IR V1

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Index Terms—Swarm drones, CIV, SFM . . .

Abstract—This article is about discussing of the efficiency of formation of drone swarms in 3D scene reconstruction [1]. We consider that a formation is efficient where it gives a faithful reconstruction of the wanted object or scene. We can also consider that a formation is efficient when the reconstruction is obtained quickly or with a high definition of the wanted object/scene. This paper investigate how drone formations are tested and what results the original writers got from these experiments. We will also discuss about what has been done since the article has been posted and what they could have done to improve the quality of their results.

Article: Impact of drone swarm formations in 3D scene reconstruction

1 Introduction

Drones are increasingly being used in a tons of domains. From a military usage at the beginning [2], by using them as a remote weapons, to a humanitarian use [3] to search and rescue people after a disaster or to bring resources. Whether it's for surveillance operation, bringing resources or an offensive use, a single drone unit tend to be expensive if we want make it viable and robust. Furthermore the coverage of a large area (in a surveillance operation to rescue people after a disaster for example) with only one drone tend to be too slow with the emergency of the situation. So, usage of swarm of tiniest and lower cost drones appears. Benefits of a drone swarms are the reduce cost as mentioned, and its robustness, if one drone has a breakdown the swarm can continue is mission where for a single drone it's the end of the mission. But another benefits, it's the time spend in a surveillance because we can split our drones to cover more field in less time, and this is crucial for rescue operations. In the other hand, use of low cost drone make their autonomy drop, because of less powerful batteries, and the quality of their camera drops too.

In the following paper, we analyze an article [1] about the impact of the formation of an swarm of drones in the accuracy of the 3D reconstruction. Section 2 overviews some related work in literature while Section 3 presents contributions and results brought in the presented article. Section 4 discuss the limitation and positive points of the article. And section 5, conclude our analyze.

2 Context and Related Work

Since 1979 UAV are used for photogrammetry because there are a low cost way to have photos from above, but they still need some adjustments about the stability and become more common around 2004 [4] and usage of 3D vision with small autonomous drone become to being investigate [5]. With a swarm of autonomous drones, we can get a 3D reconstruction with by taking multiple images with different angles of view. The algorithm SFM (Structure From Motion) that is used by the author of this article [1] uses this principle.

From 2001 [6], researches are made on how to keep a formation of mobile autonomous robots. The aim is to make a "swarm" of robots move, from a point A to an other point B, in an environment filled with obstacles and how it could avoid the obstacle to reach their destination without breaking their formation. These robots are not flying drones but this is a first step into the formation we will discuss.

Few years later, in 2006 [7], an other research is made about leading a swarm of UAV through a defined ordered sequence of waypoints (points in the 3D environment), in constrained environments. They found an algorithm to make the flight formation safe[1] in constrained spaces.

Then some research have been focused on the dynamic adaption of drones swarms to their environment to monitor in narrow spaces [8], they are searching a way to face the issue of keeping the distance between drones in a formation constant. To do so, they put sensors on each drone and thanks to an algorithm, dynamically adjust each drone according to the distance they got from an other drones without any external assistance.

And the last few years before this article [1], investigations were focused on optimizing drones trajectory to achieve a purpose or to maximize the reconstruction accuracy. In 2014 study have been made on how efficiently enclose a target with a swarm of drones by adopting a geometric formation [9]. Furthermore usage of drones swarm for 3d reconstruction are under investigation by 2012 with the SFLy[2] project [10], which aims to create a swarm of autonomous drones to map an unknown environment. But there are no studies comparing the accuracy of the 3d reconstruction from several drones formation and this is what the article [1] is about.

1. Makes the UAV avoid being damaged
2. Swarm of Micro Flying Objects

	d_0	d_1	d_2	d_3	d_4
d_0	0	1	1	0	0
d_1	0	0	1	0	0
d_2	0	0	0	0	0
d_3	0	0	1	0	0
d_4	0	0	1	1	0

Formation 1

	d_0	d_1	d_2	d_3	d_4
d_0	0	0	0	0	0
d_1	1	0	0	0	0
d_2	1	1	0	1	1
d_3	0	0	0	0	1
d_4	0	0	0	0	0

Formation 2

	d_0	d_1	d_2	d_3	d_4
d_0	0	0	0	0	0
d_1	0	0	0	0	0
d_2	0	0	0	0	0
d_3	0	0	0	0	0
d_4	0	0	0	0	0

Formation 3

	d_0	d_1	d_2	d_3	d_4
d_0	0	0	0	0	0
d_1	1	0	0	0	0
d_2	1	1	0	0	0
d_3	1	1	1	0	0
d_4	1	1	1	1	0

Formation 4

	d_0	d_1	d_2	d_3	d_4
d_0	0	0	0	0	0
d_1	1	0	0	0	0
d_2	0	1	0	0	0
d_3	0	0	1	0	0
d_4	0	0	0	1	0

Formation 5

Fig. 1: Drones formations with their graph matrices representing if a drone lie within the FOV of an other one (from [1])

3 Contributions

3.1 Approach

The core of their contribution is the comparison of the localization and reconstruction accuracy of a 3D scene by different drone formations. They compare five formations of five drone each (see figure 1). At a given time, each drone acquire an images and then compute a set of descriptors of this image before sending it to the reconstruction unit. Once that is done, a standard SFM[3] algorithm compute an estimation of the 3D coordinates of each point from the scene. SFM principle is to match correspondences between the views, these points, which belongs to multiple views, are related thanks to a SIFT[4] descriptor. Then they refine this result with a bundle adjustments, which is an optimal estimation of the 3D coordinates of points of the scene and the camera positions and calibrations simultaneously [11]. An optimal estimation aims to minimize errors between the projection on the estimated points on the scene and the detected points.

Sometime drones lie within the FOV[5] of an other drone resulting of an occlusion of the scene and a loss of accuracy but they decided to use this as side information (call CIV[6]) to calibrate cameras and improve the SFM accuracy by adding the camera in-view information (like is position and calibration) in the bundle adjustments. To use CIV each drone needs to know the appearance of others, so at the beginning of the flight each drone communicates it appearance to the others with a SIFT descriptor. Furthermore, to foster CIV, drones in back of the formation are set to a higher altitude (see the video sequence [12]).

All their test are done within a simulation of a street with buildings, cars and street light (see figure 2).

3. **Structure from motion:** Estimation of a 3D object from capture of 2D images of the same object with different points of view

4. **Scale-Invariant Feature Transform :** Description of interesting point, that are invariant within the luminosity or the rotation

5. Field Of View

6. Camera In-view

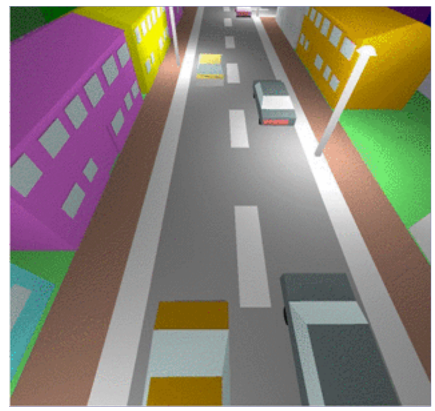

Fig. 2: Simulation (from [1])

3.2 Results

The first thing shown in their results is about drone identification, and they found that we need to match with at least 60%, of their descriptors.

They have also shown that the more they exist matching points, belonging to the scene, between couples of different images and more the reconstruction will give better 3D points coordinates of the scene. To maximize matching points, we need to minimize the distance between them to get matching points, but in a configuration that minimize drones occlusions. The authors also precise that there is a correlation between σ and the improvement brought by the camera in view strategy. We can calculate σ with the following formula.

$$\sigma = \sum_{i=0}^{n} \frac{|S_i|}{n} \tag{1}$$

Where n is the number of drones and $|S_i|$ is the number of drones the i^{th} drone has in his field of view.

Next, they compare each drone formation on an accuracy criteria. And for each formation, they look the average MSE[7] between what they expect and what they actually got with the simulations. Results show that the first formation (see Fig.1) is the formation which got the lower average MSE thanks to the minimum number of occlusions and the different distances of the UAVs with respect to the scene to be

7. Mean Squared Error

reconstructed. Still according to their results, the formation one has the high value of σ, which correspond with the fact that σ helps for the accuracy of the reconstruction.

4 Discussion

4.1 Limitations

Given that this article is written for a conference (the 2016 IEEE International Conference on Image Processing), there is a certain amount of information lacking[8]. For the drone formations, there is no further information on the height of each drone from the scene, or even the distance there is between each of them. In the *Experimental results* section of the article, there is a *Avg. baseline* value for each formation, but there is no clue on what unit is used there, making the result difficult to interpret. The fact that this value is also a mean of the distance between drones is not either useful.

There is also other absent information that would have been useful if we want to reproduce the experiment, like information about the experimental conditions. What program they used to realize their environment and which parameters. Further information would have been good to have like camera characteristics, or even drone ones, like length, width, speed etc...

Now we are going to talk about improvements they could have done to their experiments. The simulation could be more realistic in terms of scene graphics, because in the given image we saw building made of simple shape and unified colors, and they also could add moving objects to the scene (despite there is cars on the images, we can see in the video [12] that they are not moving).

Their contributions are about comparing drone formations and it would make sense to use more or less drones in each formation and why not comparing results from formations with different number of drones (e.g. comparing a five drone formation with a six drone formation) especially as they use a simulation it would be easy to setup, but they said that they would test the scalability of their result in an future research.

Finally, they just compare the accuracy of the 3d reconstruction, but one of the reasons to use a drone swarm is the time of the reconstruction, so it would be more interesting to add a comparison of the speed of the reconstruction from each formation to see if formations have an impact on it too. But they also said that it would be tested in a future work.

5 Positive points

The fact that the experiment is realized in a simulation allow them to have a deterministic model, which guarantee that each formation has the same scene to analyze, making the comparison possible. That being said, they also tried to make the experiment more realistic by adding some noise to camera location, which is inherent to real world sensors.

8. We didn't find (or there is not?) a more detailed version of this article.

6 Conclusion

We saw in the discussion part (Sec. 4), that drone swarm formation has an important role on the quality of the reconstruction of a scene. In the article [1] they mainly speak about the precision of the reconstruction over other parameters (like the speed of the reconstruction). After comparing five formation of five drones each, they found that a inverted **V** shaped formation gives a better reconstruction accuracy than with the others. The experimental conditions are not really perfect, they could have used a better 3D engine, compare more formations with different amount of drones in it, but in fact they are the first to do such experiences, furthermore, they said that there will be more experiences about this subject. Up to now, there is no other article done which aims to compare drone formations, not even from the same authors. A possible way to improve their result may lie in using another method than the bundle adjustment which is a highly "expensive" algorithm. The method discussed in the article [13] could be a path to explore for in order to obtain better results.

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