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Selecting the Visual Landing Markers Located on a Ship Deck for UAV Automatic Landing

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Abstract

Of all the flight modes of unmanned aerial vehicles (UAVs), the landing approach and the landing itself are the most difficult and dangerous ones. To perform an automatic landing on a ship deck using a computer vision system (CVS), a UAV must analyze the visual landing markers located on the deck. When the UAV is about to start landing, these markers must be clearly visible and discernible. The aim of this study is to detect markers in order to build a trajectory taking the UAV to an imaginary boundary of a heterogeneous group of ships that includes the target ship. The cutting-edge method of solving this problem consists in running tests identifying the optimal conditions for a successful search for and recognition of landing markers installed on a ship deck. The experiment covers eight types of markers. The research findings back the efficiency of the developed technology for the computer vision-aided detection by UAVs of visual markers located on a ship deck. Of the eight possible types of landing sites, the one was chosen that demonstrated the best detection and recognition capabilities. Research has proved the efficiency of the proposed algorithms for solving this problem. Unmanned aerial vehicles were used as a tool for designing and building a system for the automatic detection of artificially embedded markers on images supplied by the UAV on-board electro-optical system.

Keywords: Unmanned aerial vehicle, landing on a ship, landing markers, visual markers, color-based recognition scheme, detection.

INTRODUCTION

Of all the flight modes of unmanned aerial vehicles (UAVs), the most difficult and dangerous one are the landing approach and the landing itself. It is due to the challenges associating with the control of a UAV during landing, which escalate in poor visibility when visual orientation is restricted or impossible. Apart from that, a landing UAV causes the most crashes as the device is harder to control due to the short duration of the landing process.

Currently there are no commercial systems on offer allowing the automated selection of landing sites for an unmanned aerial vehicle descending on a moving ship. The existing automatic landing systems are based on the Global Positioning System (GPS), radio direction finding systems or other external 3D positioning systems that require the installation of special equipment on the landing site.

To perform an automatic landing on a ship deck using a computer vision system (CVS), a UAV must analyze the visual landing markers located on the deck. When the UAV is about to start landing, these markers must be clearly visible and discernible. The recognition of landing markers can be hampered by weather conditions such as the rocking of the ship, change of the bearing depending on the wind direction, etc.

LITERATURE REVIEW

An on-board computer vision system is intended to help detect and recognize objects as well as guide and navigate aircrafts by ground reference [1, 2, 3] in uncertain or variable observing conditions. The decisions related to the detection or recognition of objects (or references) are based on comparing the obtained images with the object descriptions outlined in corresponding feature dictionaries or through references loaded into the computer vision system [4, 5, 6, 7, 8].

The objects used as markers for optical navigation are required to have a low computational cost of detection and recognition, high sighting accuracy, tolerance of the change of view angle and lighting, resistance to seasonal changes, and a wide range of altitudes at which this category of markers can be used [9].

The search for and the identification of the sought-for object, the recognition of visual landing markers (signs) can be performed through isolating a certain set of features [10, 11]. The book [10] offers different correlation algorithms that can be used to detect and recognize landing markers. The studies [11] provide a detailed review of image and video processing algorithms, including the ones used for searching for, recognition and measurement of the coordinates of various objects of search.

If at the time of making a decision about landing the UAV is outside the operator-controlled area, it is necessary to choose a convenient landing area. The paper [12] suggests equipping the runway with linear markers with predefined parameters, akin to road marking, but it does not examine the problem of landing a UAV on a ship with a limited-size landing area.

For the automatic detection, recognition and tracking of markers in the UAV electro-optical system during take-off and landing, the papers [13, 14] suggest using a marker geometry-based recognition algorithm [13, 14] and utilizing artificial neural networks. The paper [15] considers algorithms for the automatic selection of landing sites and the possibility to test these data through the automatic landing of a UAV on a specially appointed landing pad. These methods can be applied to the automatic landing of a UAV on a terrain compartment, without taking into account the specifics of a moving ship studied in this paper.

Depending on the selected algorithm, the position of the object can be determined by the coordinates of its minimum bounding rectangle, or by the outline of that object, or the coordinates of the points that are most characteristic for the object. The solution to the problem of object detection creates an opportunity for analyzing the qualitative composition of the scene depicted on the image and establishing the relative positions of the objects. The study [16] reviews some motion detection algorithms, which consist in identifying moving objects based on several images or video frames of the same scene. The template-based object detection method implies having an image of the object with highlighted features – a template – and a test image that is being compared to that template. The result of this comparison is the similarity measure. If this measure exceeds a predefined threshold, then the test image is considered the image of the object.

The paper [17] considers empirical methods of comparing the efficiency of boundary detectors and image segmentation algorithms; it also examines the quantitative assessment criteria used for the comparison.

The aforementioned studies tend to leave a possible change in the bearing or speed of a moving ship out of the equation when looking for ways to detect markers in order to build a landing path for the UAV; nor do they help choose out of the numerous available markers the one which would be best recognized by the computer vision system installed on the UAV.

MATERIALS AND METHODS

The problem of selecting the landing marker for a UAV using computer vision has been solved experimentally, with the details of the experiments given below.

The research included:

- recognition of landing markers;
- measurement of the positions of color-based markers on the ship deck (with due consideration for the rocking parameters) in order to calculate the landing path.

The results of the study can be used for automatic landing of UAVs and can help find and identify markers on a ship deck.

Various color-based recognition schemes were pilot-tested to find out if they can be applied for marker detection by UAVs.

Let us look closely at a UAV flying into the visual marker search area. We will assess the efficiency of different markers with different color schemes in terms of their potential to be recognized as landing sites by a UAV computer vision system.

The proposed algorithm was tried out experimentally against the images obtained from the electro-optical system installed on a UAV. Figure 1 depicts a UAV reaching the vicinity of a landing marker located on a ship deck.

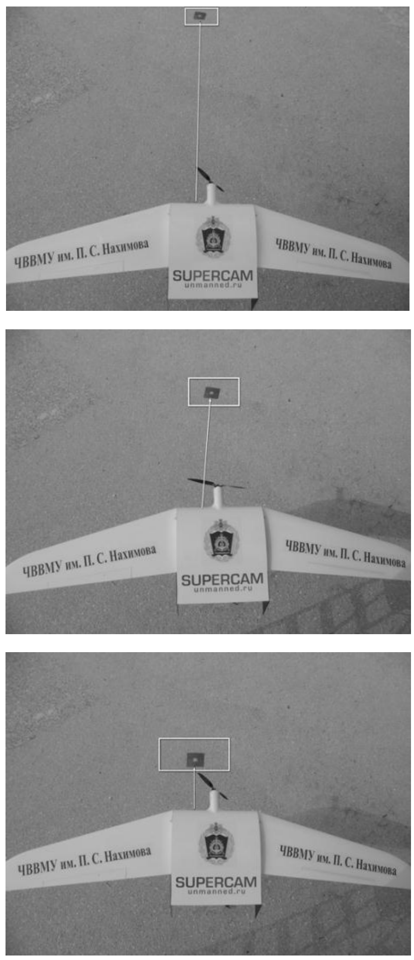

Figure 1: The process of the UAV approaching the landing marker area

The quality of detection was evaluated against a certain set of ground truth reference data with a given number of detection frames, which have been gathered empirically, via direct observation. This approach to estimating software quality is called the discrepancy method [18, 19].

The detection algorithm is as follows:

1. Convert the RGB color space into HSV.

With 8-and 16-bit RGB images, the values of R, G and B are converted into a floating point value in the range of [0;1].

2. Find points that belong to the predefined HSV range.

The H, S and V values are assigned lower and upper limits, then each point of the image converted into the HSV color space is checked to see if its parameters fall into the set range.

3. Dilate the objects in the image.

The dilation function zooms in on the objects in the image using a structuring element that examines the window surrounding each given pixel and selects the maximum value.

4. Erode the objects in the image.

The erosion function zooms out on the objects in the image using a structuring element that examines the window surrounding each given pixel and selects the minimum value.

5. Determine the outline of the image.

Let us denote the original image as

$$F = \{f_{ij}\}$$

Let us set NBD (the outline index) to 1.

Let us go through the image one line after another and check all pixels for which the following is true:

$$f_{ij} \neq 0$$

Each time we start at a new line, we will reset LNBD (the outline index in the current line) to 1.

(1)Let us choose one of the following:

a. If $f_{ij} = 1$ and $f_{i,j-1} = 0$, then the pixel (i,j) is on the left edge of the outline followed by the right edge of the outline, in which case we will increment NBD and do the assignment $(i_2,j_2) \leftarrow (i,j-1)$.

b. Alternatively, if $f_{ij} \geq 1$ and $f_{i,j+1} = 0$, then the pixel (i,j) is on the left edge of the outline following by the first point in the inner space (which in its turn can contain other outlines), in that case we will increment NBD and, provided that $f_{ij} > 1$, will assign $LNBD \leftarrow f_{ij}$.

c. Otherwise go to (4).

(2) Depending on the types of identified edges and the edge with the index LNBD, we will determine the parent of the current edge according to Table 1.

Table 1: Edge detection

Edge B \ Edge B’	Outer edge	Edge of the inner outline
Outer edge	Parent edge of edge B’	Edge B’
Edge of the inner outline	Edge B’	Parent edge of edge B’

(3) Starting from the initial point (i,j), we will iterate along the outline:

a. Starting from (i_2,j_2), check the pixels around the point (i,j) and find a non-zero pixel. Suppose (i_1,j_1) is the first non-zero pixel. Having found the non-zero pixel, assign NBD to f_{ij} and proceed to (4).

b. $(i_2,j_2) \leftarrow (i_1,j_1)$ and $(i_3,j_3) \leftarrow (i,j)$

c. Starting from the element next to (i_2,j_2) counter-clockwise, check the pixels in the vicinity of the current pixel (i_3,j_3) in order to find the non-zero pixel. Suppose the first matching one is (i_4,j_4).

d. Change the value f_{i_3,j_3} of the pixel (i_3,j_3) according to the following rules:

i. If the pixel (i_3,j_3+1) is a zero pixel in step (3.a), then $f_{i_3,j_3} \leftarrow -NBD$.

ii. If the pixel (i_3,j_3+1) is a non-zero pixel in step (3.a) and $f_{i_3,j_3} = 1$, then

$$f_{i_3,j_3} \leftarrow NBD.$$

iii. Otherwise leave f_{i_3,j_3} unchanged.

e. If $(i_4,j_4) = (i,j)$ and $(i_3,j_3) = (i_1,j_1)$, then proceed to (4); else $(i_2,j_2) \leftarrow (i_3,j_3)$, $(i_3,j_3) \leftarrow (i_4,j_4)$ and go back to (3.c).

(4) If $f_{ij} \neq 1$ then $LNBD \leftarrow |f_{ij}|$ and carry on the line-by-line iteration of pixels starting from $(i, j+1)$. The algorithm stops as soon as it reaches the right-bottom corner of the image.

6. Approximation of a polyline to the required level of accuracy.

This is implemented using the Ramer-Douglas-Peucker algorithm that allows finding a line with fewer points similar to the approximated one with a larger number of points.

RESULTS

The quality of detection is measured as the ratio of the number of frames where the object was detected to the total number of frames.

$$Q = \frac{fr}{Fr} * 100\%$$

Q – quality of detection;

fr – number of frames where the object was detected;

Fr – total number of frames.

The study presents the results of the comparative analysis of standard (cross, circle) and color-based recognition schemes.

COLOR-BASED SCHEMES AND THEIR RECOGNITION

A. BLACK CROSS ON THE WHITE BACKGROUND

The first sample of a color-based marker was a black cross on the white background (Figure 2). The initial dimensions of the marker were 1.5x1.5 m.

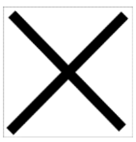

Figure 2: Black cross on the white background

The idea was to detect the crossing lines and, based on their visible length and known dimensions, establish the distance. However, the video footage contained numerous lines of that kind, and filtering them out by their length was not feasible. Besides, sun flares would split the lines, which further increased the number of false detections. Consequently, the detection rate for the first color-based marker was poor (Figure 3).

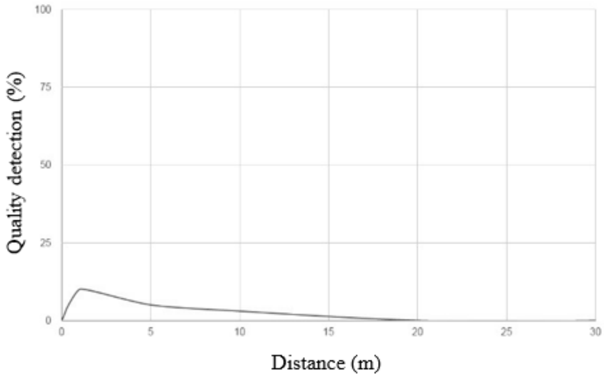

Figure 3: Color-based scheme detection results (Figure 2)

B. BLACK CIRCLE WITH A LINE ON THE WHITE BACKGROUND

To mitigate the numerous false detections of the first color-based marker, it was decided to use geometric shapes. One of the options is a circle (Figure 4).

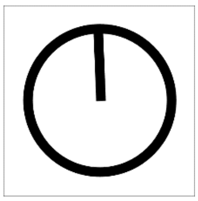

Figure 4: Black circle with a line

This marker helps solve a related problem of determining the rotation angle of the landing site to the UAV. For that very purpose, the line was drawn from the center of the circle towards its margin.

When used against the circle, the search algorithm demonstrated very good results at altitudes up to 10 mand fairly poor ones at altitudes above 10 m, with the dimensions of the color-based marker being 1.5x1.5 m (Figure 5).

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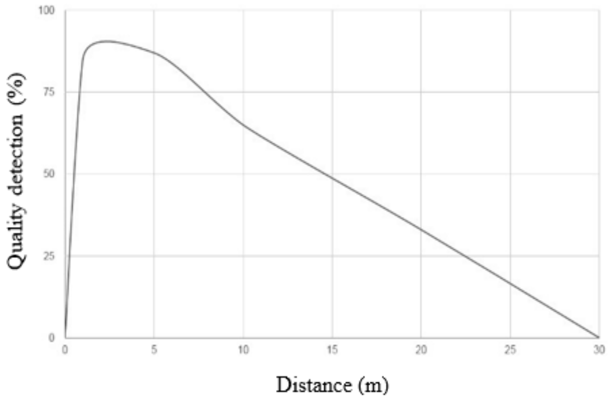

Figure 5: Color-based scheme detection results (Figure 4)

Virtually no false detections and consistent results regardless of the flares on the surface of the landing site. The distance was calculated based on the area of the detected circle given its predefined dimensions. The angle was calculated based on the direction of the line. Since the line was being located inside the previously detected circle, false detections were ruled out.

This method of marker detection requires high computational resources. Its preliminary stage was associated with limited performance.

It is worth noting, that detection of geometric shapes still seems promising unless the detection is performed at a high altitude or from a large distance. Within this scope, there is still room for testing markers similar to QR codes.

C. PURPLE SQUARE WITH A LINE

To secure a better detection at a high altitude and improve performance, the chosen sample had to a solid-color shape with a white line from the center to the edge (Figure 6).

Figure 6: Purple square with a white line

The purple color was chosen as the least typical one for a ship deck. The distance was being calculated based on the area of the outline of the detected purple shape given its predefined dimensions. The angle was being evaluated inside that outline.

The altitude measurement algorithm worked well for altitudes between 1.5 m and 20 m. The lower limit can be explained by the fact that at the specified altitude the landing site fills the entire camera screen, so measuring altitude is impossible. At the upper limit, the landing site fits into less than 20x20 pixels on the processed image, so detection becomes a problem (Figure 7).

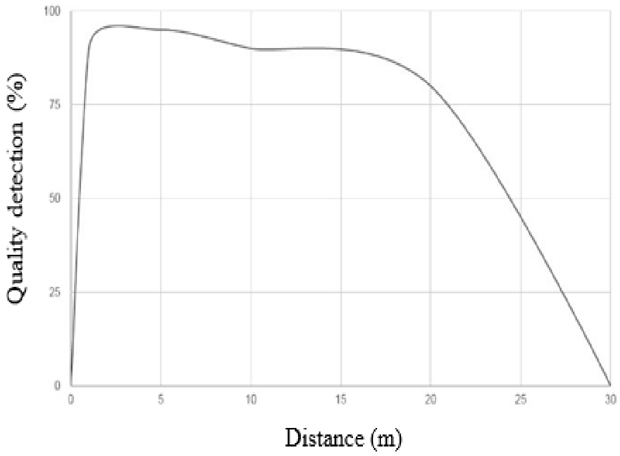

Figure 7: Color-based scheme detection results (Figure 6)

The upper limit seems to be acceptable as it is assumed that at that altitude the landing will be aided by the magnetometer, including for ships with a metal deck. At the same time, the lower limit of 1.5 m was too high.

Moreover, measuring the rotation angle at a high altitude was not possible as the white line was completely lost.

D. PURPLE SQUARE WITH A WIDENING WHITE LINE

To solve the problem of measuring the rotation angle at a high altitude, it was suggested to widen the white line (Figure 8).

Figure 8: Purple square with a widening line

It allowed measuring the angle at the upper limit of the algorithm, yet it deteriorated the overall accuracy of the angle measurement causing the value of the angle to fluctuate within a wide range (Figure 9).

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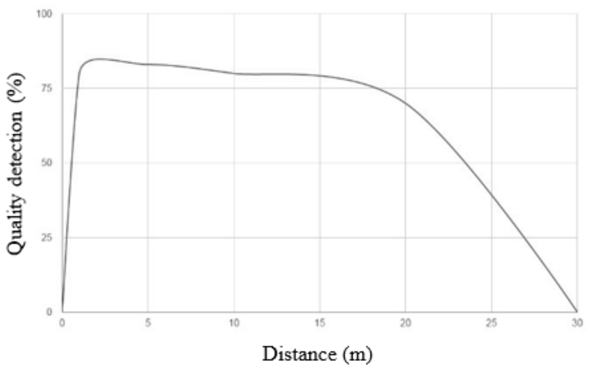

Figure 9: Color-based scheme detection results (Figure 8)

E. GREEN SHAPE INSIDE THE PURPLE SQUARE WITH A WIDENING LINE

To lift the lower limit of 1.5 m, a new landing mark was tested, which looked like a purple square with a widening line from the center to the edge, with a green square inside (Figure 10).

The idea was to measure the distance above the landing site and, based on its value, the detection algorithm will switch to a smaller, green square.

Figure 10: Green shape inside the purple square with a widening line

With this configuration the detection improved at lower altitudes in the range of 0.5 m to 1.5 m. However, at medium altitudes and near the upper detection limit, the presence of the green square interfered with the detection of the purple square (Figure 11).

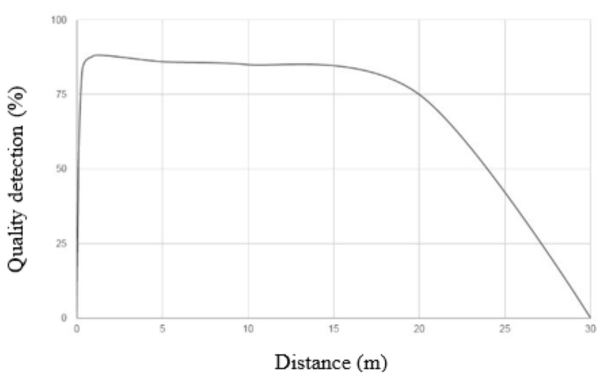

Figure 11: Color-based scheme detection results (Figure 10)

F. AN OFF-CENTER GREEN SHAPE SHIFTED DOWN INSIDE A PURPLE SQUARE WITH A WIDENING LINE

To eliminate the interference of the green square in the detection of the purple one, the green square had to be shifted down (Figure 12).

Figure 12: An off-center green shape shifted down inside a purple square with a widening line

This offset did make a difference, and the purple square was now detected quite well in the range between the medium to upper altitudes, and the green one was detected at low altitudes, 0.5 to 1.5 m (Figure 13).

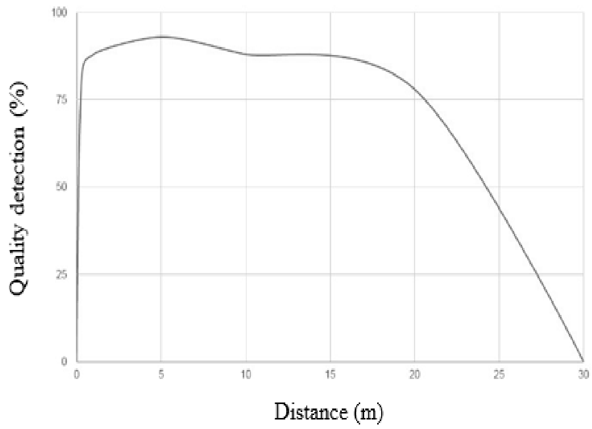

Figure 13: Color-based scheme detection results (Figure 12)

G. GREEN SQUARE INSIDE A PURPLE SQUARE

Upon obtaining the test results for the sixth marker sample, a decision was made to change the way the UAV was controlled during the automatic landing. Previously, the shape had to be shifted in order to move the UAV, now it can be controlled through changing either the bank angle or pitch angle. This control mode bypassed the need to measure the rotation angle to the landing marker, which would require turning the camera in such a way that its rotation angle matched the bearing of the UAV. Consequently, the marker had to look like a green square centered inside of a purple square (Figure 14).

Figure 14: Green square inside a purple square

With the new control mode, this color-based landing marker produced excellent results (Figure 15).

Now the UAV was able to maintain a consistent "grip" on the color-based marker.

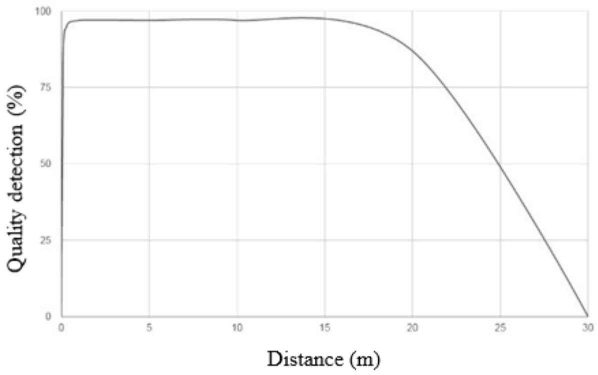

Figure 15: Color-based scheme detection results (Figure 14)

H. FINAL VERSION

To further improve the marker detection rate, the seventh version was amended in the following way:

A yellow square was introduced inside the green one, for detection at an altitude less than 0.5 m;

To increase the upper detection limit, the color-based marker was scaled by the factor of 1.5, so now the dimensions of the shapes became 2.25x2.25 m for the purple square, 0.5625x0.5625 m — for the green square and 0.140625x0.140625 m — for the yellow square (Figure 16). The yellow and green colors were introduced to help detect the marker at lower altitudes.

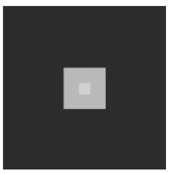

Figure 16: Yellow square inside a green square located inside a purple square

The best detection rate was achieved with the final version of the marker, namely the yellow square inside the green square, which it turn was inside the purple square (Figure 17).

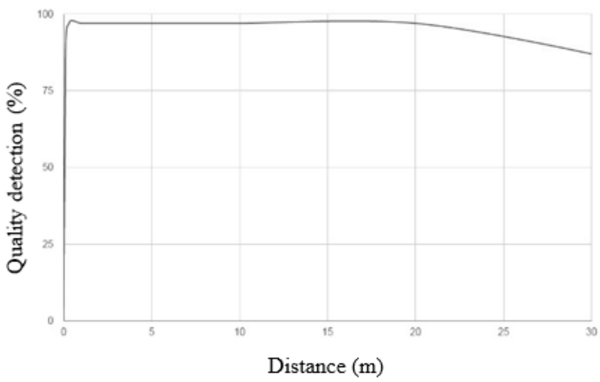

Figure 17: Color-based scheme detection results (Figure 16)

Figure 18 depicts the aggregated results of the conducted tests.

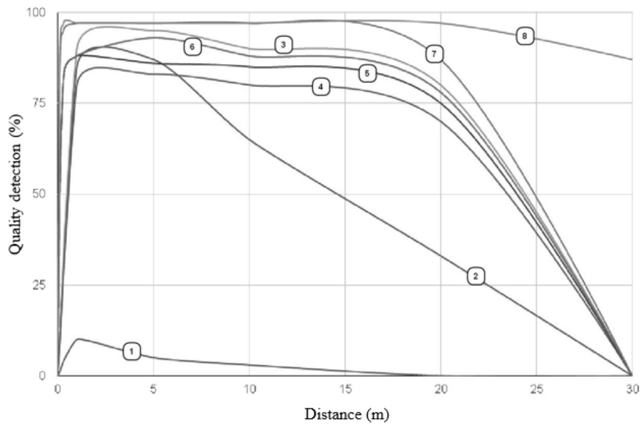

Figure 18: Aggregated test results:

1 – a black cross on the white background

2 – a black circle with a line

3 - a purple square with a white line

4 – a purple square with a widening line

5 – a green shape inside the purple square with a widening line

6 - an off-center green shape shifted down inside a purple square with a widening line

7 – a green square inside a purple square

8 – a yellow square inside a green square located inside a purple square

The data are provided at the points of 1, 5, 10, 20 meters for the later versions. Also, the additional points of 0.5 m and later 0.25 were introduced for the measurements. With the exception of the final version, no data were acquired for altitudes above 20 m, so at the point of 30 m, the lines on the graph stand to zero. The intermediate values were calculated for the differentiable function.

DISCUSSIONS

Let us examine the data acquired in the course of these experiments and draw conclusions as to how efficient landing markers are in assisting UAVs during landing.

The results of the experiments with various markers used for the landing of UAVs have shown that the eighth marker version presents an opportunity to introduce changes into the process of UAV control during the automatic landing. Previously, the shape had to be shifted in order to move the UAV, now it can be controlled through changing either the bank angle or pitch angle. This control mode bypassed the need to measure the rotation angle to the landing marker, which would require turning the camera in such a way that its rotation angle matched the bearing of the UAV. Consequently, the marker had to look like a green square in the center of a purple square with an addition of a yellow square.

Therefore, having run the tests to justify the optimal look of a marker for the automatic landing of a UAV on a ship deck using a marker-detection computer vision system, it is reasonable to say that the eighth marker fits the purpose best as any changes in the distance make an insignificant impact on the quality of detection unlike all other considered markers.

CONCLUSION

1. The conditions have been defined for the successful detection of markers searched for by a flying UAV.
2. An experiment has been conducted to justify the optimal look of a marker for a UAV landing on a ship deck.
3. It has been demonstrated that by altering the look of the marker it is possible to change the UAV maneuvering algorithm during its automatic landing on a ship deck.

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