairly good choice because enough shape information is available in this image size. Satellite images are available in different spatial resolutions. Generally these are 1 m/pixel, 2.5 m/pixel, 5 m/pixel and larger sizes. We experimented with 2.5 m/pixel spatial resolution satellite imagery. 1000*1000 pixels image size means 2.5 sq. km. area on ground. Selection of size of satellite imagery is dependent upon inertial sensors inaccuracy. Inaccuracy of such sensors increases by increase in time and there is not linear relationship between inaccuracy and time. These sensors follow exponential relationship between time and inaccuracy. Therefore as the time of flight increases, larger area has to be selected. 2.5 km choice for satellite imagery size is suitable for smaller duration flights. Location information by image matching algorithm is used to correct inaccuracy of inertial sensor. But this correction information does not rely upon one match. At least three matches are required for reliable information. Also, subsonic aerial vehicles are generally covering 200 m/sec.
All these constraints dictate to speed up the process. Now there were two possible approaches. Either design specialized architectures for configurable logic or design faster algorithms. We followed the later approach.

Basically we modified chamfer matching. In chamfer matching, aerial image and satellite images are treated separately. Edges are extracted from aerial image. Similarly edges are extracted from satellite image and then edge extracted information is converted into distance transformed image. A correlation surface is created by using edge extracted image of aerial image and distance transformed image of satellite image. Then a minimum is searched in correlation surface to find the best match. The basic procedure in development of correlation surface is that

values are summed from distance transformed image and considered as one value in correlation image. Selection of values of distance transformed image is done according to

edge points of aerial image. This summation process is carried at all possible locations of satellite image. Basically if aerial image is of dimensions 100*100, then a block of 100*100 pixels are selected from distance transformed image of satellite image. There are edge points in aerial image and only corresponding location of these edge points are summed from distance transformed image of satellite image. Edge points of aerial image are mainly important, not the whole aerial image.

Edge points of aerial image are used for data access from distance transformed image. Suppose we consider that restoration process is quite stable over large variations of lighting and weather conditions. Then we may say that edge points of aerial image and edge points of satellite image for a particular shape may not be varying by large number. Matching process is carried out by accessing corresponding locations of satellite image from a block equivalent to size of aerial image at a time. Suppose we keep information about number of edge points in a particular block (equivalent in size of aerial image) of satellite image. Now, number of edge points for each blocks are computed for all possible blocks in satellite image. Therefore we have certain possible locations for each number of edge points. This information can be represented in a tabular form which describes edge points versus corresponding block locations. We stored this information by using hashing technique of data structures. Now when aerial image is processed and edge points are extracted from aerial image, then number of edge points is counted. Number of edge points gives us clue about possible locations of satellite image where these much number of edge points may occur. So our search space is reduced from whole satellite image to fewer locations and matching procedure is extremely fast.

This procedure makes real time matching of aerial image in satellite image. The only tradeoff is additional memory storage for linked list storage.

## 4. CONCLUSION AND FUTURE WORK

The above mentioned procedure makes matching process executable in real time and search over large satellite imageries. The results were encouraging. Reliability of this scheme is mainly dependent upon stability in shape information or lighting condition invariant shape extraction. Now I am planning to experiment with adaptive edge extraction by using neural networks. Such method is

described in detail in [7]. So design of more robust algorithm will be possible.

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