Lightscribing the sky with micro UAVs

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Abstract. Nowadays Unmanned Aerial Vehicles (UAVs) are intensively used both for the military and civil purposes. Their reliability has increased over the past decades. However, general public is still rather skeptical about these technologies. Therefore, in order to promote UAVs, we made an art installation with a drone equipped with LED. In this paper we present obtained results and some technical details of this project.

Keywords: Micro UAV, path optimization, UAV art, projective geometry

1 Introduction

Unmanned Aerial Vehicles (UAVs) were originally meant to be used by the military forces. Since then these technologies made a huge step forward: drones became more reliable and intelligent. As a result, nowadays they are also used for a wide variety of civil services (e.g. construction site surveillance or agricultural monitoring). However, perception of UAVs by a general public is still not completely positive.

In order to popularize UAVs in general and micro UAVs in particular, researchers have decided to employ drones not for their traditional tasks like surveillance and tracking, but for the entertainment purposes. For example, in March 2012 during one of the TED talks Prof. Kumar released a video where a fleet of microdrones performs a James Bond theme song [1], [2]. Later this year his group from GRASP Lab, University of Pennsylvania, was one of the organizers of a great UAV light show at the Cannes Lions International Festival of Creativity [3]. Another group of researchers from Ars Electronica Futurelab, Austria, set a world record on simultaneous formation flight of 49 quadrotors [4], [5]. As a result of these activities, non-scientific community starts to show interest in this new technology.

Within the project "Collaborative microdrones" ("cDrones") [6] we decided to create an art installation to support the idea of promoting micro UAVs. As it was mentioned, the light shows with UAVs proved to be efficient. Therefore, our idea was to use LEDs mounted on a UAV and perform something different from the related projects. We switched from the life videos, as it was done before, to pictures taken by a camera with a long exposure time. A drone would follow the predefined path in a shape of a text or a picture which will be captured by the camera.

Realization of the whole idea faced several challenges. For example, the flight time of a UAV is limited by its battery capacity and exposure time of a camera. However, the picture should be visible and recognizable. In addition, the payload of micro UAV is up to several hundred grams. Therefore, LED on the UAV should be light and bright enough at the same time. However, we could overcome these restrictions and show satisfactory results which will be described in the following sections.

The rest of the paper is organized as follows. Section 2 describes the whole work flow, used hardware and its modifications. Transformation from the vector-graphic picture to a set of waypoints is described in Section 3. Optimization of the obtained sequence of waypoints is explained in the Section 4. Finally, in Section 5 we present achieved results and draw some conclusions.

2 System Description

In the cDrones project we have developed a framework that is able to coordinate multiple UAVs. Although the goals of the cDrones project differ from our idea of the art installation, we still can use the planning pipeline of this framework with slight modifications. The modifications affect the computation of the waypoints and the computation of the optimized route which are described in sections 3 and 4.

2.1 Planning Pipeline

The planning pipeline consists of four main steps:

1. Read an image or a text which should be sketched in the air from the file and transform it into a sequence of way points.
2. Apply several transformations to this waypoints sequence so that the image fits into the camera viewport and it has no perspective distortion.
3. Compute an optimized path through the waypoints.
4. Generate a GPS waypoint file for the UAV.

2.2 UAV Platform

The UAV platform we chose for our art project is the MD4-200 from microdrones GmbH which we also use in our cDrones project. However, we had to modify the UAV in order to use it for drawing on the sky. Instead of the camera, we mounted two LED lamps that are bright enough to be seen in the dark and on the long-time exposure images.

For our application the LEDs need to be switched on in a certain waypoint and switched off in another waypoint. Our idea is to use the camera trigger for this purpose. This allows us to switch on/off the LEDs via the remote control in the manual flight mode and via waypoint actions in the waypoint mode. The Pentax A40 camera on the MD4-200 is usually triggered via the camera remote control feature. Therefore, an infrared LED is mounted on the drone instead of the camera and is connected to the UAV trigger output. When the camera is triggered, the MD4-200 directly outputs the pulse-width modulation (PWM) signal with the sequence to trigger the camera. We can not use this PWM signal directly to switch the LEDs on and off. Hence, an additional electric circuit is required. Instead of the short PWM signal, we need a single clean pulse. Therefore, we use a NE-555 based monoflop which provides a single pulse of about 1.2 s from the PWM trigger output. The pulse of about 1.2 s is required because, from our experience, in waypoint navigation mode the MD4-200 sends two camera trigger pulses with a delay of about 1 s for each camera trigger waypoint action. If the pulse is shorter than 1 s the lights are switched on with the waypoint action and after 1 s switched off in the same waypoint. To overcome this behavior, we increase the pulse width to be more than 1 s. The monoflop is connected to a toggle flip-flop which drives a relay. The toggle flip-flop allows us to change the LEDs on/off state by a single trigger pulse. The relay, on the other hand, allows us to power the LEDs by a separate 12 V battery while the main circuit runs on 5 V taken from the UAV.

Figure 1 shows our MD4-200 with the LEDs mounted instead of the camera. We also mounted a small reflector to cast most of the emitted light towards the camera on the ground.

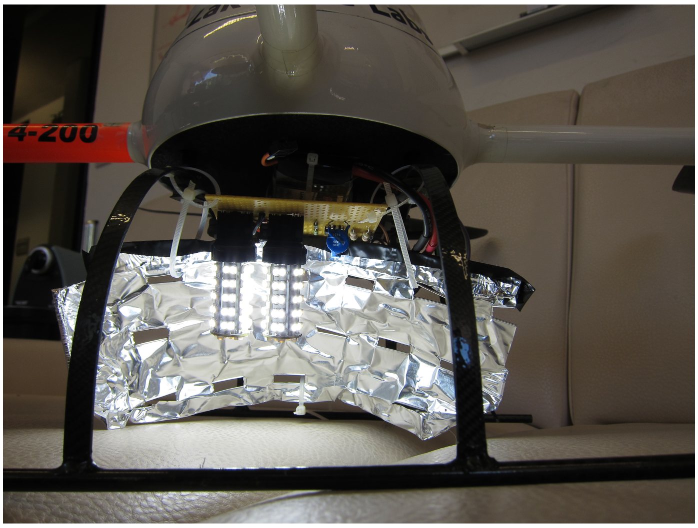


Fig. 1. MD4-200 with two 3.5 Watts LED lamps.

3 Image Preparation

In the planning of waypoints for the projected image on the sky the following aspects had to be considered: i) the written symbol or text should present no perspective distortions, ii) the limited flight time should be synchronized to the camera exposure time, and iii) the lightning conditions should be appropriate for taking a long time exposure photography and nice art output.

We fulfilled these requirements by utilizing a homography projection onto a virtual horizontal plane in the sky. In order to minimize the energy consumption and the total flight time, we decided to fly at the same altitude level. Furthermore, this should prevent appearance of bright dots in the output photography, due to the slow ascending and descending velocities of the used UAV when changing the altitude level.

The projective geometry mapping is computed in advance and applied to the input data before route optimization, cf. Section 3.2. After the route optimization, presented in Section 4, the projection scale is revised if required. This revision is triggered by the simulation model implemented in our UAV framework that verifies planned routes according their to energy consumption.

3.1 Creation of the Model

The first step in the model projection is the import of the defined model. Our proposed method can deal with any vector graphics in the scalable-vector-graphic (SVG) format with included *paths* according to the specification, cf. [7].

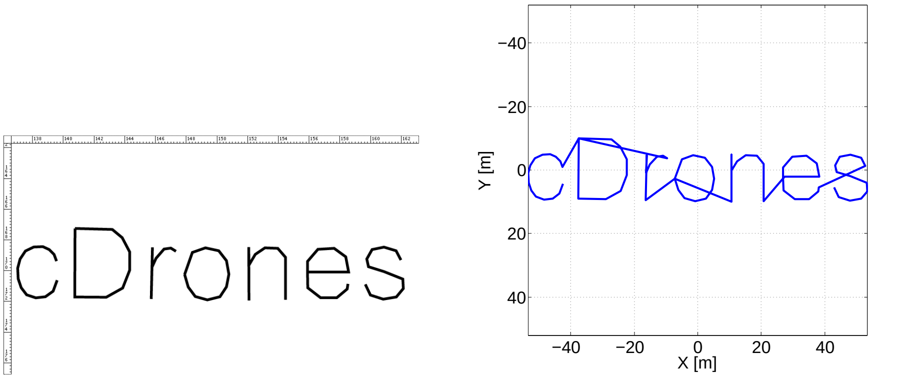
These SVG paths are converted to the input format of our framework. For this purpose, we implemented a filter that extracts a list of coordinates from the SVG document, which we call waypoints and marks the beginning and ending points of every connected path, e.g., a letter in a text.

Figure 2 demonstrates the input SVG document, cf. Figure 2(a), and the extracted path in Figure 2(b), where SVG path coordinates are converted up to scale and are connected between ending and beginning points of separated paths.

3.2 Homography Mapping

In order to compute the projection matrix, i.e., homography $\mathbf{H}$, we need to know approximate position of the camera (x,y,z), flight altitude a and camera field-of-view k (FOV). Then we can compute view angles α and β as shown in Equation 1. Equation 2 shows calculation of the camera origin $\mathbf{o}$ and model translation $\mathbf{t}$. The final projective model is optimized by its maximum width w_{max} to utilize the whole FOV of the camera. At the same time it is limited by the maximum flight time.

$$\alpha = \frac{\pi}{2} - atan\frac{a}{x}, \quad \beta = \frac{\pi}{2} - atan\frac{a}{y} \tag{1}$$



(a) Input model in SVG document format

(b) Input model as a connected sequence of waypoints

Fig. 2. Input documents and converted paths for our UAV framework

$$\mathbf{o} = [0,0,0,1]', \quad \mathbf{t} = [x,y,a,1]', \quad w_{max} = 2 \cdot x \cdot tan\frac{\kappa}{2} \tag{2}$$

The final projection of the model, defined by its points $\mathbf{p}_n$, is transformed in the 3D space by $\mathbf{T}$, cf. Equation 4. Here $\mathbf{R}$ is a rotation matrix calculated as shown in Equation 3. It depends on already computed angles α and β, and the global rotation angle γ (yaw). Angle γ is defined by the scene setup and fixed throughout the whole process. In Figure 3 the resulting 3D transformation onto the image plane, i.e., points $\mathbf{p}_T$, is demonstrated in blue ($*$) considering the FOV of the camera and the required scale.

$$\mathbf{R} = \mathbf{R}_x \cdot \mathbf{R}_y \cdot \mathbf{R}_z = f(\alpha,\beta,\gamma) \tag{3}$$

$$\mathbf{T} = [\mathbf{R}\,\mathbf{t}]_{4\times4} \tag{4}$$

Finally, the transformed points $\mathbf{p}_T$ are projected from the estimated image plane to a horizontal plane at the expected flight altitude a, cf. Equation 5. For simplification of Equation 6 only the projection of the four points $\mathbf{p}'$ of the bounding box of the model are determined by intersecting the projection rays with the horizontal plane at $z = a$.

$$\mathbf{r} = \mathbf{p}_T - \mathbf{o}, \quad \mathbf{n} = [0,0,1]', \quad \mathbf{p}' = \mathbf{r}\frac{a}{\mathbf{n}\cdot\mathbf{r}} \tag{5}$$

$$\mathbf{p}' = \mathbf{H} \cdot \mathbf{p}_n \tag{6}$$

The resulting homography is applied to all points of the model, as sketched in Figure 3. The transformed model on the virtual image plane is presented in blue ($*$) from the camera's view point. Furthermore the projected model, denoted in green ($\bullet$), is visualized on the virtual horizontal projection plane at the flight altitude. These projected points are further processed in the next stage of our UAV framework by the path optimization.

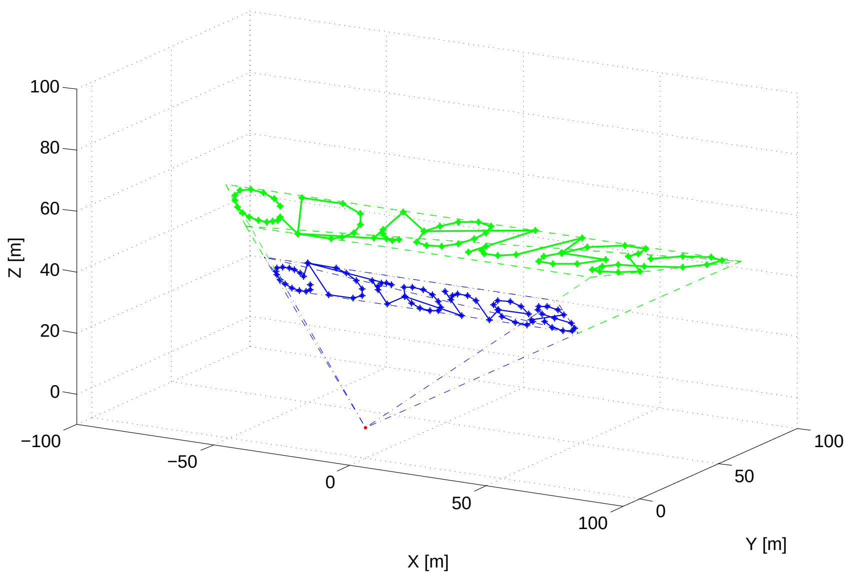


Fig. 3. Projecting the text onto the virtual horizontal plane in sky at $z = 50m$.

4 Path Optimization

After the homography transformation the next step is to define a path - a sequence of way points. Input consists of way points locations and an action of the LED (turn on/off, do nothing) at every point. An example of the input data in shown in Figure 4. As it was already mentioned, the flight time is critical and, therefore, the flight length is minimized during this optimization step. Additionally, we require that image parts which we call "blocks" (e.g. letters in a text) should be visited in the same sequence as they were given in the SVG file.

Path length is a sum of all individual distances between the way points in this path. In order to fulfill the requirement, we distinguish 3 cases of distance computation for a pair of points:

1. If way points are within one block (e.g. letter) than the distance between these points is equal to 0;
2. If way points are at the beginning or at the end of neighboring blocks (LED is switched on/off) than the distance is a Euclidean distance between them;
3. Otherwise, the distance is infinite.

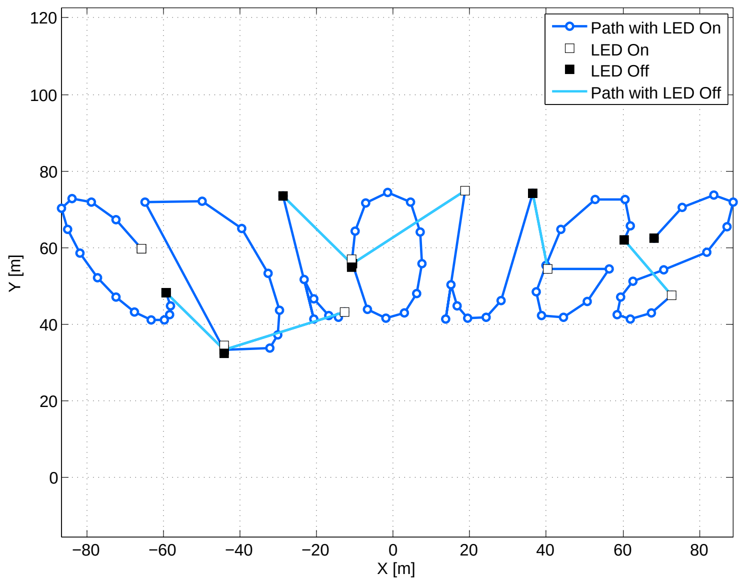


Fig. 4. Output of the homography.

Additionally, if a block is a closed curve (e.g. letters "o" and "D") then all of its way points are treated as if they would change the LED state (case 2).

Since the way points are already given in a sequence, they can be seen as a path which will improved by a heuristic. For this purpose, we implemented a well-known method of combinatorial optimization called 3-opt [8]. It replaces 3 edges from the path by another 3 edges so that the result is a correct path as it is shown in Figure 5. If obtained path is shorter than the current one than the new path is accepted. These operation is repeated as long as no more improvements can be found.

Optimized path for the word "cDrones" is shown in Figure 6. Dashed line represents the initial path whereas green and red lines indicate the optimized path. New edges are marked with the red color.

5 Results and Conclusion

5.1 Simulation Results

For safety reasons we developed a simulation environment that simulates and verifies the generated waypoint data before flight. Since the flight was performed during the night, the simulation is of outermost importance. In this simulation the flight time and approximate energy consumption is verified according to the UAVs capabilities, with the additional payload of the battery for the LED lamps.

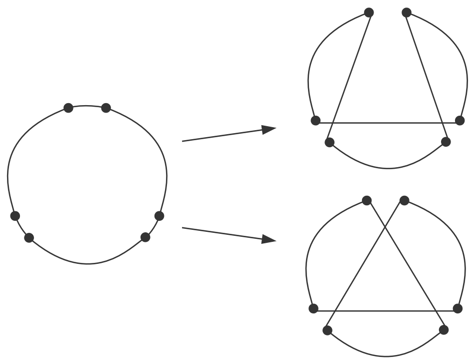


Fig. 5. Possible path modifications for the 3-opt heuristic.

5.2 Photography

In this project we were using a Nikon D7000 DSLR as primary camera with an optical remote trigger that was manually synchronized with the flight duration. When the power LED was switched on the first time after take off, the camera trigger was released. After completing the flight and powering off the LED the last time, the camera shutter was closed. This camera was positioned in the defined origin $\mathbf{o}$ with a focal length of 16 mm resulting in a FOV $\kappa \approx 72\,^\circ$.

In addition, we used a second camera, i.e., a Nikon D700 DSLR with a focal length of 14 mm resulting in a FOV of approximately 104 ° for a wider view of the scene. This camera was positioned off the perfect view point, at $\mathbf{o} + [-4, 11, 1.8]'$. Already by the small shift of this camera we could explore the increased distortion of the projection in the images in Figure 8(b) and Figure 9(b).

In Figure 10 the recorded flight path of one model was analyzed in Google Earth. For this analysis the user's camera view was approximated to the proposed camera origin.

For more details on the evaluation process we made a short video that presents our work [9].

5.3 Outlook

The system presented in this paper can be improved further by the use of a multiple UAVs with possibly different colors of LEDs. Additionally, different flight altitudes will result in lines with different thickness.

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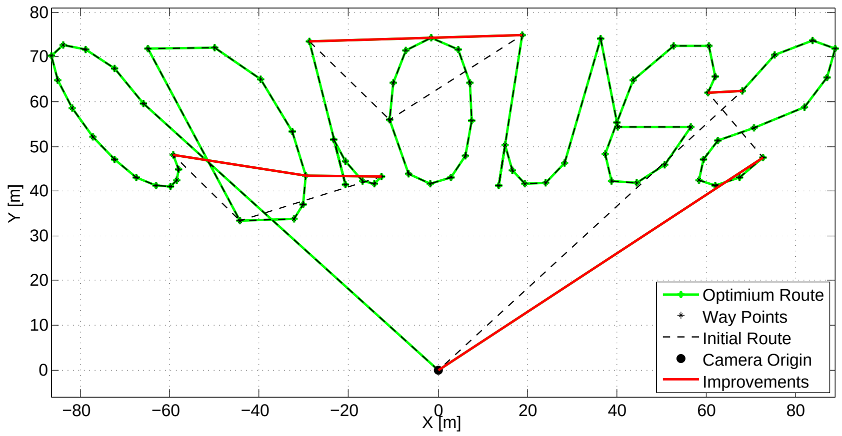

Fig. 6. Optimized path for the word "cDrones".

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References

1. : Article "Quadrotors Come to TED". `http://www.upenn.edu/spotlights/penn-quadrotors-ted` (September 2012)
2. : Article "Quadrotors Play Bond Theme, Are Clearly Working for Evil Masterminds". `http://spectrum.ieee.org/automaton/robotics/diy/quadrotors-play-bond-theme-are-clearly-working-for-evil-masterminds` (September 2012)
3. : Article "Watch This Mind-Blowing Quadrotor Performance". `http://spectrum.ieee.org/automaton/robotics/artificial-intelligence/watch-this-mindblowing-quadrotor-performance` (September 2012)
4. : Video of the world record on the biggest number of simultaneously flying UAVs. `http://www.youtube.com/watch?v=ShGl5rQK3ew` (September 2012)
5. : Article "Quadrocopters at the voestalpine Klangwolke". `http://www.aec.at/aeblog/en/2012/07/31/quadrocopter/` (September 2012)
6. Quaritsch, M., Kruggl, K., Wischounig-Strucl, D., Bhattacharya, S., Shah, M., Rinner, B.: Networked UAVs as aerial sensor network for disaster management applications. Elektrotechnik & Informationstechnik (e&i) **127**(3) (March 2010) 56–63
7. Bowler, J., Brown, C., Capsimalis, M., Cohn, R., Cole, L.D.: Scalable vector graphics (SVG) 1.0 specification (2001)
8. Lin, S.: Computer solutions of the traveling salesman problem. Bell System Technical Journal **44** (December 1965) 2245–2269

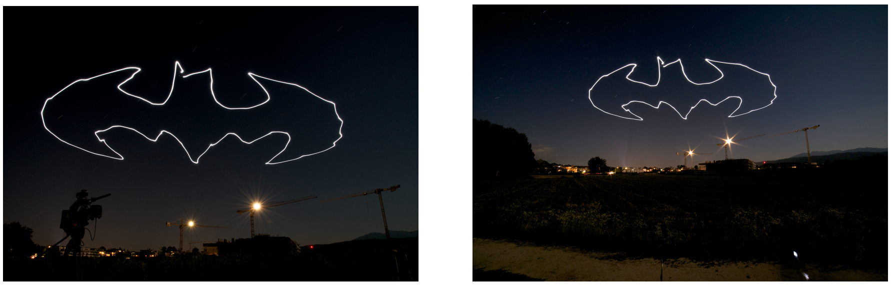
Fig. 7. Long time exposure photography of the model with an exposure time of $t = 395\,s$

(a) Camera D7000 in position **o**

(b) Camera D700 in an off-site position

Fig. 8. The text "SINUS", exposure time $t = 293\,s$

9. cDrones: cDrones UAV NightScribe. Website (August 2012) Available online at http://t.co/VJY4Gxf6; visited on September 15th 2012.



(a) Camera D7000 in position $\mathbf{o}$ (b) Camera D700 in an off-site position

Fig. 9. A famous symbol in the sky, exposure time $t = 272\,s$

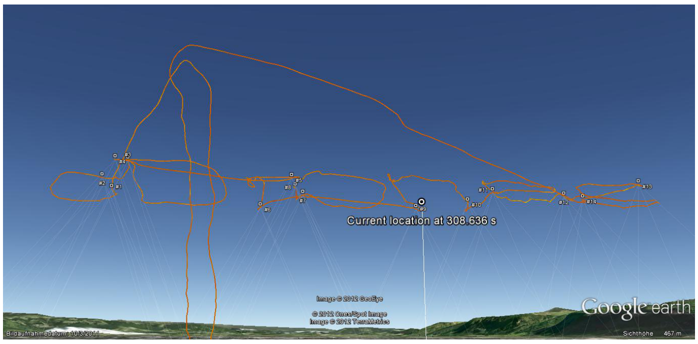


Fig. 10. Recorded flight data from the approximated camera view, presented in Google Earth.