International Journal of Control, Automation and Systems 16(6) (2018) 3013-3025
http://dx.doi.org/10.1007/s12555-018-0017-x

ISSN:1598-6446 eISSN:2005-4092
http://www.springer.com/12555

Autonomous Vision-based Target Detection and Safe Landing for UAV

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Abstract: Target detection is crucial for many applications of Unmanned Aerial Vehicles (UAVs) such as search and rescue, object transportation, object detection, inspection, and mapping. One of the considerable applications of target detection is the safe landing of UAV to the drone station for battery charging and its maintenance. For this, vision-based target detection methods are utilized. Generally, high-cost cameras and expensive CPU's were used for target detection. With the recent development of Raspberry Pi (RPi), it is possible to use the embedded system with cheap price for such applications. In the current research, RPi based drone target detection and safe landing system are proposed with the integration of PID controller for target detection, and Fuzzy Logic controller for safe landing. The proposed system is equipped with a USB camera which is connected to RPi for detecting the target and a laser rangefinder (LIDAR) for measuring the distance for safe landing. To verify the performance of the developed system, a practical test bench based on a quadcopter and a target drone station is developed. Several experiments were conducted under different scenarios. The result shows that the proposed system works well for the target finding and safe landing of the quadcopter.

Keywords: Fuzzy logic, ground effect, quadcopter, safe landing, target detection.

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1. INTRODUCTION

Quardcopter, also known as a quadrotor, is one type of UAV, which is lifted and propelled by four rotors [1, 2]. The quadcopter has high maneuverability, as it can hover, take off, cruise and land in narrow areas. Quadcopters have simpler control mechanism compared to the other UAVs [3].

Recently, there have been increasing interests in the UAVs applications such as surveillance, search and rescue, and object detection [4–8]. Especially, target detection is an important pre-function in the UAVs applications, as it is required for a safe landing to drone station for battery charging or some other tasks. However, detecting a target, and landing is not an easy task due to the lack of sensitivity of sensors used for this application. For these applications, image processing techniques are generally used.

The autonomous quadcopter system can be divided into four processes:

1) Taking off.
2) Performing the task.
3) Detection of the ground target.
4) Safe landing.

Detecting the ground target and safe landing is the most challenging part, as any mistake in any of them can lead the quadcopter to tip over, which will cause the destruction of the quadcopter or even harm any human in its range due to the big size of the propellers and high rpm used in it.

There have been a lot of research regarding target detection and safe landing. In [9], a target detection algorithm based on GPS and camera is proposed. Other research presents an image processing based target detection algorithm using high specification CPU's [10]. In [11, 12], several ways to control the drone using cloud computing-based vision is proposed. Also, there are numbers of works that focus on the communication between the drone and the ground target [13]. Some researchers were trying to detect and track shaped targets cite14,15, while others tried to detect people and vehicle [16]. In [17, 18], an image processing algorithm, that works using color detection by a camera is proposed.

One of the most challenging parts of target detection is the timing of the image processing. So, the best way is to use a graphical processing unit (GPU) which is optimized for imaging algorithms.

Most of the prior research shows good performance. However, they are either using a normal navigator GPS to detect the position of the target, which is not accurate, as the used GPS accuracy is limited to 7-8 m and GPS

Manuscript received January 10, 2018; revised April 28, 2018; accepted June 5, 2018. Recommended by Associate Editor Son-cheol Yu under the direction of Editor Jessie (Ju H.) Park.

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cannot work indoors, or they are using a higher specification CPUs, which is very expensive and consumes more power.

One problem with quadcopter safe landing is the ground effect. Ground effect is a nonlinear effect generated near the ground while landing. It causes the increase in thrust of the rotors that will cause floating of the quadcopter above the ground. This will make landing difficult and lead to high power consumption.

The current research focuses on the problems of the previous research works. It focuses on replacing the high specification and expensive CPUs with a much cheaper one. It also focuses on overcoming the ground effect. In order to overcome the cost problem, a vision-based target detection algorithm based on PID controller using RPi is proposed. A novel, Fuzzy logic based safe landing algorithm is developed to overcome the ground effect which exists near to the ground while quadcopter is landing. The proposed system is equipped with a USB camera connected to RPI for detecting the target and a laser rangefinder (LIDAR) for measuring the distance for safe landing.

To verify the system performance, a practical test bench based on a quadcopter and a target drone station was developed. Several experiments were conducted under different scenarios and results were obtained. The practical configuration of the proposed system is discussed in detail in Section 2. Section 3 presents the ground effect phenomenon. The proposed target detection and safe landing algorithm are explained in Section 4. Section 5 includes the simulation results of the proposed safe landing algorithm. Section 6 demonstrates the experimental results of the proposed system. Finally, the conclusion is drawn in Section 7.

2. CONFIGURATION OF THE PROPOSED VISION-BASED TARGET DETECTION AND SAFE LANDING SYSTEM FOR QUADCOPTER

The proposed vision-based target detection and safe landing system consist of the following components: flight controller, RPi, USB camera, ESC module, RC receiver/transmitter, BLDC motor, a LIDAR sensor, and camera gimbal with quadcopter mainframe. A block diagram of the overall system is shown in Fig. 1.

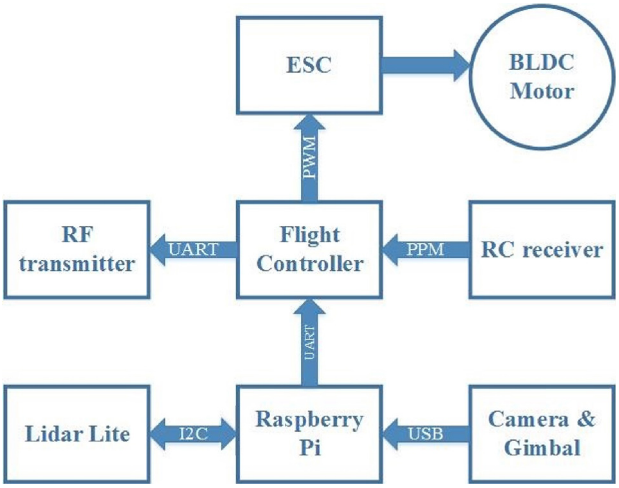


Fig. 1. Block diagram of the overall system.

2.1. Flight controller

The flight controller is the brain of the quadcopter. It reads all data coming from the sensors and calculates the best commands and finally sends it to ESC module. ESC module can receive the rpm data from the flight controller and RC receiver to control the speed of each BLDC motors. The flight controller used in this work is Pixhawk flight controller. The Pixhawk flight controller has an ARM Cortex M4 CPU with a clock frequency of 168 MHz. It is equipped with a 10 DOF-IMU, to measure roll, pitch, yaw, and altitude. It also has eight PWM outputs which can support up to eight BLDC motors. It also has several connectivity options for additional peripherals like UART, I2C, CAN, SPI, and ADC, etc.

The reason for utilizing the Pixhawk flight controller is because it can be interfaced easily with the ArduCopter, which is an open source code that is written in C++ and is free for modification.

2.2. Raspberry Pi (RPI)

The RPI is a low cost, small size computer with a wireless LAN and Bluetooth connectivity. It can be plugged into a computer monitor using an HDMI cable, and it uses a standard mouse and keyboard. It is capable of doing everything that can be done with a desktop computer. It can also help to learn various programming languages such as Python and C++.

In the current work, RPi 3 is used, because it has higher CPU performance than the previous versions. RPi 3 is good for vision-based image processing which requires fast execution time. Generally, the image processing algorithm for target detection based on PID controller and the fuzzy logic algorithm for a safe landing is implemented inside of RPi. The USB camera is connected to RPi via USB port which continuously sends the captured images to RPi. Inside of RPi, two types of control algorithms, image processing for target detection and Fuzzy logic for safe landing process the data received from the USB camera and LIDAR. This data is sent to the Pixhawk flight controller which generates the flight control commands.

2.3. Camera and gimbal

The camera used in this work is a 720p USB camera. It's a cheap camera which can be directly connected to

Raspberry Pi. Furthermore, a 2D-gimbal is used for allowing the camera to always face the ground while the quadcopter is hovering around.

2.4. LIDAR-Lite rangefinder

LIDAR-Lite is a low power and lightweight 40 m rangefinder. This rangefinder is used due to its characteristics of low noise, high efficiency, and high range. It is used to calculate the altitude of the quadcopter that is used in the RPi for a safe landing.

3. GROUND EFFECT

In all types of UAVs, ground effect is the increased force near the ground in comparison to high altitude.

UAV's lifting force can be divided into two parts:

1) IGE (In Ground Effect),
2) OGE (Out of Ground Effect).

IGE is a condition where the downwash of air from the main rotor can react with a hard surface (the ground) and give a useful reaction to the UAV in the form of more lift force available with less power required. OGE is the opposite of IGE, where there are no hard surfaces for the downwash to react against. For example, a UAV hovering 45m above the ground will be in an OGE condition and will require more power to maintain a constant altitude than if it was hovering at 4 m. Hence, a UAV will always have a lower OGE ceiling than IGE due to the amount of available power [19].

IGE and OGE effect in quadcopter UAV is shown in Figs. 2 and 3. IGE effect is the most important issue to be considered when designing an auto landing controller mechanism. Therefore, the designed controller must be intelligent enough to overcome its nonlinear effect during the landing process.

4. AUTONOMOUS VISION-BASED TARGET DETECTION AND SAFE LANDING ALGORITHM

4.1. Vision-based target detection algorithm

A color based image processing algorithm is proposed in the current study and implemented by using Open CV library. USB camera is installed on the quadcopter and it keeps on taking snapshots continuously, which is processed by the color based target detection algorithm as shown in Fig. 4. The color-based target detection and safe landing algorithm can be divided into three main parts:

1) Target detection part(based on image processing).
2) Safe landing part (based on Fuzzy logic).
3) Stabilization control part.

In target detection part, the captured image is converted from RGB (Red, Green, and Blue) format to HSV (Hue, Saturation, and Value) format. Afterward, a thresholding is applied to the output image. The thresholding works by selecting a pixel value. If the pixel value is greater than the threshold value which is fixed in the code, the output will be white color, otherwise, it will be black color. Then, morphology transformers are used on the output image to get rid of any noise in it. Finally, in order to calculate the centroid of the image, a 1st order spatial moments around the x-axis, y-axis and the 0th order central moments of the binary image is calculated. 0th order central moments of the binary image are equal to the white area of the image in pixels. The center of the detected white area can be stated in pixels as in (1) and (2).

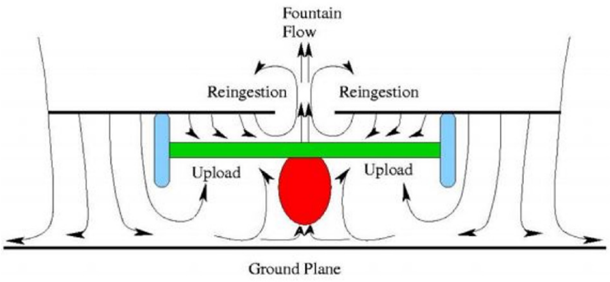


Fig. 2. Quadcopter thrust effect under IGE.

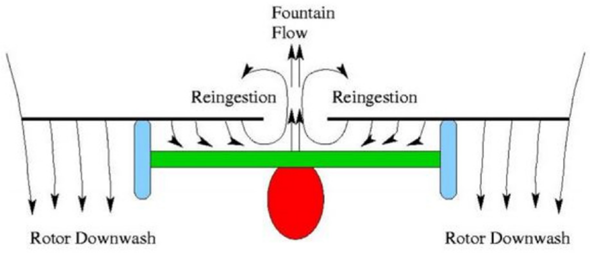


Fig. 3. Quadcopter thrust effect under OGE.

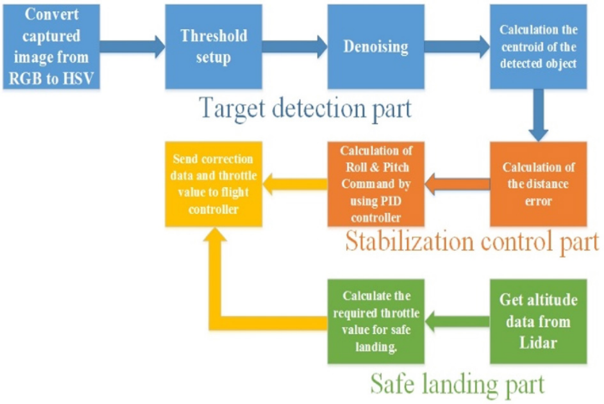


Fig. 4. Color-based target detection and safe landing algorithm.

$$x_{target} = m10/m00, \tag{1}$$

$$y_{target} = m01/m00, \tag{2}$$

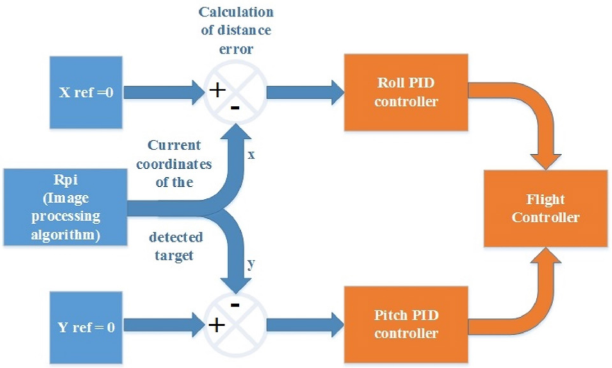


Fig. 5. Vision-based PID controller for target detection.

where $m10$ is the 1st order spatial moments around x-axis, $m01$ is the 1st order spatial moments around y-axis, and $m00$ is the 0th order central moment.

After that, the centroid of the target is compared to the centroid of the frame image. The deviation of the centroids between them is used to calculate the required roll and pitch angle for stabilization of quadcopter.

In stabilization control part, the distance error is used as an input to the PID controller. A PID controller is a feedback control mechanism commonly used in industrial control systems [20]. In this work, PID controller which is shown in Fig. 5 is utilized for generating the required roll and pitch angle commands to make the quadcopter hovering above the detected ground target.

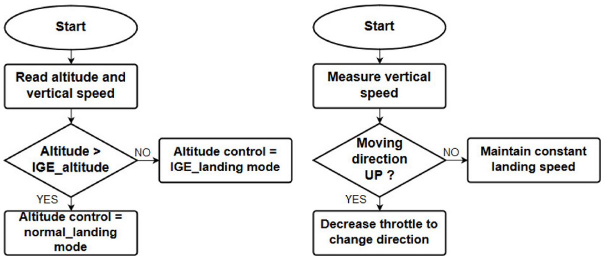
As it is depicted in Fig. 5, image processing algorithm keeps on calculating the centroid of the detected target. These centroids are subtracted from the reference $(0,0)$, which is the centroid of the frame image. Finally, the output of PID controller is given to the flight controller.

Simultaneously, LIDAR sensor keeps on measuring the altitude of the quadcopter. This data is used in the fuzzy logic controller to calculate the required throttle value for a safe landing. Next section will cover this part in details.

4.2. Fuzzy logic based safe landing algorithm

When the drone detects the colored target on the ground at a certain altitude, safe landing algorithm is activated. In this work, we utilize Fuzzy logic based safe landing algorithm which can be thought of a mixture of two kinds of landing algorithms, a position and velocity control algorithm [21–23]. The flowcharts of each control algorithms are shown in Fig. 6.

Position control technique utilizes the current position information of the quadcopter. It continuously generates a slightly smaller throttle value than the previous one until the quadcopter lands at a ground. This control technique is safe. However, the response of this algorithm is too slow and it does not consider velocity information. Furthermore, some safety issues are present because there is no way of considering landing speed. For example, if the landing velocity is too fast, quadcopter might get crashed. Otherwise, if the landing speed is too slow, quadcopter can't land at a ground target and just hovers above the ground target. Whereas, in velocity control technique, the controller continuously generates the proper throttle value to land quadcopter at a constant speed. Similarly, almost same drawbacks are present in this method such as safety issues and slow landing. The drawbacks of the aforementioned techniques are caused by the ground effect which exists near the ground while quadcopter is landing.



(a) (b)

Fig. 6. (a) Flowchart of the position control algorithm. (b) Flowchart of the velocity control algorithm.

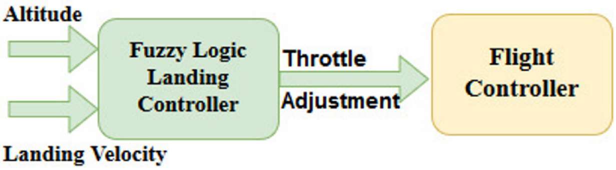


Fig. 7. Block diagram of the proposed fuzzy logic controller.

Generally, some advanced auto landing algorithm should be required to compensate for the ground effect. So, a fuzzy logic based auto landing algorithm, illustrated in Fig. 7, is proposed. The proposed fuzzy logic controller has two inputs (altitude and speed) and one output (throttle value). Rule base in the fuzzy logic controller is very important. In the current research, the above two control algorithms (position and velocity control) are considered together to build up the rule base.

Generally, the fuzzy logic controller is made up of, fuzzification, rule base, the defuzzification process [24]. The fuzzy input, output membership functions, and a rule base are designed in MATLAB/ SIMULINK.

4.2.1 Fuzzification and designing the rule base

Fuzzy input-output membership functions and rule-base is designed in MATLAB/SIMULINK using the Simulink fuzzy toolbox. The universe of each input and output is carefully selected according to desired ranges. This fuzzy logic controller has two inputs and one output, 30 rules are made for optimum landing control. Input and output membership functions are shown in Fig. 8. The universe of discourse of each membership function defines the operation range of that specific fuzzy linguistic variables. These ranges are adjustable and act similar to PID gains. These fuzzy linguistic variables are defined as IGE_NG (IGE range Near Ground), IGE_FG (IGE range Far Ground), OGE_Small, OGE_Medium, OGE_Big and OGE_VBig for the corresponding distance input as in Fig. 8(a). Fuzzy linguistic variables for the second input in vertical velocity is defined as NB (Negative Big), NS (Negative Small), Normal, PS(Positive Small), PB(Positive Big) as shown in Fig. 8(b). Velocity input parameters are the most important parameter in this controller which controls the landing velocity and direction at the same time. The fuzzy set 'Normal' indicates the normal landing velocity for safe landing. Whereas in Fig. 8(c), NB, NM, NS and PS, PM, PB fuzzy linguistic functions for landing velocity input. Negative velocity like NB and NS indicate high-speed landing velocities and Positive velocity indicates the upward moment of the quadcopter. Equation (3) explains landing velocity calculation formula.

$$Vel_{land} = \frac{Alt_{current} - Alt_{pre}}{\Delta t}, \tag{3}$$

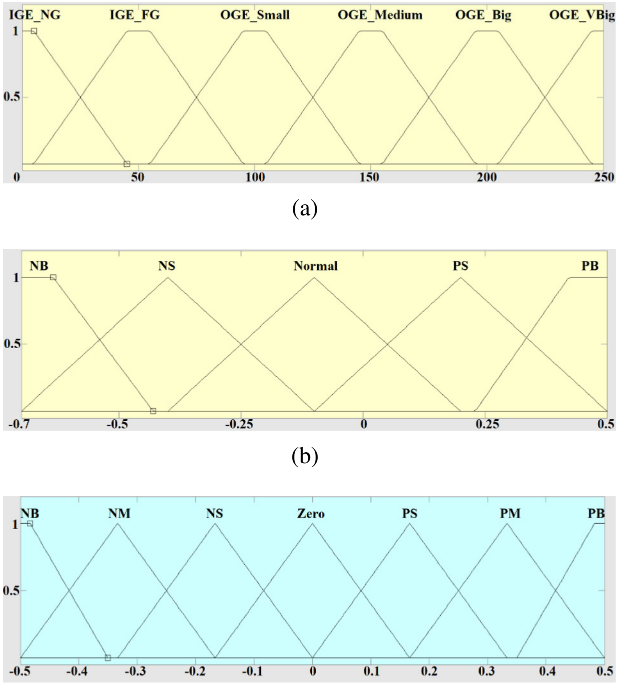
where Vel_{land} is the landing velocity, $Alt_{current}$ is the current altitude, Alt_{pre} is the previous altitude, and Δt is the time difference between the current altitude and the previous altitude.

Distance range is taken from 0-250 cm, any value above 250 cm will be taken as 250cm for fuzzy logic input. IGE range is fixed to 100 cm for this quadcopter system. IGE range depends on quadcopter size and value of thrust produced by its propellers, the IGE range will increase with high thrust producing quadcopters. The IGE range is adjustable and it can be set according to the quadcopter specification. In this designed landing controller, IGE is divided into two separate operating regions. First is IN_IGE_FG and second is IN_IGE_NG, IGE starts getting effective from the boundary region of IN_IGE_FG and this effect keeps on increasing exponentially as altitude decreases. Two-step division of IGE expands the control option to make the controller precise and reliable over different scenarios. Landing velocity ranges from −0.7 to 0.5 m/s, the "±" sign indicates moving direction, negative means moving downward and positive means moving upward. Throttle adjustments are throttle percentage values need to be added or subtracted from actual throttle percentage in flight controller ranges from −0.5 to 0.5.

Equation (4) gives the relation between actual and adjusted throttle.

$$Trottle_{input} = Trottle_{pre} \pm Trottle_{adj}, \tag{4}$$

where $Trottle_{input}$ is the throttle value of flight controller, $Trottle_{pre}$ is the previous throttle input, and $Trottle_{adj}$ is the throttle adjustments values from landing controller.



(a)

(b)

(c)

Fig. 8. (a) Fuzzy input (distance). (b) Fuzzy input (velocity). (c) Fuzzy output (throttle Adjustment).

These ranges for each parameter can be changed in fuzzy logic or gains can be used for more precise tuning. Making the rules-base is most crucial part of the fuzzy logic controller, the whole function of this controller depends on the rule base. Table 1 shows the 30 rules designed to control the auto-landing operation. The ordinary fuzzy logic controller works similar to PID controller with fixed gains. Therefore, to implement the proposed landing algorithm, the rule base is modified to overcome the PID controller drawbacks. This rule-base works in two different Modes, Mode A and Mode B.

Mode A: This is normal operation mode when quadcopter altitude is more than IGE range. Here, vertical velocity and direction of the quadcopter are monitored and controlled to land with a constant velocity (−0.2 m/s) within the normal range. In this case, throttle adjustment values work between NS to PS unless until any uncertain change in velocity happens such as quadcopter is landing with very high velocity or quadcopter is going upward as shown in Table.1 (Mode A). NM and PM will be used to change the landing velocity and direction in this case.

Mode B: The second scenario is when quadcopter is within IGE range, throttle adjustments are then shifted to NB and PB for a quick change in throttle values to keep the landing velocity constant to −0.2 m/s as thrust gets more effective within IGE range as shown in Table 1 (Mode B). NS and PS don't provide enough thrust changes to keep the landing velocity constant under IGE range. To

Table 1. Fuzzy logic rule base for safe landing.

Altitude Velocity	Mode B		Mode A			
	IGE_NG	IGE_FG	OGE_Small	OGE_Medium	OGE_Big	OGE_VBig
NB	PB	PB	PM	PM	PM	PM
NS	PB	PM	PS	PS	PS	PS
Normal	Zero	Zero	Zero	Zero	Zero	Zero
PS	NB	NM	NS	NS	NS	NS
PB	NB	NB	NM	NM	NM	NM

improve the controller performance to next level, landing controller operation under IGE range is divided into two steps. First is IGE_FG, quadcopter starts entering inside IGE range in this region. Therefore, Throttle adjustment commands are shifted towards higher gain values to provide enough throttle adjustments to overcome IGE. The second region is IGE_NG, IGE gets more effective in this region which delays the landing time and keeps the quadcopter hovering for a long time before complete landing. To overcome this problem, gains are sifted more towards high values which make the throttle adjustment commands to work between NB and PB values. PB and NB landing velocity inputs will get invalid due to very low altitude therefore only PB and NB throttle adjustment commands will perform rest landing operation. The transition region between Mode A and Mode B needs to be smooth to avoid any kind of abrupt speed change. This transition response depends on the overlap region between IGE_FG and OGE_Small fuzzy linguistic variables. Fig. 9 explains operation regions for Mode A, Mode B, and a transition region between Mode A and Mode B.

4.2.2 Defuzzification

When the quadcopter is landing at a certain altitude, corresponding rules are used to generate the practical throttle adjustment value for a safe landing. There are many defuzzification methods for this. In this work, we utilize the Center of Gravity (CoG) method [25]. Throttle adjustment values calculated from CoG method are added or subtracted from throttle percentage value as in (4). Finally, the output of the fuzzy logic controller is given to flight controller as shown in Fig. 6.

4.3. Proposed target detection and safe landing algorithm

To get better performance, the aforementioned target detection and safe landing algorithm are combined in the proposed algorithm. The combined algorithm can be thought as two algorithms working simultaneously with each other, where the safe landing algorithm is the main algorithm, and the target detection algorithm is used to decrease the distance between the quadcopter and the center of the detected target as much as possible.

For this, the proposed algorithm can be divided into two scenarios according to the quadcopter altitude. In Scenario 1, since there is no ground effect on the quadcopter,

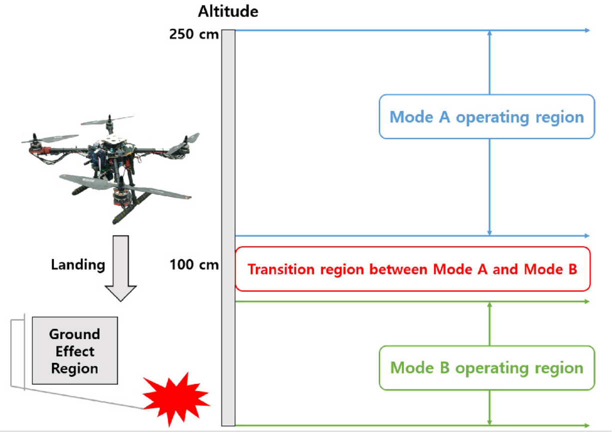
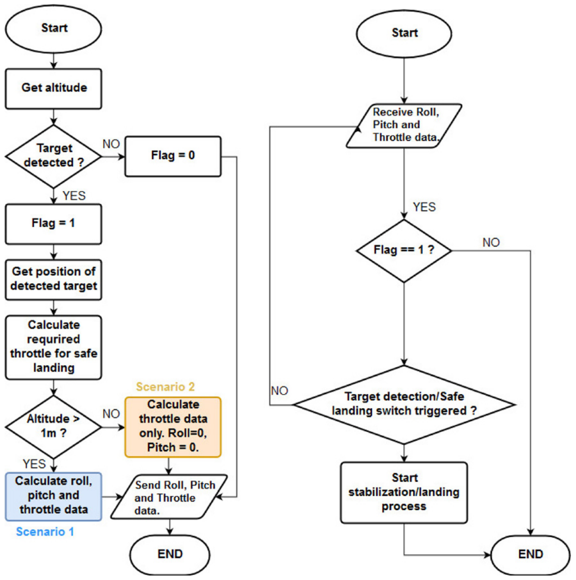


Fig. 9. Operating regions of proposed fuzzy logic landing controller.



(a) (b)

Fig. 10. (a) Flowchart of target detection and safe landing algorithm. (b) Flowchart of the received data processing inside of the flight controller.

PID controller for target detection keeps on calculating the roll and pitch values to make both centroids coincide with each other. Simultaneously altitude information from the LIDAR sensor is used for safe landing algorithm. In Scenario 2, to avoid any effect from the ground effect, both roll and pitch values from the PID controller are zero. From this moment on, only safe landing algorithm is activated in this mode.

Fig. 10 shows the flowchart of the proposed target detection and safe landing algorithm. The first flow chart is for the target detection and safe landing. During this process, LIDAR sensor keeps on measuring the altitude of the quadcopter and RPi calculates the required throttle values for a safe landing. Simultaneously, target detection algorithm works continuously until the target is detected at the altitude of 1 m (Scenario 1). When the quadcopter is under 1 m, the Fuzzy logic based safe landing algorithm is triggered. During this process, roll and pitch values are zero (Scenario 2).

The second flowchart shows the data packet processing inside of the flight controller. Whenever the flight controller receives the data packet, it will check whether the target is detected or not by checking the flag. If the target is detected, it will send commands to quadcopter to start stabilizing the quadcopter and safe landing. Furthermore, two emergency switches on the RC transmitter are provided to support the safe operation of the quadcopter. One is for the manual trigger of target detection, and the other is for the manual trigger of a safe landing.

5. SIMULATION STUDIES

MATLAB/SIMULINK is used to test the proposed safe landing algorithm based on fuzzy logic to overcome the ground effect. The used simulation system is available on MATLAB file exchange and it is free to use. The purpose of this system is to study the behavior of a quadcopter. A GUI is provided to show real moments of quadcopter in 3D space. The full system is shown in Fig. 11(a).

As mentioned before, the output of Fuzzy logic controller can be multiplied by a gain value to tune the best response from fuzzy logic. Equation (5) describes the fuzzy logic output calculation by COG technique.

$$\mathrm{Throttle}_{\mathrm{adj}} = \mathrm{K}\left(\frac{\sum_{i=1}^{n}\mu_i\mu(i)}{\sum_{i=1}^{n}\mu(i)}\right) \tag{5}$$

where $\mathrm{Throttle}_{\mathrm{adj}}$ is the Fuzzy logic output value, K is the throttle adjustment gain, i is the input number, μ_i is the corresponding membership value, μ is the fuzzy input, and n is the total number of inputs.

Fig. 12(a) shows the Fuzzy logic safe landing controller response at different gain values, while Fig. 12(b) shows the landing velocity response at different gains. As shown in Fig. 12(a), higher gain value improves the response time. However, when the gain is very high, it will disturb the landing under IGE threshold. Also, in Fig. 12(b), it can be seen that fuzzy logic based landing controller keeps landing velocity constant at the desired value, and changing the gain value will affect the settling time. In both figures, the gain value of 1.05 shows the best response, and it shows that the Fuzzy logic controller that combines both speed and position control strategy covers the IGE efficiently according to the designed rule base. Moreover, fuzzy logic landing controller provides steady state landing velocity which makes the landing process smooth and safe.

6. EXPERIMENTS

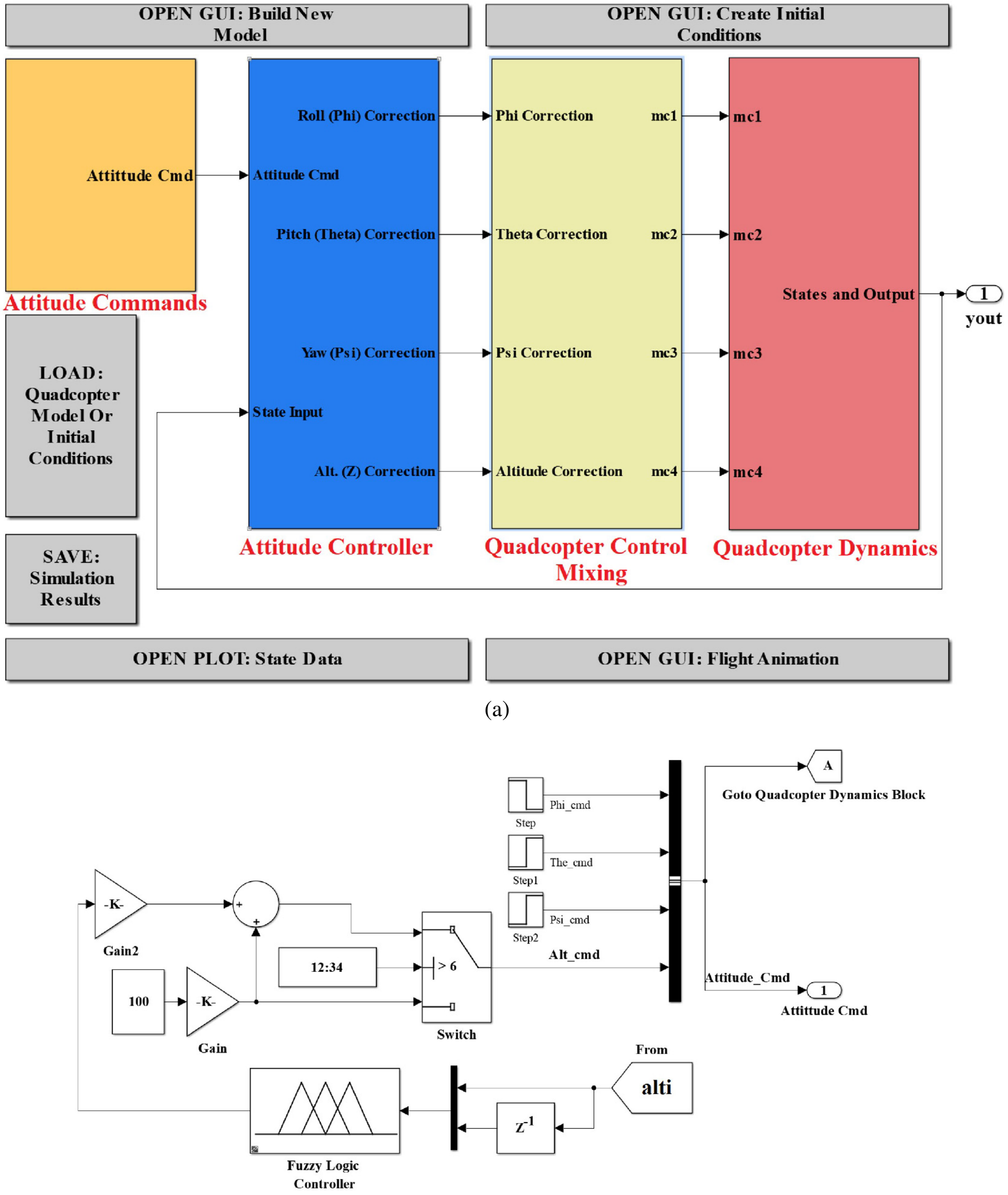
To verify the performance of the proposed target detection and safe landing algorithm, several experiments were performed indoor and outdoor. The experimental system is composed of quadcopter frame with flight controller and RPi controller which executes target detection and safe landing. Even though the RPi is not powerful enough for real-time target detection and safe landing, we tried to use the RPi owing to its low cost.

6.1. Target detection algorithm

To perform the target detection, USB camera with a resolution of 160×120 is used for guaranteeing the proper execution time that will not affect the performance of the whole quadcopter system. Fig. 13 shows a top view and a side view of the quadcopter system.

As it is shown in Fig. 13, a USB camera and a gimbal are connected to the RPi. Gimbal is used to make the camera facing the ground while the quadcopter is maneuvering. Generally, the quadcopter can come to the vicinity of the ground target with the help of GPS information. When the quadcopter is hovering in the vicinity of the target at an altitude of about 2.5 m or higher, the camera starts to keep on taking snapshots continuously. Each snapshot is processed by image processing algorithm to calculate the centroid of the detected target inside of the frame image. Fig. 14 shows the sequential results of the vision-based target detection algorithm.

As it is indicated in Fig. 14, the captured RGB image is converted into HSV image. After applying the thresholding technique to the HSV image, an image can be obtained with lots of black spots inside of the detected target. In order to remove these spots, the morphological transformation is used. Finally, it is possible to calculate the centroid of the detected target. If the centroids of the detected target are available, this information is given to the PID controller to calculate the required roll and pitch angle for stabilizing the quadcopter.



(a)

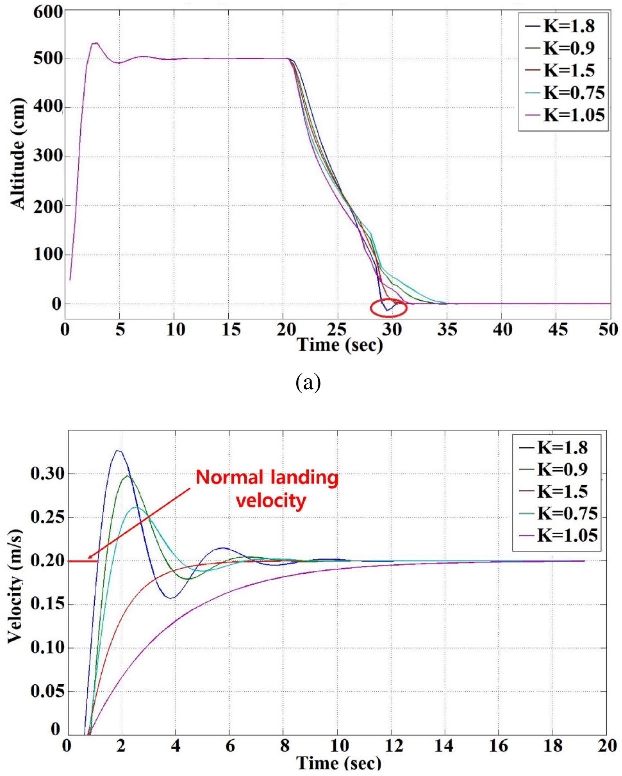
(b)

Fig. 11. (a) Quadcopter simulation system. (b) Attitude command block.

6.2. Generation of a lookup table for the fuzzy logic controller

Generally, the Fuzzy logic controller is a complicated controller that takes long computation time. In the current application, RPI is responsible for performing two tasks at the same time. Especially, image processing takes a large execution time due to its huge data size. Therefore, implementing Fuzzy logic controller in parallel with image processing will cause processing delay which can cause catastrophe. To overcome this problem, a pre-calculated lookup table method is used instead of a real-time Fuzzy logic controller. Additionally, the Simulink model is utilized as shown in Fig. 15 to pre-calculate the output of Fuzzy logic controller corresponding to different input values.

Landing velocity signal is made ranging from -0.7 to 0.5 m/s using signal builder block, and output throttle adjustment values are saved for 0-250 cm altitude, with a 5cm difference. The simulation program is executed for all landing velocity inputs at each altitude point and output of the Fuzzy logic controller is recorded. For example, altitude input of quadcopter is fixed to 250 cm and land-



(a)

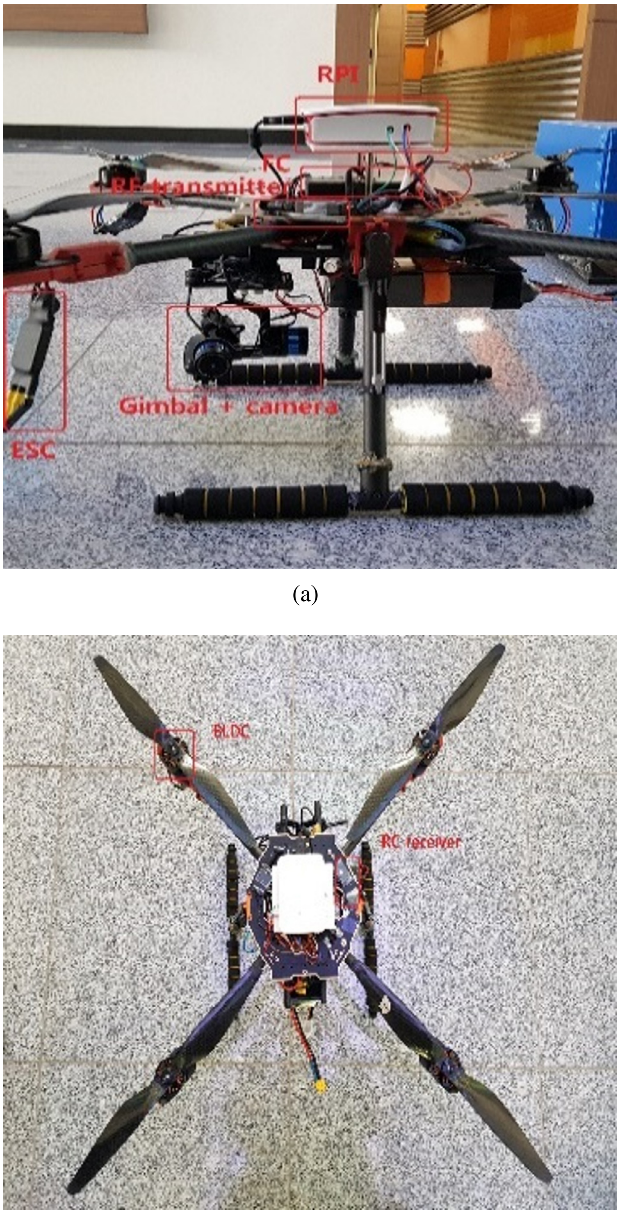
(b)

Fig. 12. (a) Fuzzy logic landing controller gain tuning. (b) Landing velocity response for fuzzy logic landing controller at different gains.

ing velocity input is provided from −0.7 to 0.5 m/s with the step size of 0.048 m/s, corresponding output throttle adjustment values are recorded. The same process is repeated for each altitude point from 0-250cm with a 5cm difference. Conclusive look-up table has been created with 25 different velocity values aligned in rows with 52 different altitude values as columns which made look-up table of 1300 values. This look-up table is written inside the RPi. The landing controller measures the altitude and velocity using LIDAR and then round off the data to exactly match the look-up table inputs.

When the safe landing process is triggered, the real-time altitude and velocity measurements can be calculated using LIDAR sensor. These measured values are then rounded off to match the actual look-up table entries. The rounded off values of velocity and altitude are used as input for the look-up table, which generates the corresponding throttle adjustment output for these specific inputs. Finally, this data is further sent to flight controller via UART communication to update the attitude commands for a safe landing. These instructions are updated every 200 ms in the flight controller.

Initially, the quadcopter is hovering at an altitude of 2.5 m and target detection algorithm is triggered. Once the quadcopter detects the target, it starts the stabilization process to make the quadcopter hovering right above the ground target. At this point, safe landing process is initiated. From this point, safe landing and quadcopter stabilization work simultaneously to overcome any destabilization due to environmental conditions. This process continues until quadcopter reaches 1m altitude. From now on, quadcopter stabilization is turned off and only safe landing algorithm works for faster landing process. Altitude is measured in cm unit via LIDAR rangefinder and data is recorded every 500 ms using RF transceiver.



(a)

(b)

Fig. 13. (a) Side view of the quadcopter system. (b) Top view of the quadcopter system.

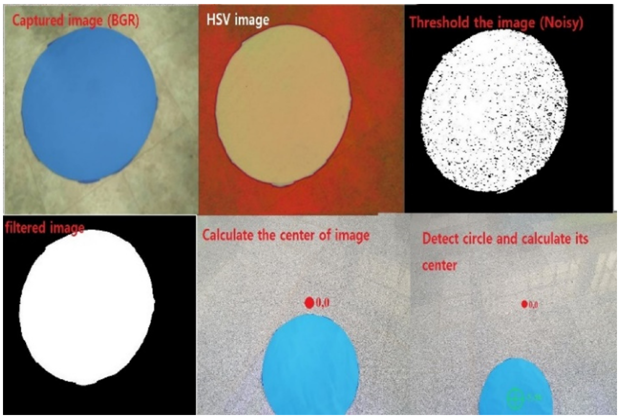


Fig. 14. Sequential results of image processing algorithm indoor.

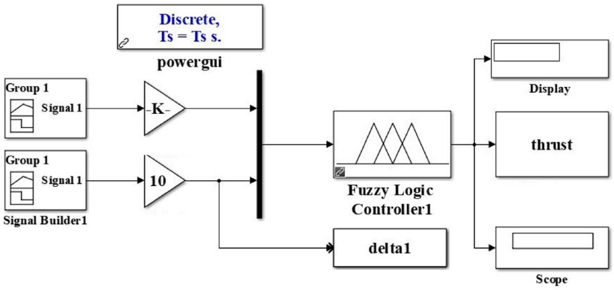


Fig. 15. Simulink block for generation of lookup table.

6.3. Experimental results

To verify the feasibility of the proposed target detection and safe landing algorithm, several experiments are performed. Initially, the quadcopter is hovering at an altitude of above 2.5 meters (Scenario 1). During this period, target detection and safe landing algorithms are simultaneously activated. For the target detection, a PID controller is used. The roll and pitch PID controllers used the gains listed in Tables 2 and 3.

PID controller for target detection keeps on calculating the roll and pitch values every 10 ms to make both centroids coincide with each other. Simultaneously, altitude information from the LIDAR sensor is used for safe landing algorithm every 100 ms.

Table 2. PID gains for pitch control.

Y	P	I	D
PID1	3.8	0.075	0.084
PID2	4.0	0.05	0.07

Table 3. PID gains for roll control.

X	P	I	D
PID1	3.5	0.05	0.07
PID2	3.0	0.01	0.1

When the quadcopter reaches an altitude of about 1 m (Scenario 2), roll and pitch PID controller stops working. From this moment on, safe landing algorithm is only activated. The whole response of the proposed algorithm is shown in Fig. 16. Fig. 16 represent the centroid deviation between detected target's centroid and the frame image's centroid while testing the target detection algorithm indoor and outdoor. As it can be seen in the figures, PID1 shows better response and performance than PID2. Table 4, shows the response time of the target detection algorithm indoor and outdoor. As it can be seen in Table 4, the outdoor test took more time because of the environment effect.

Fig. 17 represents the trajectory of the centroid of the detected target with different PID gains indoor and outdoor. In Fig. 17, the Start point represents the centroids of the detected target at an altitude of 2.5 m, and the Endpoint represents the centroids of the detected target at an altitude of 1 m. As can be seen in the figures, PID1 shows a better response than that of PID2.

Fig. 18(a) and (b) show the response of the proposed target detection and safe landing algorithm indoor and outdoor, while Fig. 19 shows the response of the auto landing function that is implemented inside the pixhawk. Table 5 shows the response time of the proposed algorithm indoor, outdoor and the auto landing function response time of pixhawk.

As shown in Table 5, when the drone is less than 1 m, the proposed safe landing algorithm shows a much better response to overcome the ground effect and land more smoothly than the one that is implemented in the pixhawk.

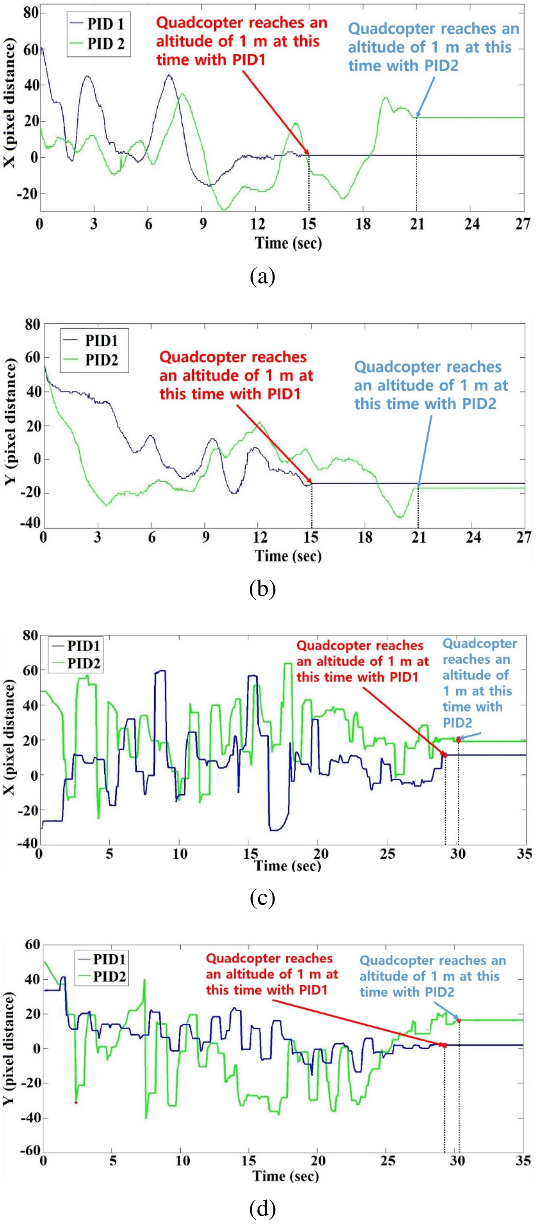
Fig. 20 shows photos taken during testing the proposed algorithm indoor and outdoor. Photo 1, shows the quadcopter hovering at an altitude of 2.5 meters, photo 2 shows the stabilization and safe landing process. Photo 3, shows the quadcopter at an altitude of below 1 meter where only safe landing is working, and photo 4 shows the final landing to the ground target.

7. CONCLUSION

In this paper, a vision based target detection and safe landing algorithm have been proposed. Target detection algorithm based on color is developed using PID controller for quadcopter stabilization. Also, a safe landing algorithm based on the fuzzy logic controller has been developed to overcome the ground effect. Furthermore, the

Table 4. Target detection response time.

PID	Indoor (sec)	Outdoor (sec)
PID1	14.8	28.8
PID2	20.5	30.2



(a)

(b)

(c)

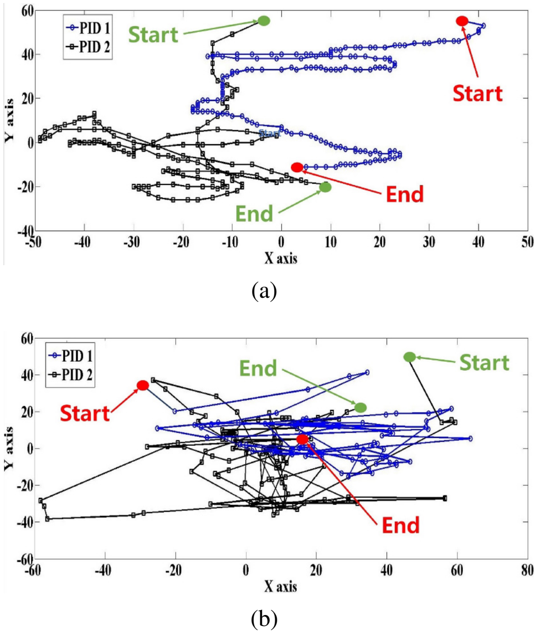
(d)

Fig. 16. Response of proposed algorithm in (a) '*x*' position indoor, (b) '*y*' position indoor, (c) '*x*' position outdoor, (d) '*y*' position outdoor.

Table 5. The response time of the proposed algorithm.

Altitude	Indoor (sec)	Outdoor (sec)	Pixhawk (sec)
2.5 to 1 m	15	28	27
< 1 m	5	5.5	18
Total time	20	33.5	45

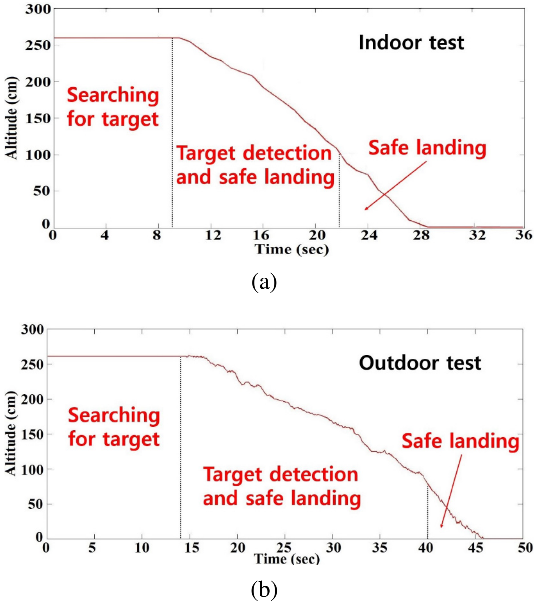
relatively cheap embedded controller was used for real-time applications such as target detection and safe landing. The proposed target detection and safe landing algorithm can be used in many application such as mining detection,



(a)

(b)

Fig. 17. The trajectory of the centroid of the detected target (a) indoor, (b) outdoor.



(a)

(b)

Fig. 18. Experimental results of fuzzy logic landing controller (a) indoor, (b) outdoor.

where the UAV can safely land after detecting target for wireless charging then continue its task. In order to verify the performance of the proposed algorithm, several experiments are performed indoor and outdoor. The obtained results show that the proposed system works well indoor and outdoor for the target finding and safe landing of the quadcopter. Furthermore, this system is currently being improved to safe land on a moving target.

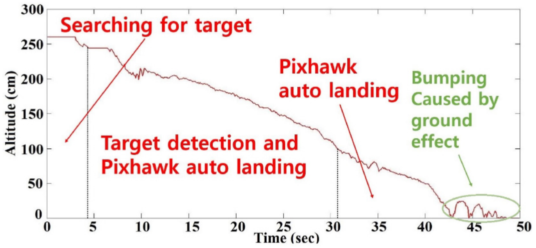


Fig. 19. Experimental result of Pixhawk auto landing.

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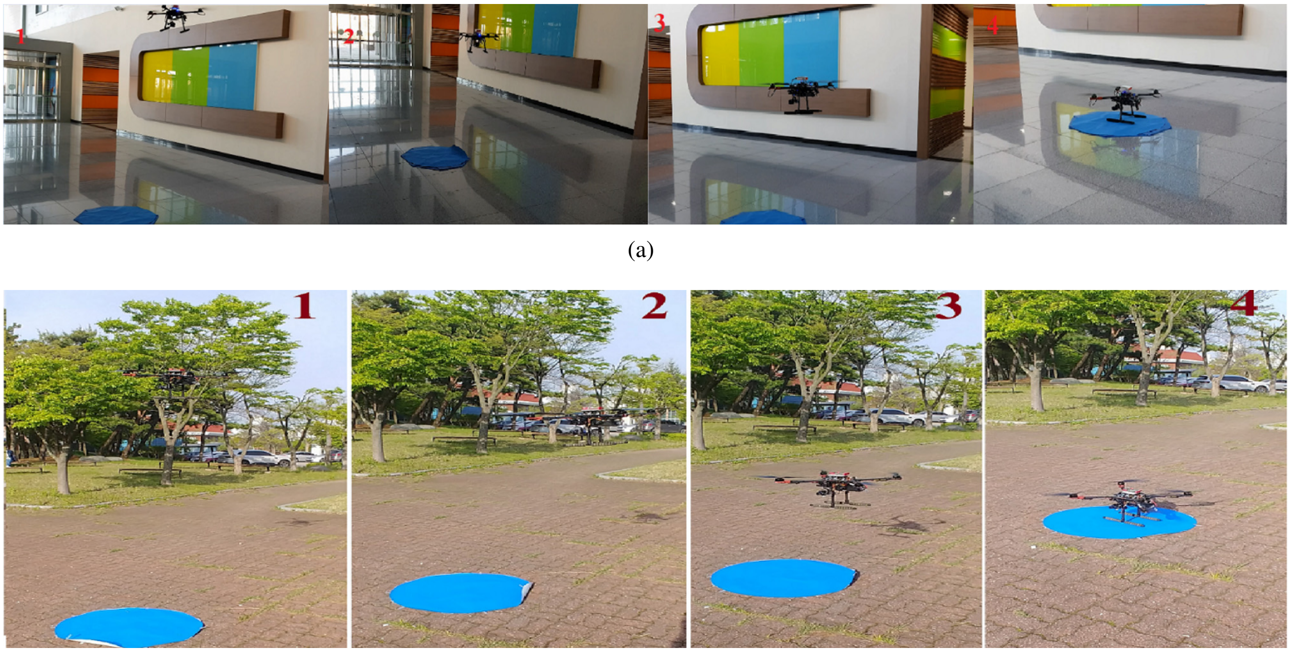

(a)

(b)

Fig. 20. Photos taken during practical test (a) indoor, (b) outdoor.

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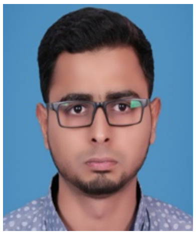

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