Single Stroke Light Painting with a Quadrotor Robot

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***Abstract*— We investigate trajectory generation alternatives for creating single-stroke light paintings with a small quadrotor robot. We propose to reduce the cost of a minimum snap piecewise polynomial quadrotor trajectory passing through a set of waypoints by displacing those waypoints towards or away from the camera while preserving their projected position. Our results use a variety of one-stroke animal illustrations as targets.**

I. INTRODUCTION

Light shows with areal robots have become a reality, with thousands of robots operating like flying pixels, each with a controllable light, and coordinating to form shapes and messages in the sky to amaze crowds at large sporting events. But rather than exploring the frontiers of robot swarm cooperation, in this work we investigate the minimalist problem of producing light paintings with long exposure photograpy of a single aerial robot. Robots have become a vehicle for exploring ideas in the production of creative artifacts, for example, in drawing [1], stippling [2], [3], and painting [4]. At the core of many of these endeavors are important technical challenges and computational problems that require a scientific approach to designing and evaluating these robot systems.

In our work, we directly put into practice the seminal work of Mellinger and Kumar [5], which proposes polynomial trajectories and shows that a differentially flat representation of the quadrotor permits a convenient formulation for generating high quality quadrotor trajectories. This technique is a convenient approach to the problem, especially due to the availability of the Crazyswarm software [6] that we use in this work. Given a set of waypoints to fly in the path of a single stroke light painting, restricting the path of the robot to a plane is unnecessary because the primary goal is to have the path of a light on the robot project to the desired illustration in the photograph. Because high curvature trajectories involve larger cost (i.e., higher snap), we displace waypoints off the plane while preserving their projection in order to generate a slightly longer optimized trajectory of similar appearance with better overall cost. Figure 1 shows a photo of the quadrotor robot we use in our light painting work and a preview of the results.

II. METHOD

The input 2D desired trajectory is specified by a set of waypoints defined on a plane normal to the camera's viewing direction and at a fixed distance. We chose a variety of single-stroke animal figures for our light paint trajectories, defining camel, penguin, and flamingo trajectories based on famous

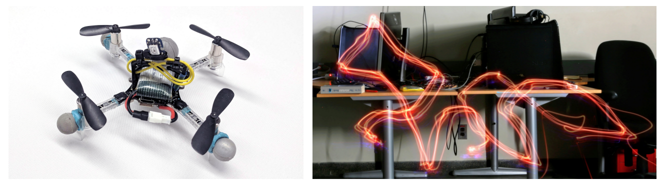

Fig. 1. A NeoPixel mounted on a Crazyflie 2.0 (left) illuminates during flight to create light paintings in a long exposure photograph. A composite image (right) shows multiple light paintings of a fox.

continuous line drawings by Picasso, and a variety of other animal trajectories based on a set of one-line animal logos created by the French creative duo known as DFT.

In our experiments we optimize for 1 m/s and 1 m/s^2 maximum velocity and acceleration, respectively, and note that trajectory waypoint sequences which contain spans shorter than 20 cm tend to have much larger cost due to high curvature. Thus, we set a 20 cm distance threshold between waypoints and define two straightforward procedures for altering the waypoints to reduce the optimized trajectory cost. We loop over the waypoints until we find a waypoint that is within 20 cm of the previous. We then compute two positions on the line between the center of projection of the camera and the problematic waypoint, which are 25 cm from the previous waypoint (an additional 5 cm is added to the span for extra effect). At this moment, we either choose to move the robot closer or farther to the camera. We update the problematic waypoint as well as all subsequent waypoints to the new depth value. This scales all the remaining points to be closer together when choosing to move toward the camera, which would seem to be counterproductive except that we cannot simply let the trajectory get pushed arbitrarily far from the camera because it must stay within the motion capture volume. Therefore, we explore two different strategies: keeping the robot in a fixed *depth range*, and keeping the robot as close to the original plane as possible, which we call the *perturbed depth* method.

III. RESULTS

Figure 2 shows the cost reduction we obtain for the depth range and perturbed depth approaches in comparison to the original planar trajectory. Trajectories which have many short spans, such as the penguin, show the largest reduction. The cost of the perturbed depth optimized trajectories tends to be lower than the depth range trajectories by a small amount. The optimized trajectories for the modified waypoints will end up using different amounts of depth. For snake, the depth range case uses 92 cm while the perturbed planar case uses 51 cm. Figure 3 shows the resulting trajectories. We

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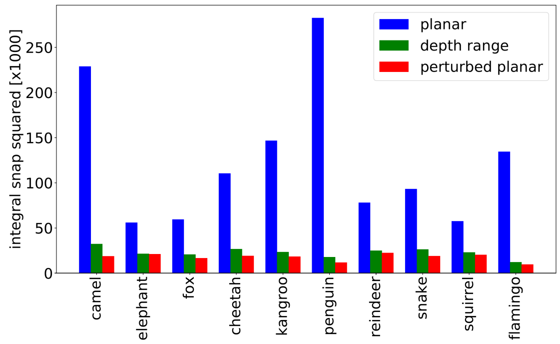

Fig. 2. Integral of snap squared of optimized trajectories is greatly reduced with both depth range and perturbed planar waypoint modification techniques.

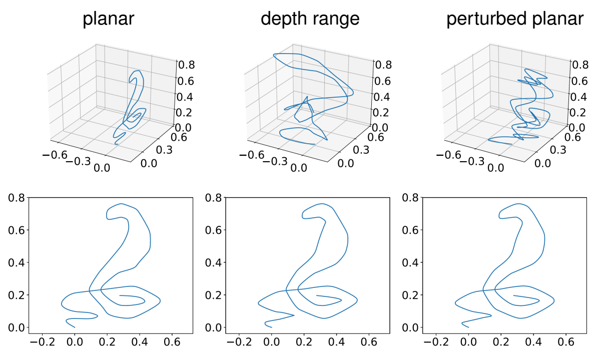

Fig. 3. The optimized trajectories for waypoints displaced in depth project to very similar images as seen by the camera.

investigate variability of the results produced by the robot under different approaches compared to the planar flight trajecotry condition, and provide a quantitative evaluation of our results with Frechet distance computations in our recently published work [7].

We use a NaturalPoint motion capture system with 12 cameras and run the CrazySwarm software with polynomial control trajectories computed offline. With slightly modified firmware, we can send light commands synchronized with the flight trajectory to set the colour of the NeoPixel and turn it on and off. We use a Canon 70D camera for all of our results, for which a collection of examples can be seen in Figure 4. We used a 28 mm prime lens, closed the aperture to f/22, and set the ISO to 100 to allow for long exposure photographs under low ambient light without over exposure. The shutter is held open (B mode) for the duration of the trajectory, which varies depending on the figure. Ultimately, the different animal figures take only a few tens of seconds to draw. We also explore a number of creative long exposure photographs that include human participation (see Figure 5).

IV. CONCLUSION

Our inspiration for this work comes from the unusual and beautiful effects created by amateur photographers, as well as the single-stroke light paintings performed by Picasso. We believe that we have succeeded in the creation of a set of interesting photographs, in part due to the quality of one-line animal illustrations that we used as initial waypoints. Ultimately, we speculate that this kind of quadrotor light painting could have interesting applications at festivals, theme parks, or corporate events.

Fig. 4. Single stroke light painted animals: elephant, camel, cheetah, kangaroo, penguin, squirrel, snake, flamingo, and reindeer. Each long exposure photo was taken over approximately 10 seconds.

Fig. 5. Human participation in long exposure photographs to create whimsical scenarios: Hadouken magic, batman wings, bursting skeleton, and lifting a barbell.

REFERENCES

[1] P. A. Tresset and F. F. Leymarie, “Sketches by Paul the robot,” in *Proceedings of Symposium on Computational Aesthetics in Graphics, Visualization, and Imaging*, 2012, pp. 17–24.

[2] B. Galea, E. Kia, N. Aird, and P. G. Kry, “Stippling with aerial robots,” in *Proceedings of the Joint Symposium on Computational Aesthetics and Sketch Based Interfaces and Modeling and Non-Photorealistic Animation and Rendering*, ser. Expresive ’16, 2016, pp. 125–134.

[3] B. Galea and P. G. Kry, “Tethered flight control of a small quadrotor robot for stippling,” in *2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Sept 2017, pp. 1713–1718.

[4] T. Lindemeier, J. Metzner, L. Pollak, and O. Deussen, “Hardware-based non-photorealistic rendering using a painting robot,” *Computer Graphics Forum (Eurographics)*, vol. 34, no. 2, 2015.

[5] D. Mellinger and V. Kumar, “Minimum snap trajectory generation and control for quadrotors,” in *2011 IEEE International Conference on Robotics and Automation*, May 2011, pp. 2520–2525.

[6] J. A. Preiss*, W. Hönig*, G. S. Sukhatme, and N. Ayanian, “Crazyswarm: A large nano-quadcopter swarm,” in *IEEE International Conference on Robotics and Automation (ICRA)*, 2017, pp. 3299–3304, software available at https://github.com/USC-ACTLab/crazyswarm.

[7] K. Ren and P. G. Kry, “Single stroke aerial robot light painting,” in *to appear in Expressive ’19*, 2019, 7 pages.