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Autonomous Fire Fighting Mission Using Unmanned Aerial Vehicle Image Processing

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Abstract

In this study, an adaptive Unmanned Aerial Vehicle (UAV) design and software for fire extinguishing mission has been realized. With a water release mechanism mounted on the designed UAV, water is taken from the determined area and discharged to the determined area. While designing the UAV, attention was paid to ensure that it is fast, light, maneuverable and has a high load carrying capacity. The body is designed to be high strength and lightweight. For this reason, the UAV Octo Quad X8 (4 rotors, 8 motors & propellers) has a chassis type. It is aimed for the UAV to perform this task autonomously. The Python software language will be used to determine the area where the water will be discharged and the Haversine formula will be used. As a result of the experiments, the hit rate of the water to be discharged into the center of the 3-meter pool was 90%.
Keywords: Image processing, Haversine formula, Autonomous flight.

İnsansız Hava Aracı ile Görüntü İşleme Kullanılarak Otonom Yangın Söndürme Görevi

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Özet

Bu çalışmada, yangın söndürme görevi için uyarlanabilir bir İnsansız Hava Aracı (İHA) tasarımı ve yazılımı gerçekleştirilmiştir. Tasarlanan İHA'ya monte edilen bir su bırakma mekanizması ile belirlenen bölgeden su alınıp tespit edilen bölgeye suyun boşaltılması sağlanmaktadır. İHA tasarlanırken hızlı, hafif, manevra kabiliyeti yüksek ve yük taşıma kapasitesinin fazla olmasına dikkat edilmiştir. Gövde, yüksek dayanıma sahip ve hafif olacak şekilde tasarlanmıştır. Bu sebepten dolayı İHA Octo Quad X8 (4 rotor, 8 motor&pervane) şase tipine sahiptir. İHA'nın bu görevi otonom bir şekilde yapması amaçlanmıştır. Suyun boşaltılacağı alanın tespiti için Python yazılım dili kullanılacak olup Haversine formülünden yararlanılacaktır. Yapılan denemeler sonucunda 3 metrelik havuzun merkezine boşaltılacak suyun isabet oranı %90 olmuştur.
Anahtar Kelimeler: Görüntü işleme, Haversine formülü, Otonom uçuş

1. Introduction

Firefighting is a difficult task that requires determining the location of the fire, reaching the target location as soon as possible and effectively extinguishing the fire. According to the forestry statistics data of the General Directorate of Forestry in Turkey [1], there were 27,150 fires between 2012 and 2021, and 226,545 hectares of land were burned in these fires. These fires caused many fire injuries and direct property damage.

Today, as forest fires increase, solutions to this problem are expected to increase as well. In order not to risk human life during a natural disaster such as fire, unmanned and autonomous aircraft can be used. Thanks to the intervention of these vehicles in the fire, it is of great importance to reduce the damages that may arise because of natural disasters. In this study, it is aimed to find a solution to the mentioned problem. In the design of the UAV, which will fly autonomously, the necessary parameters have been calculated for it to have sufficient water carrying capacity and to carry this water. Using Unmanned aerial vehicles (UAV), it can operate in cloudy weather, covering large areas. It can workday, night, long-term. It can be easily recovered and is inexpensive compared to other aircraft. When electric UAVs are used, it can benefit the environment. They can carry different loads for different tasks. It can detect the target area efficiently and reach the designated area quickly. It can be performed without human pilot/operator involvement or with minor interventions [2 - 10].

When the literature studies were examined, Spurny et al. It offers a new approach to autonomously extinguishing indoor fires inside a building by Micro-Scale Unmanned Aerial Vehicle (MAV). It covers controlling and estimating MAV status, detecting a building entrance, multi-mode MAV localization during outdoor-indoor transition, indoor motion planning and reconnaissance, fire detection and location estimation, and fire suppression [11]. Chen et al. He used it as a six-rotor UAV carrier to design a flight robot suitable for urban fire control. First, urban fire control UAV hardware based on the embedded system was built. Next, an emergency fire monitoring system is created using the Internet of Things and the public cloud. Finally, the flame retardant mechanical device of the UAV is designed according to the box structure. The applicability of the proposed method has been confirmed by practical experiments that provide a reference for research on the application of UAVs in the flame retardancy of urban fire emergencies [12]. Qin et al. presented the design and implementation of a UAV for outdoor firefighting application. The proposed UAV firefighting system consists of a self-designed quadcopter as a platform, a transmission system to collect and discharge water, real-time kinematics (RTK)-based navigation system, and a mission control system to monitor and coordinate the UAV. In our proposed autonomous cooperative framework, the UAV initially finds the optimal path (based on distance and power consumption) to the fire point. After reaching the fire target, the mission control system will direct the UAV to suppress the fire [13]. Yuan et al. An unmanned aerial vehicle (UAV) based forest fire detection and tracking method is proposed. First, a brief demonstration of the UAV-based forest fire detection and tracking system is presented. A forest fire detection and monitoring algorithm has been developed by applying image processing techniques. Experimental results showed that the proposed methodology can effectively remove fire pixels and monitor the fire zone [14].

Restas has tested flight control, data transmission and flight capability to demonstrate the tactical effectiveness of using UAVs for fire monitoring. He also tested the infrared camera system to analyze the effect of changing flight parameters, to predict the spread of fires based on online data transmission. As a result, it can be offered to the use of even the smallest firefighters with the use of UAVs. Increasing reconnaissance effectiveness will result in increasingly effective response measures. Thus, it will increase the forest area saved while reducing the forest areas destroyed [15].

In this study, an adaptable UAV design and software for fire extinguishing mission is presented. As a solution to this problem, a rotary wing UAV was designed. The designed UAV was developed to have 4 rotors and 8 engines. In this way, it was ensured that the UAV was light, maneuverable, durable and capable of carrying more water. A water intake and release mechanism has been designed under the UAV by considering the logic of extinguishing with the same helicopter. This mechanism is designed to be positioned 3.5 meters below the bottom of the UAV with the help of a rope, so that the UAV can take water from a safe distance and respond to the scene from a safer distance.

2. Materials and Methods

2.1. UAV Mechanical System Design

According to the results of the research made in reference [16], suitable configurations to be used for UAV systems that will carry heavy payloads have been analyzed. Using these analyses in line with the realization of the planned mission, it was determined that the most suitable chassis type was the octo-copter X8. The main reason for this choice is the need for thrust. This type of chassis consists of 4 rotors and 8 motors. Since the propeller size to be used in the engines is 11 inches, the diagonal distance of the body between the engines is designed to be 482.73 mm. To keep the strain on the body due to the thrust force on the arms during flight, the arm length has been kept short. The body and mechanical systems are intended to have a light and durable structure. In this direction, carbon fiber, G10, aluminium, plexi glass and wood materials were examined. Because of the examinations, it was preferred to use carbon fiber material, which has the lightest and most durable structure. Some mechanical parts used in the body are made of Polylactic Acid (PLA). Carbon fiber mechanical parts are designed the Solidworks. The technical diagram and details of the UAV are in Figure 1. The body design and the placement of the plate materials used on the body are given in Figure 2. The visual figure showing the rotor arrangement in UAVs is given in Figure 3. The tensile force analysis image, which emerged as a result of the stress analysis performed on the body and motor arms, is given in Figure 4.

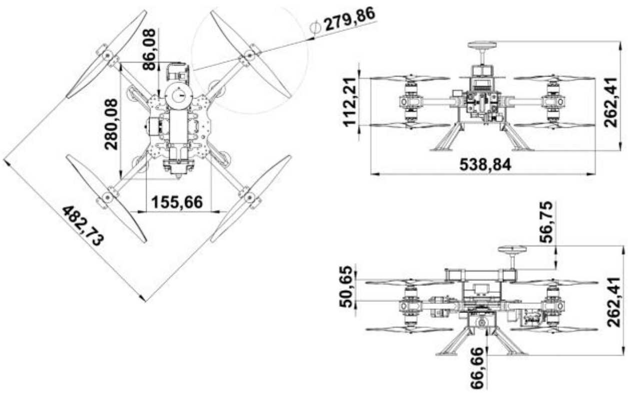


Figure 1. Dimensional parameters of the UAV

Figure 2. Designed UAV Body

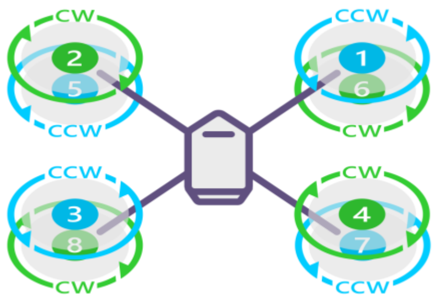


Figure 3. UAV Rotor Design

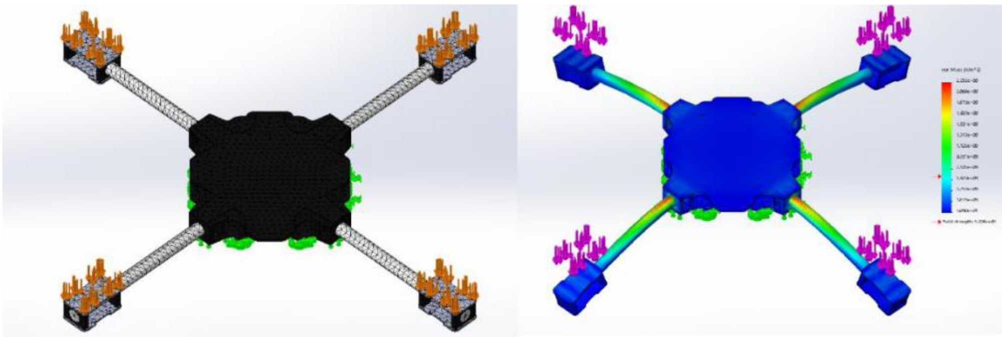


Figure 4. UAV Stress Analysis

In the final design of the UAV, the weight, balance and dimensioning parameters were determined through the Solidworks program. The body weight of the UAV, which was designed and manufactured, was calculated as 512.24 grams, unladen weight 1942.9 grams and loaded weight 3191.33. All components used in the weight table were measured with a scale with a precision of 0.01 grams.

2.2. Task Algorithm

The UAV must take water from the blue-colored water pool, whose location is known, by a mechanism, due to the purpose for which it was designed. It is expected that the water it receives will then leave the red zone, which it must be detected during the reconnaissance flight. All these steps occur fully autonomously. The autonomous flight software is written in Python and the DroneKit library is used. DroneKit-Python allows developers to create applications that run on an onboard companion computer and communicate with the ArduPilot flight controller using a low-latency connection.

It is expected the UAV to detect the red area with image processing during the reconnaissance flight. Image processing steps usually differ according to the problem [17]. In this study, the detection red color detected by the filters applied on the image taken in real time. First, the center point of the detected area is taken. The radius of the pool in meters and the radius of the pool in pixels are known. The center point of the captured camera image is the center point of the UAV. A direct proportion is established between the distance in pixels between the center point of the UAV and the center of the red pool and the distance values of the pool in meters and pixels. Equation 1 refers to the distance in meters between the center point of the UAV and the center of the red pool.

$$x = \frac{(Radius\ of\ the\ pool\ in\ meters) * (Radius\ of\ the\ pool\ in\ pixels)}{The\ distance\ between\ the\ center\ of\ the\ pool\ and\ the\ center\ of\ the\ UAV\ in\ pixels} \tag{1}$$

Thanks to the ratio in Equation 1, the distance (x) of the red pool to the UAV can be obtained in meters. This x value is a required parameter when using Haversine formula (11). The Haversine formula determines the great circle distance between two points on a sphere, given longitude and latitudes. The calculation of the distance from one location to another is affected by a certain degree of curvature, so the choice of method for calculating the distance from the earth to the surface will most likely affect the accuracy of the results obtained [18].
For this reason, another necessary parameter in the application of the Haversine formula is the angle value of the UAV with the North Pole. This angle value is found by adding the instantaneous 'rotation on the vertical axis' angle of the UAV and slope of the line going from the center of the camera to the detected object. Figure 5 shows the parameters of the Haversine formula.

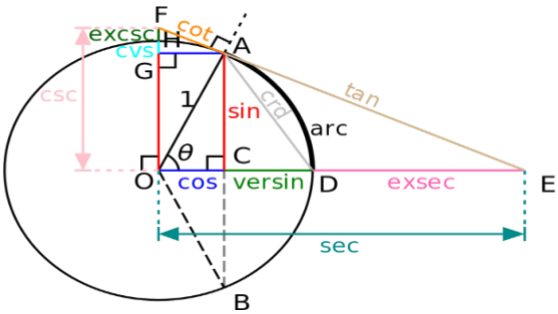


Figure 5. Haversine Formula [11]

$$a = \sin^2(\Delta\varphi/2) + \cos\varphi 1 \cdot \cos\varphi 2 \cdot \sin^2(\Delta\lambda/2)$$
$$c = 2 \cdot \mathrm{atan2}(\sqrt{a}, \sqrt{(1-a)}) \ (1)$$
$$d = R \cdot c$$
(φ: latitude, λ: longitude, R: Radius of the earth) (2)

The latitude longitude information of the center of the area determined by the parameters in Figure 2 can be accessed by the Haversine formula [19], which is shown with Equation 2 an algorithm has been developed in this direction for the UAV to reach the center of the target in the most accurate way.

2.3. Water Intake and Release Mechanism

There are studies in the literature as a water Intake and Release system [12,13]. The mechanisms made in these studies were examined and tried to be improved and applied. The task mechanism system is designed to carry 1 liter of water. In the system, 1 geared Direct Current (DC) motor, 1 L298N motor driver, 1 water transport container and a silk fishing line with a strength of 15.88 kg were used for the connections. The load carrying container is made up of pet bottle material. A 3.5-meter-long silk line was suspended from the UAV and water carrying container was attached to this silk line. To prevent the silk line from meeting the propellers, a thin perforated cloth was wrapped between the feet of the UAV. It can be seen in Figure 6.

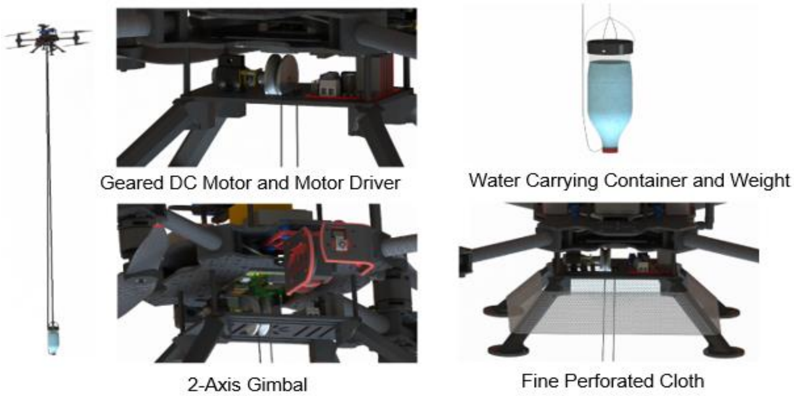


Figure 6. Task mechanism components

For the container to sink into the water during loading, 5 g weight was added to the outside of the container in such a way as to disrupt the center of gravity. In this way, it is aimed that the container cannot float on the water and the sink, the water filling process is realized. In the load release system, the geared DC motor is activated. The rope tied to the bottom of the water-filled container was pulled with the help of a DC motor and pulley system, and the container was rotated approximately 120 degrees. In this way, the water in the inverting container can be poured into the water release area. Geared DC motor and L298N motor driver circuit were controlled via a Raspberry Pi 4 auxiliary computer. Detailed images of the task mechanism are given in Figure 6. The technical details of the equipment in the mechanism are measured and given in Figure 7.

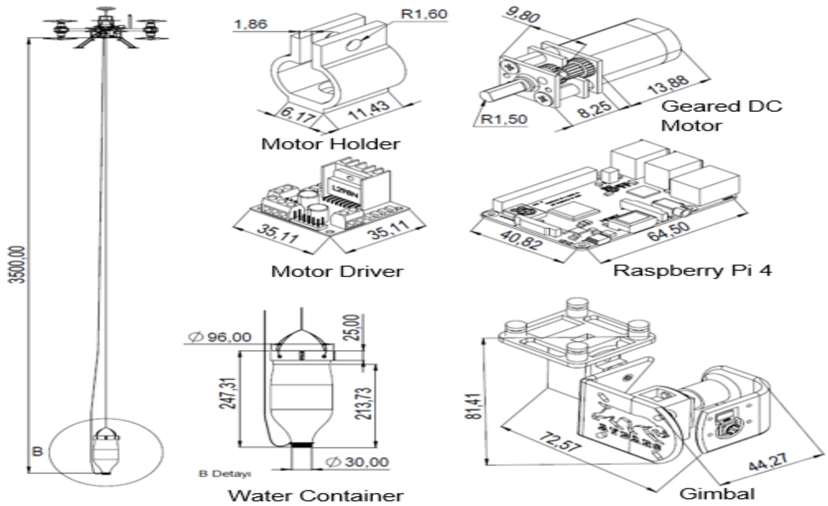


Figure 7. Technical details of the task mechanism and equipment

2.4. Target Detection and Recognition System

Image processing and GPS data were used in the target detection and recognition system. A mini computer, camera and gimbal equipment are integrated into the UAV to perform image processing. Raspberry Pi 4B was used as a mini computer. A Pi Cam v2.1 camera module was chosen as the camera. As a gimbal, a mechanism with a unique design that can move in 2 axes has been produced. The target detection and recognition system architecture is shown in Figure 8.

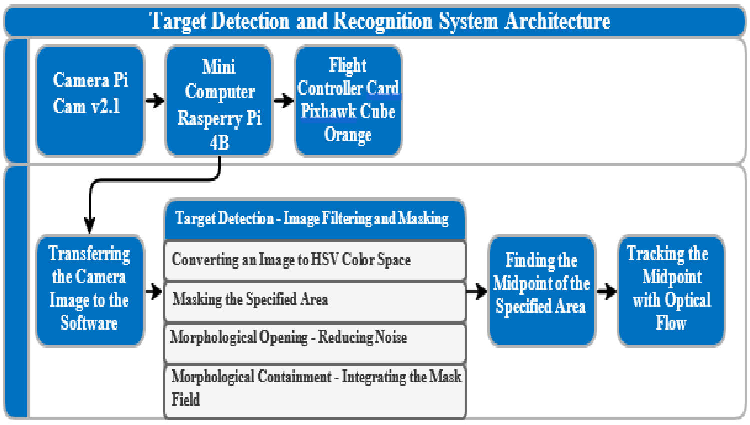


Figure 8. Target Detection and Recognition System Architecture

A target detection and recognition system were carried out with two methods. The first is the detection of the load-receiving region using GPS, and the second is the determination of the load-drop region by image processing. Task algorithms are coded in the Python language. The Python language is preferred because it has many resources and libraries. The GPS coordinates of the load-bearing area are determined before the mission and stored in the memory. A reconnaissance tour is initiated to determine the approximate location of the load release area. Area scanning starts with image processing at the approximate location detected. While scanning, the gimbal fixes the camera at an angle parallel to the ground and the vibration dampers on it, minimizing the errors caused by the movement of the UAV in the camera image. The detection and tracking topics studied in [20] are used for the red zone detection problem. Target detection is performed using the OpenCv image processing library, which is compatible with the Python programming language. In image processing, the area containing the pixels in a certain value range is masked using the HSV color space and the midpoint of this masked area is determined. In the determination of the midpoint, the detected load release area is enclosed in a circle and the midpoint error, which will shift due to the undetected regions, is minimized by the work of U. Özkaya et al [21].
The midpoint of the circle was followed by calculating the pixel shift using the optical flow method. The flowchart of the algorithm is shown in Figure 9.

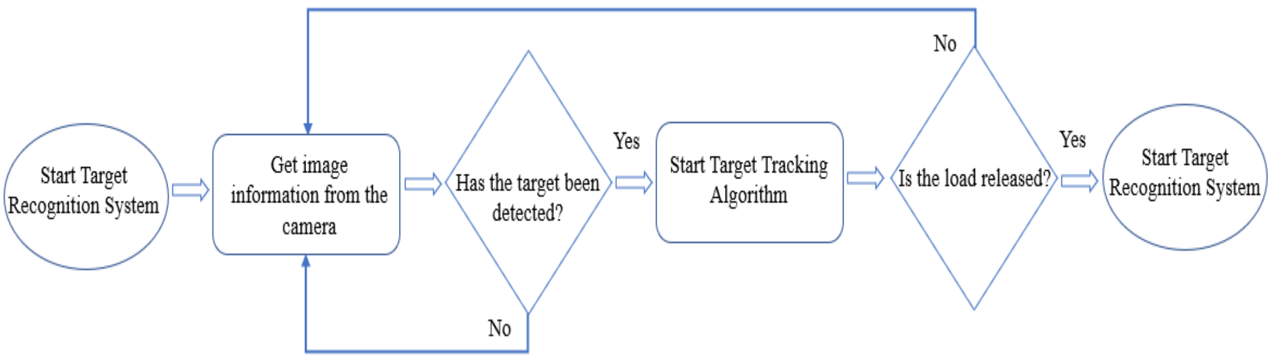
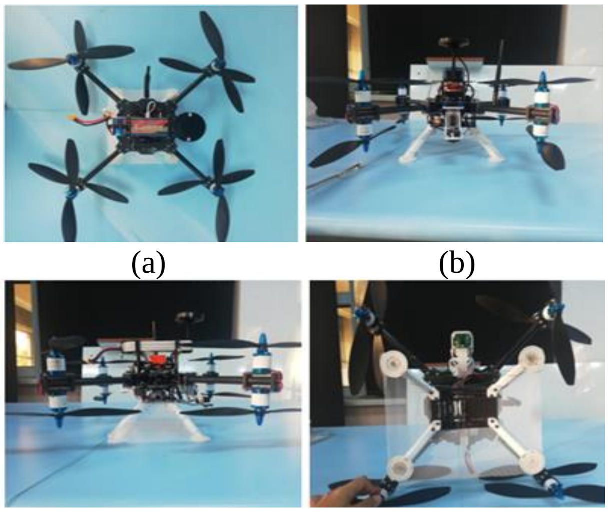


Figure 9. Target detection and recognition system algorithm flowchart

The visuals of the UAV designed and used in this study are shown in Figure 10.



(a) (b)

(c) (d)

Figure 10. Images of the UAV used in the study (a) bottom view, (b) (c) side view, (d) top view

3. Results and Discussion

In this study, which was carried out to provide assistance in emergency situations such as natural disasters, an autonomous unmanned aerial vehicle design was developed. While this study was being conducted, it was tried by creating an environment like a disaster situation, not in a real fire situation. The area where the water will be taken has been realized as a blue colored pool and its location is known. The area where the water will be released has been realized with a red colored pool, which is the color that may occur during the fire. Although the location of the water release area is unknown, it was determined by color and the water was discharged to the right point. Figure 11 shows that the UAV detected the red area while performing the task.

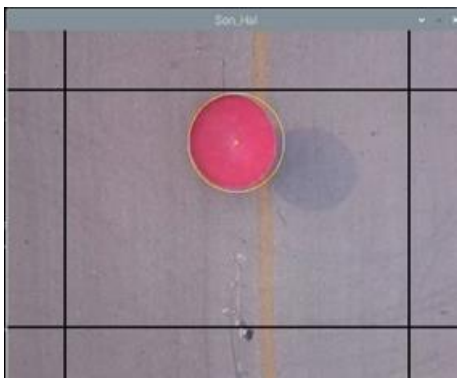


Figure 11. Red pool image from the UAV

The flight performance parameters measured during the project trials are shown in Table 1.

Table 1. Fligt Performans Parameters Table

Parameters	Values	Unit
Maximum Load Capacity	1.3	Kilogram
Maximum Flight Time	7	Minute
Gimbal Average Stabilization Speed	1	Second
GPS Maximum-Minimum Deviation Probability	2.5-0.025	Meter
Maximum Amount of Water Transported by the UAV	1.2	Kilogram
Time for the UAV to Take Water	1.45	Minute
Time to Discharge the Water into the Chamber of the UAV	30	Second
UAV Positioning Accuracy	90%	
Hit Rate to the Pool	95%	

4. Conclusions

The hardware and algorithm prepared in this study work together to perform tasks autonomously. In this project, a UAV hardware and software is designed, which aims to evacuate water to a certain area whose coordinates is unknown. The UAV takes the water required for firefighting from its known location pool. In order to intervene in the fire, the haversine method was used between the images taken from the camera and the GPS coordinates of the UAV to detect the representative red area of the fire. In order for the UAV to have a fast and high payload capacity, the UAV design with 4 rotors and 8 engines was preferred. It was aimed to affect larger areas with more payload. Thanks to the trials, the hit rate of the water to be discharged into the center of the 3-meter pool was the best 95%, while the positioning accuracy of the UAV on the red pool was 90%.

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