A simulation platform with a vision strategy for the UAV landing starting from a remote distance to a USV

Lingpeng Chen

October 29, 2022

1. Introduction

Unmanned aerial vehicles (UAV), with high integration of various sensors, have been applied to more and more situations. Its' range of applications includes filming [1], rescuing [2], battlefield [3], etc. The sustainability of the UAV is a critical problem due to the limited power supply of the drone. Therefore, landing and charging are inevitable for every drone. Up till now, UAV control systems can be mainly divided into three types: teleoperated [4], semi-autonomous [5], and autonomous [6]. However, there are many situations where there is no person standing nearby. Especially when the UAVs are working together with the USVs in the aquatic environment. These kinds of situations require the UAV to be capable of landing automatically. As to the landing problem, the studies can be divided into several streams. The early stream of study focuses on the autonomous landing of UAVs on the static platform. [7] [8] [9] Presently, more works focus on autonomous landing on a moving target. Some use classical or modern control [10] [11], while others use reinforcement learning [12] [13].

Besides, disturbance handling during the landing process is also an interesting field. It can also divide into two sub-streams: 1) free-flight landing based on a robust tracking algorithm [14] [15] 2) tethered-UAV landing [15]. As to the first sub-stream, MIT researchers did one of the best works of vision-guided landing [16]. They conducted a successful landing of a UAV on a mobile platform with external turbulent wind conditions. The main drawback of this method is that it requires a large landing pad for UAV since the touchdown positions do not keep the same in each landing. The tethered-guided UAV landing is another approach that can effectively deal with the disturbance. The PHD who supervises me contributes a brilliant idea [17]. The UAV releases down a suspended metal block to a magnetic catcher on the UAV for landing. Based on the proposed capture system, the landing pad for the UAV occupies a small space, which makes it easy to implement a UAV array.

Although the techniques mentioned above have provided various solutions to the landing problem, most of them focus on just the process of landing, which starts at a relatively close distance. In this study, we focus on developing a vision strategy for the UAV landing starting from a remote distance to the aquatic surface platform (an unmanned surface vehicle USV in my case). As is shown in Fig. 1, the whole landing process consists of approaching, camera transition, and landing. The detailed plan for the implementation will be discussed in the problem statement.

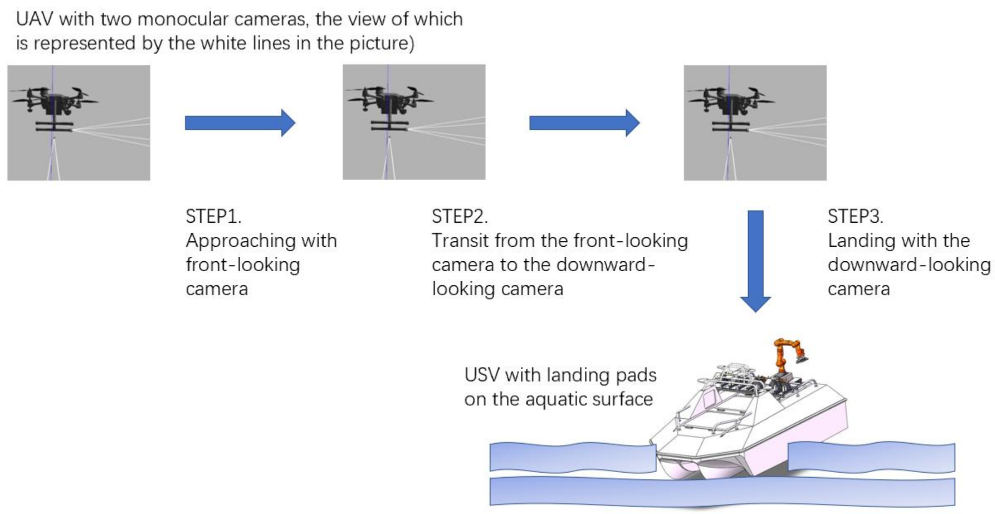

Fig. 1. The step flow of the whole landing process

2. Problem Statement

In this project, we will realize the whole process of the UAV landing, starting from a relatively distant place to the USV. It will be realized in the virtual environment of the simulator due to the limited funding and time. The UAV is equipped with two monocular cameras, one looking forward and the other one looking downward, and the flight control firmware we chose is PX4. The general picture is as follows. In the beginning, we assume that the UAV has already been guided relatively close to the USV. Say, 20 meters away. In the first stage, we will apply the HOG, a lightweight algorithm, to do the object detection with the front-looking camera due to the limited performance of the onboard computer of the UAV. The general process of the data flow of HOG is shown in Fig. 2.

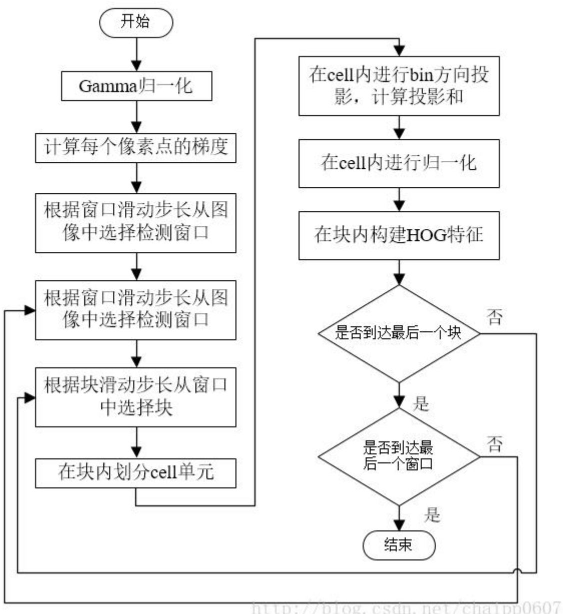

Fig. 2. The general flow chart of the HOG algorithm

We will also apply object tracking technology to solve the problem of losing frames or wrong detection. Most state-of-art trackers, except the Deep Learning approach, can be divided into two groups according to their approach, i.e., the Discriminative approach and the Generative approach. Generative approach trackers build a model of the given bounding box of the current frame and search for the area with the highest similarity in the next frame. Trackers in this approach can be further divided according to their modeling strategies, including Correlation Filtering (CF), Kalman Filtering (KF), Mean Shift (MS), etc. Correlation Filtering trackers find the best correlation filter based on the patch in the current frame and utilize this filter to search for the best matching patch in the next frame. Compared to the typical speed of 25 fps of discriminative approach trackers, the CF algorithm has a general 200 fps. Due to the high real-time performance of our task, I am going to choose the KCF algorithm, a robust CF algorithm to track the target. The program flow of the KCF is shown in Fig. 3. Then, the UAV will head toward the target at a certain altitude.

Inputs

- x: training image patch, $m \times n \times c$
- y: regression target, Gaussian-shaped, $m \times n$
- z: test image patch, $m \times n \times c$

Output

- `responses`: detection score for each location, $m \times n$

```
function alphaf = train(x, y, sigma, lambda)
  k = kernel_correlation(x, x, sigma);
  alphaf = fft2(y) ./ (fft2(k) + lambda);
end

function responses = detect(alphaf, x, z, sigma)
  k = kernel_correlation(z, x, sigma);
  responses = real(ifft2(alphaf .* fft2(k)));
end

function k = kernel_correlation(x1, x2, sigma)
  c = ifft2(sum(conj(fft2(x1)) .* fft2(x2), 3));
  d = x1(:)'*x1(:) + x2(:)'*x2(:) - 2 * c;
  k = exp(-1 / sigma^2 * abs(d) / numel(d));
end
```

Fig. 3. The program flow of the KCF algorithm

Next comes the second stage. As the UAV approaches the USV, the landing target starts to go out of the front view camera and gradually enters the view of the downward-looking camera. In order to transit the landing target smoothly from the front-looking camera to the downward-looking camera, we will apply the image registration technology.

In the third step, I will realize the final landing. In the previous study, I have already realized landing on the QR code (shown in Fig. 4). However, this method is not desirable since the QR code detection is not stable enough, and it may be hard to apply such a big QR code on the USV in the real cases. Therefore, in this study, I will apply templet matching, a robust algorithm that I learned in the ECE4513 (Image processing and computer vision by Prof. Li.), to locate the landing plate. Since we focus on the vision algorithm, we will not apply any complex control algorithm. Therefore, if the distance between the UAV and the landing pad is smaller than a certain threshold, we call it a successful landing.

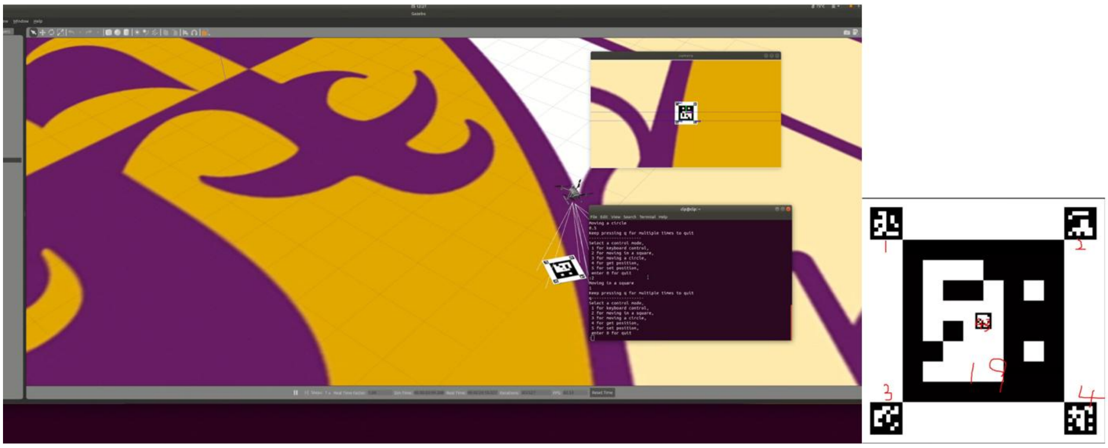

Fig. 4. My previous study of landing with the QR code in the gazebo simulator. The sub image shows the QR-code landing plate I used, which enables me to calculate the transition and rotation matrix from the UAV to the landing plate

3. Research Plan & Expected outcome

The detailed plans are as follows.

- **2022/10/30-2022/11/30** I will first establish the virtual environment in the gazebo simulator, including the aquatic surface and specially designed USV with several landing pads. Also, I will learn the algorithm of the HOG and template matching in the meantime. My virtual world's conceptual image may look like what is shown in Fig. 5.

Fig. 5. The conceptual graph of the virtual aquatic environment

- **2022/12/1-2022/12/30** I will realize step 1 and step 3 based on the algorithm I learned. Image preprocessing may be conducted before feeding into the algorithm based on the specific situation during the implementation.
- **2022/1/1-2022/1/31** I will realize the image registration (i.e., step 2) so that step 1 and step 3 can be connected together smoothly. The optimization of the whole process will also be done in this period.

4. References

[1] M. Maier and K. Kondak, "Landing of vtol uavs using a stationary robot manipulator: A new approach for coordinated control," in 2015 54th IEEE Conference on Decision and Control (CDC). IEEE, 2015, pp. 1497–1502

[2] Joshi, G.; Pal, B.; Zafar, I.; Bharadwaj, S.; Biswas, S. Developing Intelligent Fire Alarm System and Need of UAV. In Proceedings of the International Conference on Unmanned

Aerial System in Geomatics, Roorkee, India, 6–7 April 2019; pp. 403–414.
[3] You, H.E. Mission-driven autonomous perception and fusion based on UAV swarm. Chin. J. Aeronaut. 2020, 33, 2831–2834.
[4] Aleotti, J.; Micconi, G.; Caselli, S.; Benassi, G.; Zambelli, N.; Bettelli, M.; Zappettini, A. Detection of nuclear sources by UAV teleoperation using a visuo-haptic augmented reality interface. Sensors 2017, 17, 2234. [CrossRef] [PubMed]
[5] Khadka, A.; Fick, B.; Afshar, A.; Tavakoli, M.; Baqersad, J. Non-contact vibration monitoring of rotating wind turbines using a semi-autonomous UAV. Mech. Syst. Signal. Process. 2019, 138, 106446. [CrossRef]
[6] Uryasheva, A.; Kulbeda, M.; Rodichenko, N.; Tsetserukou, D. DroneGraffifiti: Autonomous multi-UAV spray painting. In Proceedings of the ACM SIGGRAPH 2019 Studio, Los Angeles, CA, USA, 28 July–1 August 2019; pp. 1–2
[7] Forster, C.; Faessler, M.; Fontana, F.; Werlberger, M.; Scaramuzza, D. Continuous onboard monocular-vision-based elevation mapping applied to autonomous landing of micro aerial vehicles. In Proceedings of the 2015 IEEE International Conference on Robotics and Automation (ICRA), Seattle, WA, USA, 26–30 May 2015; pp. 111–118.
[8] Sukkarieh, S.; Nebot, E.; Durrant-Whyte, H. A high integrity IMU/GPS navigation loop for autonomous land vehicle applications. IEEE Trans. Robot. Autom. 1999, 15, 572–578. [CrossRef]
[9] Gui, Y.; Guo, P.; Zhang, H.; Lei, Z.; Zhou, X.; Du, J.; Yu, Q. Airborne vision-based navigation method for UAV accuracy landing using infrared lamps. J. Intell. Robot. Syst. 2013, 72, 197–218. [CrossRef]
[10] Falanga, D.; Zanchettin, A.; Simovic, A.; Delmerico, J.; Scaramuzza, D. Vision-based autonomous quadrotor landing on a moving platform. In Proceedings of the 15th IEEE International Symposium on Safety, Security and Rescue Robotics, Shanghai, China, 11–13 October 2017; pp. 200–207.
[11] Lee, D.; Ryan, T.; Kim, H.J. Autonomous landing of a VTOL UAV on a moving platform using image-based visual servoing. In Proceedings of the 2012 IEEE International Conference on Robotics and Automation, Saint Paul, MN, USA, 14–18 May 2012; pp. 971–976.
[12] Xu, Y.; Liu, Z.; Wang, X. Monocular Vision based Autonomous Landing of Quadrotor through Deep Reinforcement Learning. In Proceedings of the 2018 37th Chinese Control Conference (CCC), Wuhan, China, 25–27 July 2018; pp. 10014–10019.
[13] Lee, S.; Shim, T.; Kim, S.; Park, J.; Hong, K.; Bang, H. Vision-based autonomous landing of a multi-copter unmanned aerial vehicle using reinforcement learning. In Proceedings of the 2018 International Conference on Unmanned Aircraft Systems (ICUAS), Dallas, TX, USA, 12–15 June 2018; pp. 108–114.
[14] M. Tognon, A. Testa, E. Rossi, and A. Franchi, "Takeoff and landing on slopes via inclined hovering with a tethered aerial robot," in 2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2016, pp. 1702–1707.
[15] D. Hashemi and H. Heidari, "Trajectory planning of quadrotor uav with maximum payload and minimum oscillation of suspended load using optimal control," Journal of Intelligent & Robotic Systems, pp. 1–13, 2020.

[16] A. Paris, B. T. Lopez, and J. P. How, "Dynamic landing of an autonomous quadrotor on a moving platform in turbulent wind conditions," in 2020 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2020, pp. 9577–9583

[17] C. Liu, Z. Jiang, R. Xu, X. Ji, L. Zhang and H. Qian, "Design and Optimization of a Magnetic Catcher for UAV Landing on Disturbed Aquatic Surface Platforms," *2022 International Conference on Robotics and Automation (ICRA)*, 2022, pp. 1162-1168, doi: 10.1109/ICRA46639.2022.9812270.

[18] A. Mohammadi, Y. Feng, C. Zhang, S. Rawashdeh, and S. Baek, "Vision-based autonomous landing using an mpc-controlled micro uav on a moving platform," in 2020 International Conference on Unmanned Aircraft Systems (ICUAS). IEEE, 2020, pp. 771–780.