Laser-Assisted Guidance Landing Technology for Drones

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***Abstract*—Inexact drone landings occur because of the global positioning system (GPS) resulting in measurement errors that are frequently several meters. The existing methods that tackle the problem usually use cameras. Their cost is relatively higher than the 0.5mW lasers we used in our work and the performance of vision-based methods in recognition range are only good at close ranges. A new method for increasing accuracy during descent is introduced and described in this paper using laser-guided systems mounted on a landing base for drones that we developed ourselves. Embedded system design was merged with 3D printing technology to implement our solution. The landing error margin of the developed system falls within 30 - 40 centimeters and the maximum tolerance horizontal distance between the drone and the landing base could reach up to 25 meters. Such results indicate that there are important areas to be considered if lasers were used as drone guides. Besides, we also cover future uses of our system at the end of the paper, which can help to understand its significance better.**

Keywords—drones, laser positioning, embedded system, mechanical design, 3D printing

I. Introduction

The purpose of this study is to create an algorithm that will enable drones to land with precision despite the inherent positioning errors that are customary in GPS technology. We suggest using laser guidance to improve the accuracy of UAVs during landing. This technique can provide the most cost-effective solution for this problem due to its availability, precision, and low costs. Our design utilizes unique features of lasers such as coherence which guarantees proper direction and sharpness. These qualities enable us to pinpoint the drones' exact position around the landing area and direct them precisely over a precise spot, thus compensating for inaccuracies occasioned by GPS-related positioning errors.

II. Related Works

Previous research has been conducted concerning precise landing for drones. Nguyen et al. [1] utilize a remote marker-based tracking algorithm and the design of the marker to land accurately and safely. Yang et al. [2] illustrate a way to use the system including the infrared camera array, calibration module, and tracking module to realize UAVs' accurate landing guidance. Burlion et al. [3] aim to propose a vision-based automatic landing feature for UAVs by integrating a constraint into an existing control law. The constraint ensures a specific ground point remains within the camera field of view (FoV) during landing. Nguyen et al. [4] propose a solution that uses a single visible-light-camera sensor and a convolutional neural network (lightDenseYOLO) to tackle the tasks. They develop an algorithm based on markers as well, allowing precise tracking during UAV landing.

Specification	Details
Output wavelength	650 ± 5nm
Laser shape	Dot (Oval)
Spot size	$<$ 18mm at 10m
Size	ϕ 3.6 $\times$ 9mm

Table 1. The specification of the laser used

However, these previous studies all exploit cameras as the medium for UAVs to land precisely. This could skyrocket the cost of the manufacturing of drones. At the same time, the recognition range of vision-based methods is also distance-limited. Inspired by Kim et al. [5], Stary et al. [6], and Dougherty et al. [7], if we could find a way to land UAVs accurately in the absence of cameras, the functionality of drones would become more powerful. Without cameras, drones will no longer need bright environments to land. Moreover, the operating cost of drones could be reduced and the distance for drones to recognize the landing point could be increased.

III. Development

In our research, Raspberry Pi 4B will be mounted on drone and will be used for its computer. The task will be to control the flying status of the drone, locate the drone through GPS, and communicate with the landing base. On the other hand, we utilize Arduino Nano as the computer of the landing

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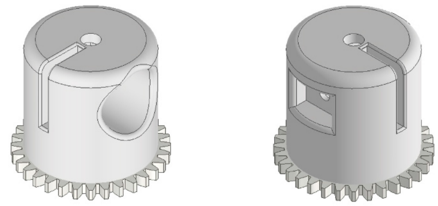


(a) Front view (b) Back view

Fig. 1. The laser-projecting module without a rotating mirror inside.

base. It is responsible for the control of the motion of laser-projecting modules and the receipt of the signal sent by the drone.

A. Hardware Development

1) Laser-Projecting Module: The device is used for projecting a laser beam wall. By shining a 0.5mW-laser beam, whose specification can be found in Table 1, through the hole on top of the module and reflected by a rotating mirror driven by a DC motor inside the module, the laser beam wall can easily be formed. 3D printing machine printed the module itself, whose structure was designed by us. As shown in Fig. 1, the circular hole on top of the laser-projecting module is for a laser beam to shine inside the chamber. The larger circular hole which can only be seen in Fig. 1a is for the installation of the mirror. The rectangular concave area that occurred in Fig. 1b is reserved for the installation of the DC motor. The long opening is for the laser to leak out to form the laser wall. Fig. 2 illustrates how the laser shines a laser into the chamber from the top of the module. Moreover, since the rotation of the laser-projecting module is driven by a stepper motor, we designed a gear at the bottom of it. There will be a smaller gear mounted on the stepper motor to transmit the rotational movement.

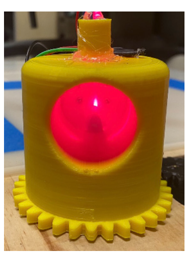


Fig. 2. The laser-projecting module with laser projected to its chamber.

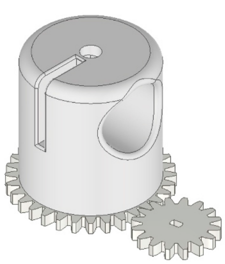


Fig. 3. The illustration of gear engagement. The small gear will be mounted on the stepper motor to transform the rotating action to the laser-projecting module. Note that the gear ratio is 32:16.

2) 5V Laser Beam Receiver Module: 5V Laser Beam Receiver Module is planned to be applied on the drone to detect whether the drone is shined by the laser wall generated by the laser-projecting module. The module will output a high level when receiving a laser signal while output a low level when not receiving a laser signal. That makes it easier for us to do laser signal-receiving tasks.

3) 28BYJ-48 – 5V Stepper Motor: To measure the extent to which the laser projecting base rotates when searching for a drone in the sky, a stepper motor will be the best option to satisfy the needs. In our research, small gears will be mounted on 28BYJ-48 – 5V stepper motors. This way, the rotating action of the stepper motors can be transformed into the laser-projecting modules. Note that the gear ratio is 32:16, which means that the stepper motor will need to complete two revolutions to drive the laser-projecting module to turn a full circle. The stride angle of the stepper motor is 0.088°, which means that the stepper motor will rotate 0.088° whenever it turns a single step. In other words, the stepper motor must turn 4096 steps to complete a revolution. Fig. 3 illustrates how the gears are engaged.

4) GT-38 Wireless Serial Communication Module: When the drone detects a laser beam, it should inform the landing base from the sky. GT-38 wireless serial communication module is used for communication between the landing base and the drone. The module makes it possible for them to transmit data at the maximum distance of 1200 meters, which is satisfying enough for the error of 10 to 20-meter error generated by GPS. It uses the UART interface to perform serial communication. The baud rate is set at 9600bps, 433MHz.

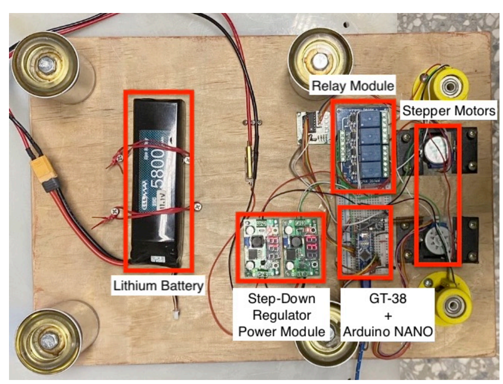


Fig. 4. The layout of the bottom of the landing base. The four metal-like columns are for support. The two yellow columns on the right are the backside of the laser-projecting modules.

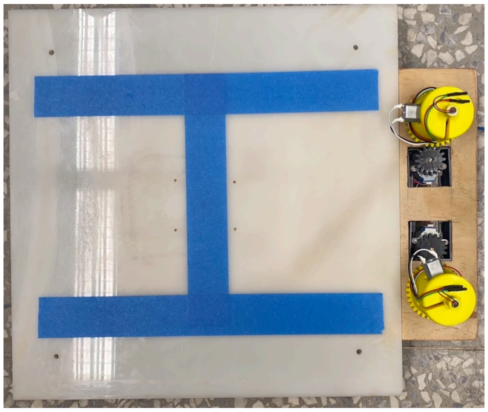


Fig. 5. The layout of the top of the landing base. The two yellow columns on the right are the laser-projecting modules. Under two little black gears are stepper motors that rotate the laser-projecting modules.

5) Landing Base Construction: The landing base is composed of an Arduino NANO, two laser-projecting modules, two stepper motors, a GT-38, and a lithium battery for power supply. Besides, two step-down regulator power modules and a 4-channel relay module are also needed for wiring. Step-Down Regulator Power Modules make it possible for us to control the power of two stepper motors and two lasers at the same time with the same power source. The 4-Channel Relay Module allows us to start the whole landing base through Arduino NANO itself instead of turning on every single component. The appearance of the bottom of the landing base can be found in Fig. 4. The top side will be reserved for landing and laser-projecting modules, as shown in Fig. 5.

B. Positioning & Landing

The idea of our research is that we use laser beams to build two rotating laser beam walls which are used for scanning the position of drones in the vicinity of the landing base. Then with the data logged by stepper motors which are used for rotating the laser-projecting module, we can derive the deviation between the position of the drones and that of the landing base. Finally, the deviation will be sent to the drone through GT-38 for it to land precisely.

As shown in Fig. 6, the drone is designated to land on the landing point, which is represented by the red star. The two red circular sectors are the laser beam walls for drone location scanning. They are generated by two laser-projecting modules, which are represented by blue cylinders and can rotate to shine the laser beam wall in all directions in order to locate the drone in the sky accurately.

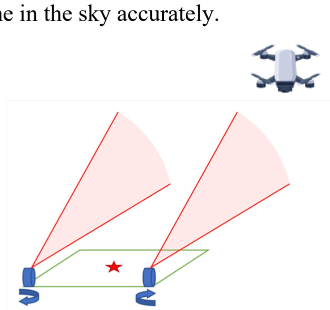


Fig. 6. The imagination of the landing situation.

1) Drone Positioning: Consider the situation where the drone is in the first quadrant of the landing base coordinate system. We can derive the expressions of deviations between the position of the drones and that of the landing base, x_{bias} and y_{bias}, by the process shown in Fig. 7, Equation (1), Equation (2), Equation (3) and Equation (4). Where point O is the designated landing point, l is the distance between two laser-projecting modules, θ_a and θ_b are the angles rotated by two stepper motors, and x_{bias} and y_{bias} are the two components of the deviation between the position of the drones and that of the landing base.

Besides, in daytime environment, the r value can reach up to 15 meters, while in nighttime condition, it can further reach 25 meters.

2) Landing Procedure: The landing procedure for the landing base is shown in Fig. 8 whereas the landing procedure for the drone is illustrated in Fig. 9. It is worth mentioning that when the drone detects the laser beam and sends back the signal to the landing base, the landing base will not conclude the measurement immediately. Instead, the laser-projecting module will alter its rotating direction and rotate slower until it receives the signal from the drone again. This subprocedure will iterate three times with both laser-projecting modules respectively to get both θ_1 and θ_2, in case the measurement is inaccurate due to the time needed for communication. Fig. 10 illustrates details of the data flow between the landing base and the drone. Each step that is shown in Fig. 10 is elaborated below:

- ① : The drone detects the laser beam.
- ②, ③, ④ : The drone sends the signal to the landing base. After the system repeats ① - ④ three times, then proceeds to the next step.
- ⑤, ⑥ : For the first time: Stop stepper motor A's detection and switch to stepper motor B then start

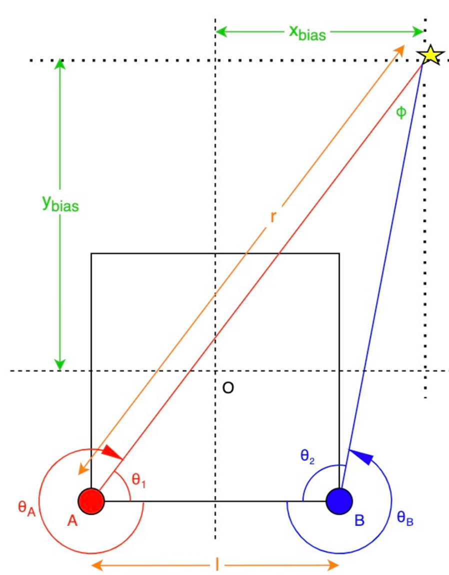


Fig. 7. The landing base is represented by the square. All the dimensions required to derive the expressions for x_{bias} and y_{bias} are also labeled. The projected location of the drone is shown with the yellow star at the top right corner, which is in the first quadrant. The red and blue arrows symbolize the turning direction of laser-projecting modules respectively.

from ① again. For the second time: Stop stepper motor B's detection.

- ⑦, ⑧, ⑨, ⑩ : Send the data from the landing base to the drone.

$$\phi = \pi - \theta_1 - \theta_2 \tag{1}$$

Where:

$$\theta_1 = 2\pi - \theta_a$$

$$\theta_2 = 2\pi - \theta_b$$

$$r = \frac{l}{\sin\phi} \cdot \sin\theta_2 \tag{2}$$

$$x_{bias} = r\cos\theta_1 - \frac{l}{2} \tag{3}$$

$$= \left(\frac{l}{\sin\phi} \cdot \sin\theta_2\right)\cos\theta_1 - \frac{l}{2}$$

$$= \left(\frac{l}{\sin(\pi - \theta_1 - \theta_2)} \cdot \sin\theta_2\right)\cos\theta_1 - \frac{l}{2}$$

$$= l \cdot \left(\frac{\sin\theta_2\cos\theta_1}{\sin(\theta_1 + \theta_2)} - \frac{1}{2}\right)$$

$$y_{bias} = r\sin\theta_1 - \frac{l}{2} \tag{4}$$

$$= \left(\frac{l}{\sin\phi} \cdot \sin\theta_2\right)\sin\theta_1 - \frac{l}{2}$$

$$= \left(\frac{l}{\sin(\pi - \theta_1 - \theta_2)} \cdot \sin\theta_2\right)\sin\theta_1 - \frac{l}{2}$$

$$= l \cdot \left(\frac{\sin\theta_2\sin\theta_1}{\sin(\theta_1 + \theta_2)} - \frac{1}{2}\right)$$

IV. Experiments

A. Indoor Drone Positioning

The demonstration video for drone positioning can be found here [8]. Since we did the drone positioning experiment indoors, rather than using an actual UAV, we simply placed the Raspberry Pi 4B in front of the landing base to simulate the drone, as shown in Fig. 11a.

When the landing base starts searching for the hovering drone in its vicinity, stepper motor A begins to turn clockwise. The landing base will record the measurement of θ_1 after receiving the signal sent by the drone three times, as shown in Fig. 11b. After that, stepper motor B does a similar process as stepper motor A does. The only difference is that stepper motor B begins to turn counterclockwise. Again, the landing base will register the measurement of θ_2 after receiving the signal sent by the drone three times, as shown in Fig. 11c.

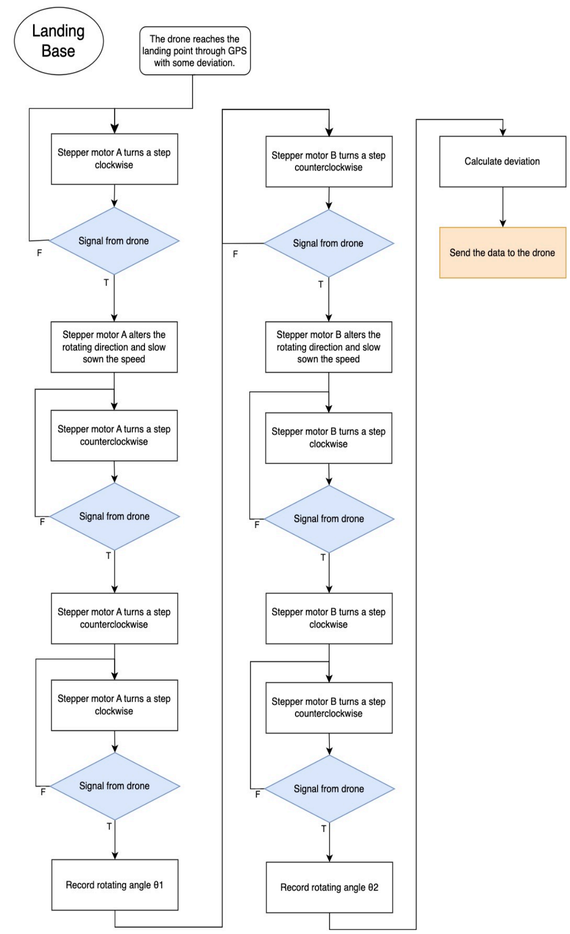


Fig. 8. The landing procedure for the landing base. After the drone is flying nearby, both the laser-projecting modules will start working in sequence to locate the drone in the sky. The flying command will be calculated and sent afterward.

B. Outdoor Experiment Setup

Comprehensive outdoor experiments with the drone were carried out after the landing base setup was finalized. The experimental scenario is shown in Fig. 12. The landing base was placed at a specific location in an open field. During the experiment, the drone took off from a place near the landing point, simulating a real-world situation where it must land on a pre-determined spot accurately.

C. Result

As shown in the demonstration video [9], we first let the drone takeoff and hover in the vicinity of the landing base. Afterward, execute the landing procedure described above. Finally, the drone could land at the specified location with little deviation of about 30 - 40 centimeters, and the maximum tolerance horizontal distance between the drone and the landing base could reach up to 25 meters. Note that we land the drone next to the landing base instead of on the landing base in case dangerous situations occur due to the small space of the platform. All the principles are the same. The only difference is we change the reference landing point when derive the deviations x_{bias} and y_{bias}.

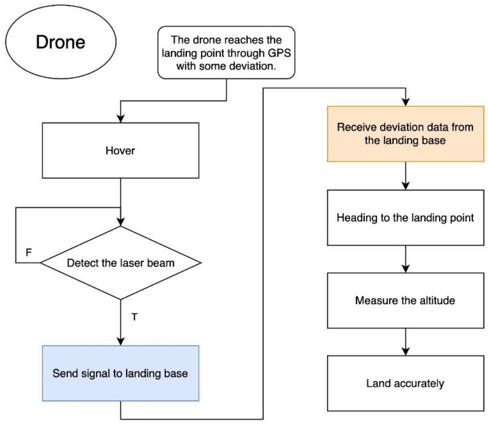


Fig. 9. The landing procedure for the drone. Once the drone starts hovering in the vicinity of the landing base, it starts detecting whether there is a laser beam shining on itself. After it confirms that it is illuminated by the laser, it will execute the flying command sent by the landing base. Finally, the drone could land precisely.

V. CONCLUSIONS

This research presents a simple methodology for drones to land at the designated location accurately. It lays the foundation for affordable and large-range landing systems. The experiment results illustrate that the methodology developed in this research could perform satisfactorily in the scenario shown above. The drones could land at the designated point with an error of about 30 - 40 centimeters using our system. Meanwhile, at nighttime condition, the maximum tolerance horizontal distance between the drone and the landing base could reach up to 25 meters.

We conducted simple comparisons between our work and other related works, as shown in Table 2. It's important to note that the actual costs and error standards are not explicitly mentioned in the papers, therefore our comparisons are approximate. The table clearly illustrates that our approach outperforms in both the "Cost" and "Error" categories compared to the other methods.

The main drawback and challenge is that the further the drone is from the landing base, the greater the error of the measurement. Based on inference, we believe that this is due to the limitation of the reaction time of the system. It inevitably takes some time for the communication modules to process the signal sent back from the UAVs. The extra time causes the measured distance to be slightly greater than the actual value. The problem could be tackled by slowing down the rotating speed of the stepper motors or increasing the number of times the laser-projecting modules alter their rotating direction. To summarize, the landing system we designed could cater to most of the situations that could occur during the landing process of the UAVs. Nevertheless, if the deviation of the GPS is way too large and exceeds the limitation of our system, we should find another way to address the issue. There is still much room to improve this research in the near future.

Work	Medium for precise landing	Cost	Error
Ours	Lasers + simple UAV control	**Low cost (0.5mW-Lasers, 3D-printing components, basic electronic components)**	**30 - 40 centimeters**
Nguyen et al. [1]	Camera + remote marker-based tracking algorithm	**Low cost (marker production and camera equipment)**	Depends on algorithm stability and camera performance
Yang et al. [2]	Infrared camera array + calibration module + tracking module	High cost (infrared cameras, laser lamps, calibration system)	Approximately 1 meter
Burlion et al. [3]	Camera + existing control law	Moderate cost (high-quality cameras and computing equipment)	Depends on camera resolution and homography matrix accuracy
Nguyen et al. [4]	Single visible-light-camera sensor + lightDenseYOLO	Moderate cost (embedded computing equipment and training resources)	**1.3 pixels, high accuracy at long distances**

Table 2. The comparisons between our work and the other related works.

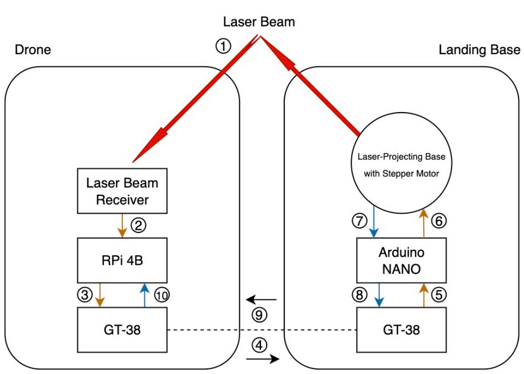
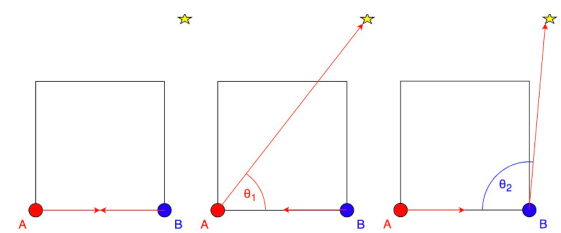


Fig. 10. The interaction between landing base and drone.

VI. FUTURE USES

A. Replenishing Supplies

If there is a hurricane, earthquake, or even war happening in the area that needs some supplies and is unreachable, our research will be suitable for the situation. The only thing we need to do to construct a landing base is to place two laser-



(a) Step 1 (b) Step 2 (c) Step 3

Fig. 11. The illustration of landing base drone-locating process. The drone is placed in front of the landing base in the demonstration video. It is used to simulate the drone hovering in the vicinity of the landing base. Stepper motor A is placed on the left side and stepper motor B is placed on the right side.

Fig. 12. The experiment conducted with drone.

projecting modules at some desired plane surface. Then report the distance between the two bases and the GPS coordinates of that location. Afterward, drones with supplies could successfully reach the destination automatically.

B. Parcel Delivery Drones

Express delivery companies can collect membership fees from customers who frequently use the services through a membership system, and then provide the installation of accurate drone landing systems at customers' homes or on the roof of companies' buildings to achieve express delivery services. When using the service, customers are able to enjoy cheaper shipping costs, and carrier companies could also save the cost of hiring delivery men. In addition, if there is no one to receive the express delivery, the technology could also ensure the delivery of the goods.

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