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RESEARCH ARTICLE

AUTONOMOUS GUIDANCE SYSTEM for UAVs with IMAGE PROCESSING TECHNIQUES

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ABSTRACT

In this study, object detection is carried out by the image processing techniques of the images captured by the camera of the UAV in an autonomous flight route. After the desired object is detected, an algorithm is designed to land near this object by autonomous guidance of the UAV. In order to ensure the functioning of the algorithm, a UAV control system including ground station software has been designed. In addition, a deep learning-based human recognition system is tested in the algorithm in order to reduce the risk of accidents that may arise from UAV crashes. Image processing techniques were applied to the images taken by the UAV with the designed system and object detection was achieved successfully. 3 different objects to be detected were determined and the processes were repeated for each object. The deep learning-based human recognition process designed in this study has been tested in terms of recognition accuracy by using different models.

Keywords: *Deep learning, Image processing, HSV, UAV, Human recognition*

1. INRODUCTION

Unmanned Aerial Vehicles (UAV) have become an essential part of the technology world. UAVs, whose usage areas are increasing, also participate in object detection processes. When the UAV is controlled by humans to perform these tasks, incidents such as accidents, disintegration, and damage to the environment and living things may occur. In this case, there is a need to minimize the problems that may arise as a result of human intervention during flight guidance and control in a UAV that is planned to be used for object detection.

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Significant advances have been realized in the use of UAVs [1-3]. Object detection, which is one of the subjects of computer vision, is an area on which many studies have been carried out recently [4, 5]. When the literature is examined, it is seen that object tracking is done with UAVs by using image processing techniques [6]. Applications of image processing techniques on UAVs are examined in [7-9]. Autonomous control has an important place among UAV applications. In [10-12], autonomous guidance systems for UAVs were evaluated. In addition, deep learning-based applications and artificial intelligence have started to be applied frequently on UAVs in recent years with their increasing popularity [13, 14].

In this study, object detection is realized by using image processing techniques. Regarding the visual and numerical data obtained, the autonomous guidance of the UAV is ensured. As a first step, the images captured by the UAV's camera were detected with the help of various filters and arrangements, and the object with the desired properties was determined. After the object was detected, the necessary algorithm was designed to land next to this object and the parameters that allow the UAV to be controlled autonomously were obtained. A deep learning-based human recognition system is included in the system design so that the UAV does not harm people during landing. As a result of these processes, the main contributions of this study are given as follows:

- The object detection and routing task is carried out autonomously without human control.
- With the benefit of being autonomous, it saves processing time, cost, and labor.
- In addition, human-induced accidents and possible risks are also reduced.
- Besides, since the properties of the object to be detected can be changed in the designed system, it provides flexibility to the user.

In the second part of the study, the system model is explained in detail. In this section, image processing steps used for UAV control systems and object detection are presented. In the third chapter, the results of the image processing techniques and the human recognition system, and artificial intelligence improvements on the system design are presented. In the last section, the obtained results are interpreted.

2. SYSTEM MODEL

In this study, firstly, the control system of the UAV was designed. Then, image processing techniques were applied to the data coming from the camera. At the end of the image processing steps, the object was detected and an algorithm was created that allows the UAV to land next to the object.

In the designed algorithm, firstly, it is expected that the user enters the physical properties of the object to be detected into the UAV control computer. Then, the departure and fixed flight information are transmitted to the UAV within the route defined with the ground station software. Then, the images taken from the UAV camera are processed simultaneously with the fixed flight and scan the object that the user wants to be detected. The UAV continues its stable flight until the object is detected. After the detection process, artificial intelligence-assisted image processing techniques are used. If there is no risk of an accident in the landing zone and no person can be detected, the UAV makes a landing near the object with the ground station software commands.

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2.1. UAV Control System

Ground station software is needed to enable the UAV to move automatically. In this study, Mission Planner with open-source code was used as ground station software. The program's support for Ardupilot and its wide and clear user interface were the main factors in its selection. In addition, tracking altitude changes, speed, GPS (Global Positioning System) position, the current supplied by the battery, and amount of usage during a flight are the features that make Mission Planner stand out. The analysis of the data received during the flight is provided, and optimization processes are carried out over the algorithm written using Python and the drone kit library. Thanks to the flight plan recording feature, possible errors are solved and diversity is offered with different map supports, especially Google Maps. Mission Planner has multiple flight modes. Among these flight modes, the most optimal one can be set.

Figure 1. A flight route set in the Mission Planner application on the DPU campus.

In addition, the problem that may occur during autonomous flight can be intervened through the program. In addition, a possible accident can be prevented with the Failsafe mode.

In the UAV control system, a flight route should be selected for the desired mission and scanning area. In this study, a flight route was determined on the campus of Kutahya Dumlupınar University (DPU), as seen in Fig. 1. This system, which provides control of the UAV whose flight route is determined, also makes the necessary interventions (landing, take-off, fixed flight, etc.) in its movements within its route.

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2.2. Image Processing Techniques

In line with a specific mission, UAVs may need to perform various tasks such as detecting an object and determining its location of the object. The image processing techniques used in the system designed to perform these operations with a high success rate were examined in two groups. The data obtained by the image processing techniques used in the algorithm is transmitted to the UAV control unit, and the UAV is directed autonomously. The system, designed using the Python software language, uses the open-source OpenCV library. The designed algorithm is embedded in the Nvidia Jetson Nano microcontroller board. This microcontroller performs image processing and deep learning techniques in line with the desired task. The obtained data is transferred to the basic units of the UAV (flight control card, ESC, engine, battery).

2.2.1. Image processing steps used for object detection

The first step of image processing is the application of the Gaussian function to the image in Figure 2 taken from the UAV camera. The picture smoothing effect of this function blurs an image similar to an average filter, and this degree of correction is determined by the Gaussian standard deviation [15]. First, the weighted average per selected kernel (9x9 matrices with pre-valued values) is obtained. The weight increases as it gets closer to the center pixel value. This makes a better correction than other filtering operations such as the average filter [7].

Figure 2. Object image taken from 5m height with UAV camera.

The next step is to change the color space. Processing the image in RGB (Red-Green-Blue) color space is very difficult and slow. In order to change the color intensity of an image, firstly, after reading the red, green, and blue color intensities from the image, changes can be made to it. Faster and easier processing can be done by using a different color space for the intensity and color formats of the image. In this way, the image can be processed faster and the operation of the algorithm can be

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accelerated and the processing time can be reduced. The color space used in this direction is defined as HSV (Hue Saturation Value), hue, saturation, and brightness. Obtaining HSV values from RGB values is provided by the following equations.

$$h = \begin{cases} 0°, & if max = min \\ 60° \times \frac{g-b}{max-min} + 0°, & if max = r \text{ and } g \geq b \\ 60° \times \frac{g-b}{max-min} + 360°, & if max = r \text{ and } g < b \\ 60° \times \frac{b-r}{max-min} + 120°, & if max = g \\ 60° \times \frac{r-g}{max-min} + 240°, & if max = b \end{cases} \tag{1}$$

$$s = \begin{cases} 0, & if max = 0 \\ \frac{max-min}{max} = 1 - \frac{min}{max}, & otherwise \end{cases} \tag{2}$$

$$v = max \tag{3}$$

H (hue) is the basic property of color and it is hue. It changes from 0° to 360° depending on its position on the standard color wheel. The higher the S (saturation) value, the more saturated the color is, and it ranges from [0 to 100%]. V (value) is called luminance or brightness and ranges from % 0 to 100.

In this study, the conversion process from RGB to HSV is performed and the desired color range is selected. The process was carried out for the objects in 3 different colors in Fig. 2. In order to test the stable operability of the system, objects with 3 different color ranges were used.

The UAV can make real-time changes between the colors in the received image. Thus, the user can select the object to be detected without any restrictions. In the algorithm, the absence of color limitation of the object to be detected provides easiness to the users. However, the color range and the background of the object must be distinctive. If the ground and object colors are the same, instabilities may occur in the object detection process. Excessively bright glass, snow, metal, etc. that may be on the ground surfaces can adversely affect the system stability. The most suitable solution against such situations is the appropriate selection of the color detection range and the color of the object.

After switching to HSV values, the image in Fig. 3 is masked. The UAV can make real-time changes between the colors in the received image. Thus, it enables the selection of the desired object to be detected.

The lower and upper limits of the determined color in the HSV color space are determined. Since the determined colors are in two different ranges in the HSV color space, filtering is done in both ranges and the color is determined according to the data obtained. The color to be determined here can be changed optionally and according to the range in the HSV space. The image of the object whose color is determined after masking is shown in Fig. 4.

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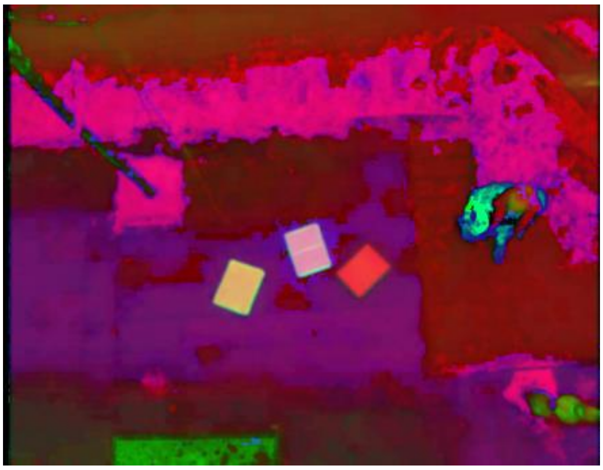

Figure 3. Image converted from RGB values to HSV values.

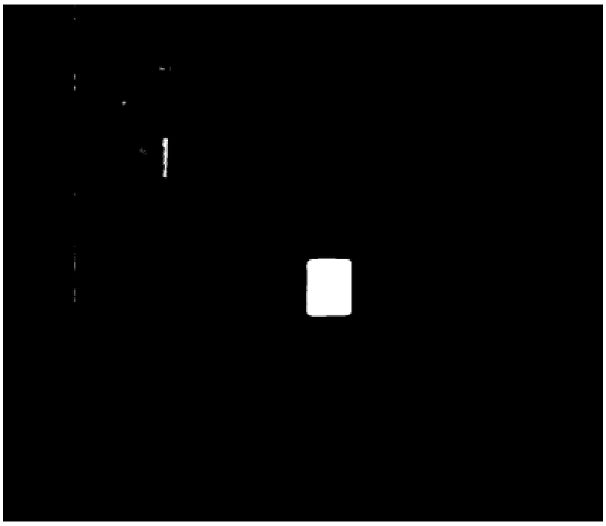

Figure 4. The image formed after masking.

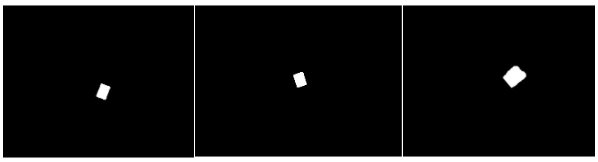

Figure 5. Applying Erosion and Dilation to the images formed after masking.

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The next step after masking is to create a contour. The concept expressed as a contour in image processing is a closed curve that connects all the continuous points that color or intensity has. Contour detection is an approach used for shape analysis, object detection, and recognition. When the contour operation is performed, there are points where the determined color intensity changes significantly. After subtracting all the contours from the binary image, the area, circumference, and circularity of the contours are calculated. The contour is removed if its circumference or circularity is less than the given threshold. Circularity is a characteristic parameter that indicates the complexity of the region shape and is calculated with the area and perimeter of the region as equations. In the contour subtraction equation below, A is the area and P is the perimeter.

$$e = \frac{4\pi \times A}{P^2} \tag{4}$$

Erosion and Dilation filters were used to remove most of the noises around the masking in Fig. 4 as in Fig. 5. With Erosion, etching is applied to the image. According to the parameters, the pixels in the specified area are abraded and the distorted image (noise) is cleaned. With the dilation process, the borders of the image given as input are expanded within the given area. Thanks to this enlargement, it is seen that the pixel groups get bigger and the spaces between the pixels get smaller.

Figure 6. Indication of the center of gravity of the detected object.

2.2.2. Functions created for tracking the detected object

In order for the algorithm to work without problems, it is first checked whether the calculated contour exists. It is possible that the factors that cause the contour not to appear are the factors such as excessive sunlight, a reflection of the light from the snow hitting the camera, and insufficient light on the object to be detected. For this reason, if no object can be detected in the algorithm, a notification is sent to the control unit of the UAV, the altitude distance is reduced at 1-meter intervals and descent is provided up to 5 meters. If no object has been detected yet, the UAV continues on the route automatically set by the Mission planner. In the scenario where the object is detected, the image moment of the detected contour is taken. Image moment is the weighted average of image pixel densities, which gives properties such as the image's radius, centroid, etc. Finally, this calculated center is designated as a point and followed up to that point.

Detection of 3 different colored objects was detected as seen in Fig. 6. The centers of gravity of the detected objects were determined [13]. The image is divided into 9 in order to follow the object whose center of gravity is detected. It is ensured that the object is located in the middle of the image divided into 9 (5th region) and that it can continue its flight in that region with determination. As seen in Fig. 6, this algorithm evaluates the image position of the object after the object is detected and in case it is not in the center, it gives the flight command to the UAV in order to keep the image of the object in the 5th region. When the object remains stationary in the middle, the deep learning-based human recognition algorithm described in the 3rd section is activated and it is checked whether there are people in the area where it will land. If there is no person in the image, the UAV control system is directed so that the UAV can land at intervals of 1 meter to 10 meters.

3. TEST RESULTS

In order for the UAV to land safely on the ground, it is necessary to conduct environmental control. As a result of processing the images taken by the camera on the UAV, it is examined whether there is a human in the image. In the absence of a human, a landing command is given to the UAV flight control system. In the case of a human, it remains stationary in the air. A deep learning-based human recognition algorithm has been designed to perform these operations.

For object detection and recognition, the YoloV4-Tiny model of the YoloV4 module, which is a deep learning architecture, which is frequently used in the literature, was used. The YoloV4-Tiny model uses the Darknet architecture to classify the types of objects. The Google colab platform, which offers ready-made programs such as NumPy, pandas, and matplotlib for machine learning, GPU, CUDA, CUDNN, Python, and data analysis, has been used. First, the cloning and installation processes of the Darknet architecture were performed on the platform. Here, the OpenCV and matplotlib libraries are installed.
Images recorded by the UAV camera were used for the object to be recognized. For the training, 1200 photographs out of 1600 photographs were used. The photographs were labeled in Yolo format using the LabelImg program and files in .txt format were created. In these text files, there are 5 numerical data including the class of the selected object in the photo, x value, y value, height, and width. 960 of the images were transferred to the training file and 240 to the test file. The train and test files, which contain the photos and the information of the object to be detected, have been converted to .txt format. Then, the deep learning layers used for YoloV3, a pre-trained convolution layer, were downloaded to Google Colab [16, 17].

In this study, training was applied to 216256 images. As seen in Table 1, the lowest success rate is 84%, and the average success rate is 93%. Human recognition accuracy rates on various photographs are shown in Fig. 7. Finally, the models trained in Google Colab were run in real-time via the PyCharm module with the necessary config, last weight files, and the Anaconda program.

Table 1. Detection rates of deep learning-based human recognition system in various images.

	Number of People	Minimum Human Detection Rate	Average Human Detection Rate

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Fig. 7	3	%99	%99
Fig. 8	4	%84	%95
Image A	4	%87	%89
Image B	5	%88	%92
Image C	2	%91	%93

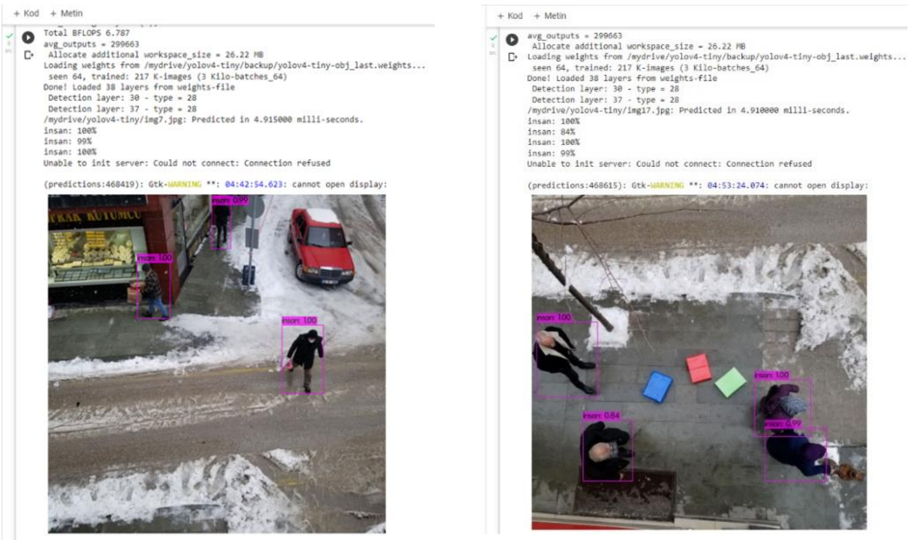

Figure 7. Application of deep learning-based human detection to UAV imagery.

4. CONCLUSION

In this study, object detection was performed by applying image processing steps on the data received from the camera of the UAV moving in a certain flight route. An algorithm has been designed so that the UAV can land at the location of the detected object. Moreover, a deep learning-based human recognition system that can be applied to UAV camera images has been realized. As a result, the autonomous guidance system algorithm design for UAVs with image processing techniques has been successfully applied. It is considered that being autonomous has the advantage of reducing processing time, expenses, and manpower. Furthermore, human-caused failures and potential risks are decreased. Finally, it gives the user flexibility because the designed system allows for changes to the attributes of the object to be detected.

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