Safety & Defense 9(2) (2023)
DOI: https://doi.org/10.37105/sd.203

The use of UAV in PAPI system inspections

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Received: 27 July 2023 | Revised: 20 December 2023
Accepted: 20 December 2023 | Available online: 23 December 2023

Abstract

This article discusses the purpose of aeronautical approach lights for landing and describes the operation of the most popular visual system. In addition, an exemplary schedule describing the periodic verification that the PAPI system must undergo has been presented. The hitherto method of carrying out the verification of indications was discussed, as well as the proposed innovative method of carrying out the verification using an UAV (unmanned aerial vehicle), where its general solution concept was described.
Moreover, the structure and operation of the program responsible for the autonomous light detection of the PAPI system and verification of their indications were discussed. A simulation was carried out using the available recordings, and then the results were described.

Keywords: inspection, PAPI lights, unmanned aerial vehicle, vision system

1. Introduction

The most critical phases of a given flight, from the pilot's mental stress point of view, are the approach and landing of the aircraft. In order to make it easier for the pilot to maneuver the aircraft in the above-mentioned flight phases, ground support systems of various degrees of sophistication are used. One of the basic facilities is the PAPI (Precision Approach Path Indicator) lighting system. These visual indicators can provide pilots with information about the airplane's deviation from the correct approach path.

Visual lighting systems are commonly used at communication airports; therefore, it is necessary to check the correctness of their indications periodically. The verification of indications is divided into ground control carried out by technical services, and air control, carried out at least once a year, by an institution authorized by the CAA (Civil Aviation Authority). The use of an aircraft for the verification and validation of the indications very often requires redirecting the aircraft to other airports and shutting down the device for the duration of the procedure. Very often, this time can last several hours. As a result, the search for a substitute has started as it would help reduce the existing requirements of the method of conducting the flight of visual aids.

An alternative may be the use of unmanned aerial vehicles in the form of multirotors equipped with a vision system. It is an innovative way to verify the indications of systems facilitating the approach to landing. Due to the much lower costs, it can be an alternative to the currently used method.

The main objective of the study, using the developed software, was to verify whether it would be possible to use the UAV-mounted vision system for the purposes of checking the correctness of the PAPI light indications in a more automated manner than is already the case.

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This article presents the purpose of air traffic lights during the approach to landing and their principle of operation. Moreover, the hitherto method of verifying the indications of PAPI units and its alternative was explained, where the general solution concept, the proposed image processing technology, the verification of PAPI system objects, and color identification were discussed. The vision system mounted on the unmanned aerial vehicle as a platform is able to verify the PAPI system indications.

2. The purpose of aeronautical approach lights for landing

The main factors affecting flight safety during the approach and landing phases are:

- atmospheric conditions,
- the lie of the land,
- the time of operations and lighting equipment of the airport.

The influence of unfavorable meteorological conditions, such as vertical and horizontal wind shear, approach speed and the spatial position of the airplane, will cause altitude changes and additional pilot load, respectively. The presence of cloud cover, rain and fog will have a negative impact on the visibility of the runway, which may result in the illusion of an overly high landing approach or a complete loss of runway visibility from the field of view (Flight Safety Foundation, 2006). The lie of the land has a significant impact on safety during the approach, as shown in Figure 1.

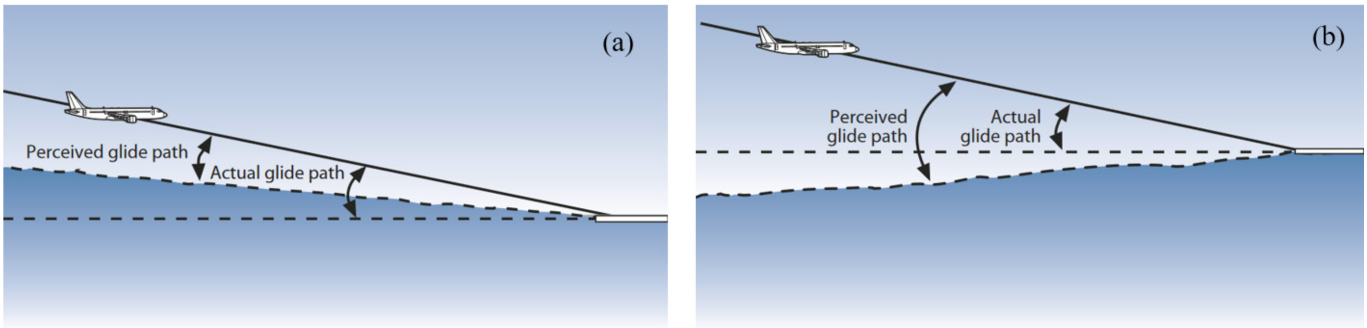

Figure 1. The phases of an airplane's approach to landing in various terrain: (a) – negative land slope (b) – positive land slope. Adopted from: "Fast, Low Approach Leads to Long Landing and Overrun" by Flight Safety Foundation.

In Figure 1 (a), the airplane is shown in the approach phase to the aerodrome with a negative land slope. The negatively inclined ground gives the illusion that the plane is at an angle that is too small for the flight path. Correcting this by reducing the descent speed, the pilot may land too late, and a missed approach procedure will be required. In Figure 1 (b), an analogous situation is shown and in this case, an airplane approaching the terrain with a positive land slope. The positively tilted ground gives the illusion that the plane is at too large a flight path angle. By introducing a correction in the form of an increased descent speed, the pilot may lead to a premature touchdown of the plane outside the runway area or hit obstacles in front of the runway (Pasek, 2006).

3. The visual approach slope systems

The visual approach slope indicating systems are designed to transmit information to the pilot remotely, based on a specific color of a given unit of the system. Thanks to this information, the pilot is able to keep the controlled aircraft at the correct height and distance from the airport. The requirements for airport visual aids are established by the rules of the international organization ICAO (2018*).*

Currently, the most common light indicator systems used at international airports are the PAPI (Precision Approach Patch Indicator) and VASI (Visual Approach Slope Indicator) systems. In addition, the visual light indicators include the PLASI (Pulse Light Approach Slope Indicator) systems, mainly used for helicopter traffic, and the OLS system (Optical Landing System), which has found its use on aircraft carriers.

The standard PAPI light system consists of four or eight units arranged in a row, located near the theoretical touchdown point, perpendicular to the runway axis, as shown in Figure 2.

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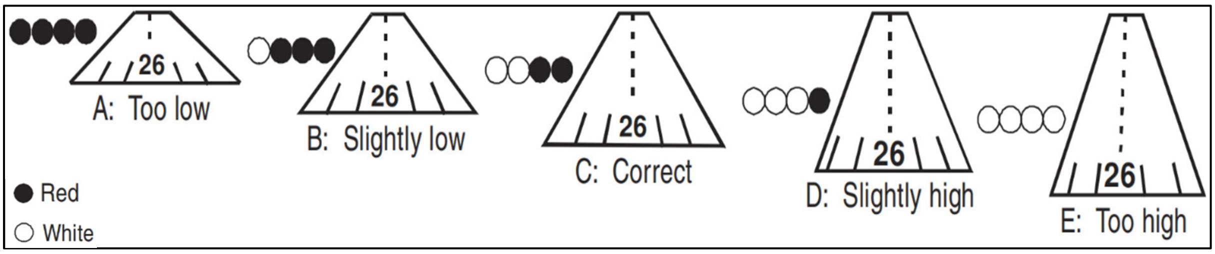

Figure 2. Scheme of interpretation of PAPI light system indications. Adopted from: "Airport Lighting Aids" by FAA.

Light indications with four PAPI units are interpreted as follows:

- Four white light units mean the pilot is well above the correct glide path;
- Three units of white light and 1 unit of red light indicate that the pilot is slightly above the correct glide path;
- Two units of white light and two units of red light mean the pilot is on the correct glide path;
- one unit of white lights and three units of red light means the pilot is slightly below the correct glide path;
- 4 red light units mean the pilot is well above the correct glide path.

The light units of the PAPI system work independently of each other, while their angular settings must be correlated with each other. The different values of the angle of inclination of each of the units cause the pilot to receive different visual information depending on the position in relation to the desired glide path. The standard angular difference of the PAPI system between successive light units for a standard descent angle of 3 [°] is 20 ['], as shown in Figure 3.

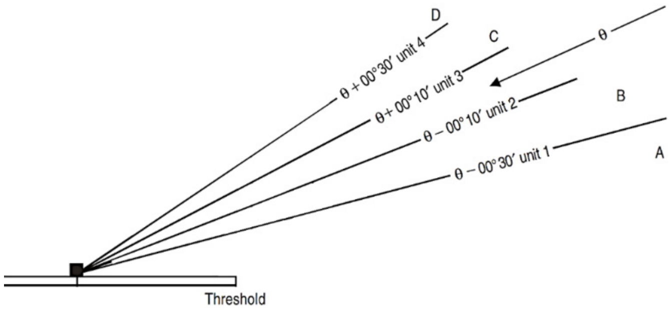

Figure 3. Diagram of angular settings of PAPI units

4. Verification and maintenance of the correct operation of the PAPI system

In order to ensure the continuous efficiency of the systems and their unambiguous indications, it is necessary to carry out periodic inspections.

Verification of indications and correct operation of the PAPI system is divided into inspections carried out on the ground and inspections carried out from the air, in accordance with the introduced schedule. An exemplary diagram of the light control program is presented below (ICAO, 1984):

a) Daily:
- each optical system must be verified to check that it functions correctly, and in the event of burned-out light sources, it must be replaced;
- check whether there are any gross errors in setting the device, and if they have been detected, they should be corrected.

b) Twice a month:
- the angular setting of the PAPI unit should be verified, and if the value is outside the tolerance, correction should be made;
- The installed red filters, refractive glass and lamps should be verified to check that they are clean. In the event contamination has been detected; a cleaning process must be carried out.

c) Once a year:
- the entire assembly structure of PAPI units should be verified, and in the event of detected undesirable changes, it is necessary to perform appropriate repairs;

- the system should be verified from the air, and in the event of any deviations from the norms, recalibration should be carried out;
- the optical system should be checked, and if there are changes in the light intensity in the unit, then the light source should be replaced. If the optical part is damaged, the entire optical system must be replaced.

d) Off schedule:
- the indications and system settings should be checked after the occurrence of very strong wind, heavy snowfall or hail;
- the field of the indicator lighting should be checked to make sure that the visibility of the system has not been limited by tall grass or snowfall;
- if a new PAPI system has been implemented at the airport, the system should be verified from the air;
- the system should be verified from the air if the PAPI system has undergone significant modifications or renovation works;
- an inspection of indications and system settings should be performed at the request of the air traffic control or another authority and in the event of an accident or incident on the runway during the landing phase of the aircraft.

From the research point of view, the most important control of the system is verification of the indications from the air, because it is possible to check how visual aids are seen by pilots, which cannot be checked in the case of ground control.

In Poland, the state air traffic management authority PANSA (Polish Air Navigation Services Agency) is responsible for the inspection of ground devices and light navigation aids. The Beech craft B300 King Air 350i aircraft, popularly known as the “Parrot”, is used to perform inspections by the PANSA agency (Szpakowski, 2020a).

Usually, the light units are checked in the evening or at night. This is to verify the full range of the systems’ lighting intensity, greater accuracy of the test, and detection of elements in the unit’s lighting area that may affect the safety of air operations.

The verification of PAPI indications consists in making a series of approaches by the plane towards the runway on which the indicator lights have been installed. During the approaches, the lighting angles of the light unit are measured. For this purpose, measuring instruments installed on board the aircraft are used, which can also be used to verify the indications of the ILS system and other radio navaids. As the pilot descends and flies towards the installed indicators, he performs an oscillating flight, simultaneously observing the PAPI system indications. If a change in the color of the indicator is detected, the pilot notes it by pressing a dedicated button on the steering wheel. Knowing the position of the indicators and the position of the airplane, the measuring equipment determines the approach angle on which the airplane was at the time the pilot pressed the button. The aim is that about 15 measurements are recorded by the pilot during a given approach. An average result is obtained from the collected measurements, and then compared with the required values. To facilitate the pilots’ task during the approach, only one selected indicator of the PAPI system is turned on. If the measured angles are outside the tolerance range, the on-board inspector communicates with the ground service to make appropriate adjustments to the angular settings of the unit. After making the correction, the flight of the PAPI system is performed again. If the airport is equipped with the ILS system, the synchronization of the indications of both devices is also verified.

In addition to verifying the angle of the lights, the crew performs a flight perpendicular to the runway axis in order to verify the range of the system lighting in the horizontal plane. The light test procedure is performed until the measurement results are acceptable. During the inspection, continuous image registration is performed, which may supplement the final inspection protocol.

The measurement and control flight are a complicated logistic task both for the crew performing the measurement and for the air traffic controllers and technicians responsible for handling PAPI lights (Szpakowski, 2019).

5. The proposed solution for the use of unmanned aerial vehicles to verify the PAPI system

Considering the complexity and length of the verification process of the PAPI system, it is advisable to find a method that will simplify the entire control while maintaining accuracy and, if possible, minimize its costs. The test methods and their results are described in more detail below in the article.

The inspection period, when using the drone, is agreed with the air traffic control in order to select an adequate time period. The aim is to make flights in good visibility conditions, with low wind speed, both during the day and at night.

In addition to the basic equipment, the UAV should include: an accurate navigation receiver, a high-resolution vision system with an optical zoom, a transmission link that will allow receiving an image from the vision system, and an external image stabilizer. For the purpose of verifying of the PAPI system indications, it is best if the unmanned aerial vehicle was a multi-rotor, which would be a light and durable structure, easy to transport, resistant to weather conditions, i.e., rain, moisture, or strong gusts of wind. The more drive sources a multirotor has, the greater the stabilization of the measuring platform and, thus, the accuracy of the measurements. Therefore, it is recommended that the UAV be equipped with a minimum of four electric motors for inspection purposes.

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Currently, drones can be used by aviation services to verify visual devices. The condition is obtaining a specific permit from the national aviation authority (Szpakowski, 2020b). The obtained permit is to confirm the acceptability of the results provided using the drone and allow for such activity. An amendment to the international aviation regulations was introduced in 2021 (Doc. 9157, Aerodrome Design Manual, Part 4 - Visual Aids, 5th edition (Amendment 1, 07/12/2021), paragraphs 8.3.43 - 8.3.46), (CURSIR, 2022), it was stated that the multirotor, which complies with the provisions contained in the amendment, can also be used to inspect and validate the PAPI system from the air, without the need to use the aircraft.

The general concept of the solution is to check the correctness of the PAPI light indications using a drone and a vision system. At a certain distance, the drone would make a climb, with the Vision System pointing towards the units, so that they are always within the camera's field of view, as shown in Figure 4.

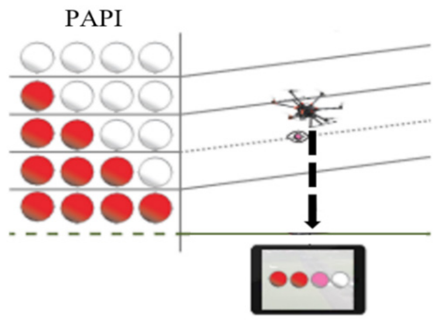

Figure 4. Diagram showing the operation of the vision system. Adopted from: "Airport Maintenance: PAPI Calibration at Paris-Le Bourget" by Elistair.

Then, the implemented software in the drone or the receiving station would be to autonomously determine the colors of the PAPI indicators in real time.

In order to obtain information about the approach angle at which the drone is currently located, it is necessary to know the geographical coordinates and the height of both the drone itself and the light units. In the case of the drone, these values can be obtained from the GNSS (Global Navigation Satellite System) receiver, while in the case of PAPI units, information contained in the AIP (Aeronautical Information Publication) can be used.

Knowing the geographic coordinates and AMSL (Above Mean Sea Level) altitudes of both devices, it is possible to calculate the horizontal *D* distance and the vertical distance *H*, between the devices. Then, using the trigonometric function, the angle of the approach path α on which the drone with the vision system is located is calculated.

A diagram showing the characteristic distances *H*, *D* and angle of the approach path α is shown in Figure 5.

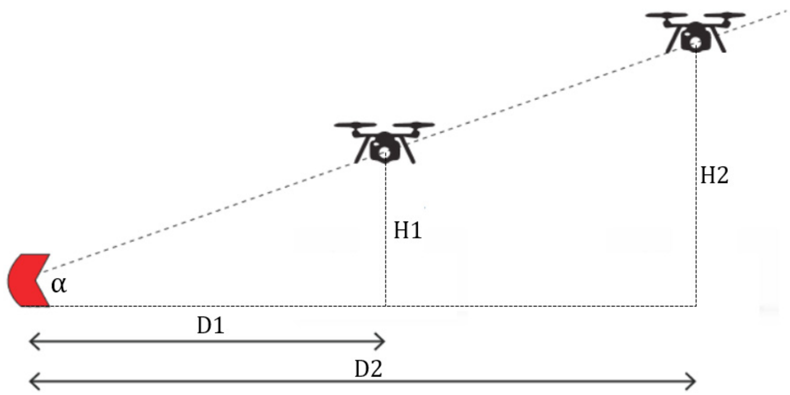

Figure 5. Diagram showing the characteristic distances H, D and the approach path angle α

In the last stage, having the value of the approach slope angle α, the identified colors of the PAPI indicators lights and knowing the desired approach angle in a given runway direction, it is possible to check whether the indicated information is correct, and if not, what color should be present. The use of multirotors allows for a more accurate determination of the current angle of the PAPI

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indicators, this is due to the fact that the verification is based on the detected pink color, which allows the angle of the unit to be determined directly. In contrast, when using the aircraft-mounted apparatus for this purpose, the measurement is subject to error due to the inertia of the pilot's reaction and the detection of only the color change (red-white).

6. Alternative PAPI system control technology

The main goal of the research is to design and implement an original program, the task of which is to locate and track PAPI indicators, and then verify the color of each of the lights in real time. Ultimately, the program would be installed in a multi-rotor or its receiving station.

To create the application, the Python language was used with the OpenCV library, which is commonly used in computer vision and real-time image processing. The recordings that were used to check the operation of the algorithms come from the CANARD company (2021), which verifies the indications of aeronautical visual aids and radio navaids system with the use of multi-rotors. It is, therefore, worth mentioning that factors such as the light intensity value of the PAPI indicator or the specification of the test apparatus used were not taken into account. The focus was only on the effect of the created algorithm in both daytime and nighttime recordings.

In order to discuss the structure of the used algorithms, the block diagram shown in Figure 6 will be helpful.

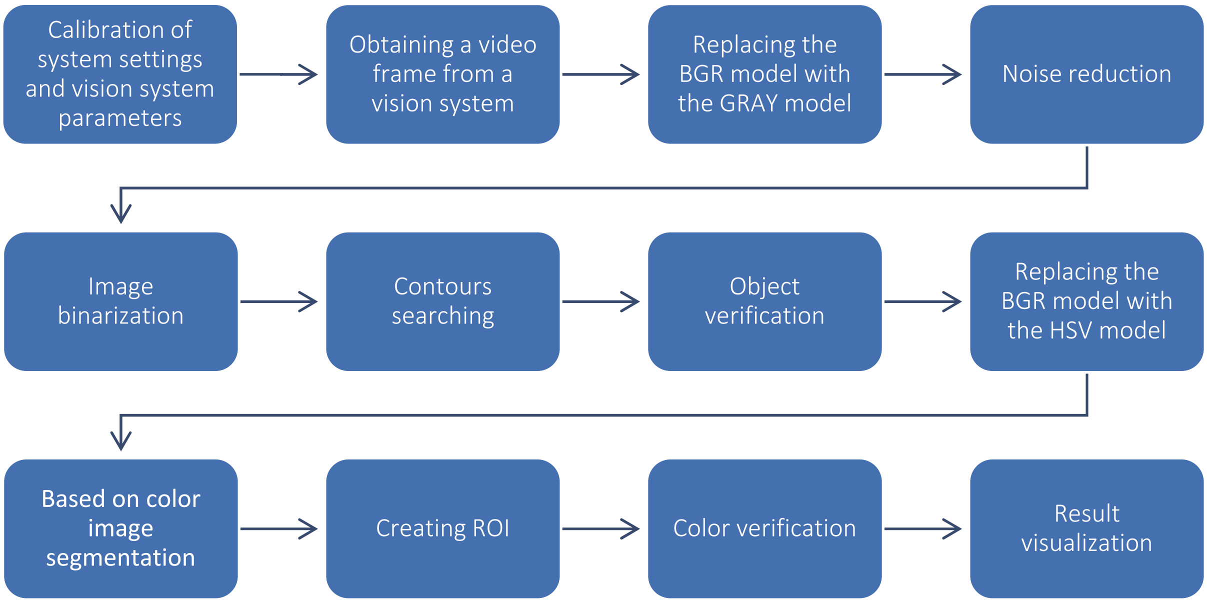

Figure 6. Block diagram of the program

The operation of the vision system and the program in a changing environment requires certain presets to be made, which will allow the proper operation of the entire system. The selection includes changing the Vision System Resolution, Contrast, Saturation, Exposure Time, White Balance, ISO Speed, and Color Temperature. It is necessary to calibrate the parameters defining the color range, which will then be identified by the software as red, white and pink during the segmentation phase.

A color image frame can be represented as a three-dimensional matrix. The dimensions of the matrix are defined by the currently selected resolution and the number of channels. In the case of the standard three-channel RGB (Red, Green, Blue) system, the first layer of the matrix is responsible for the red color, the second for the green color, and the third for the blue color (Elgendy, 2020). The numeric value that indicates the intensity of a given color can range from 0 to 255, with 0 being the minimum intensity and 255 being the maximum intensity. The value of each channel determines the color of the pixel.

The GRAY model is one of the simplest models that define color by only one value. This value determines a given pixel's degree of brightness of, from black to white. The range of values that a given pixel can take varies from 0 to 255, where 0 indicates black and 255 indicates white.

The noise reduction algorithm works by replacing the value of the middle cell with the median of pixels around the pixel under consideration. The number of pixels taken into account depends on the size of the defined matrix.

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Image binarizations is a method based on determining a threshold value above which all values in cells take a value equal to 255, while below, as they take a value equal to 0.

The next process is searching for contours. The selection of the appropriate threshold value allows obtaining an image with a separate light area of each light unit of the PAPI system. Based on the high contrast of pixels, in this case, a binary image, the function finds all points on the border of the white area and saves the area parameters and their coordinates.

The edges obtained in the previous step are transferred to conditional instructions that allow the PAPI system light units to be detected in the image. The following are checked:

- The minimum number of break points of a figure outlined in a given area
- The minimum value of the surface area
- The appropriate ratio of the width to the height of the rectangular area
- The appropriate ratio of the area of the circle to its circumference, according to the equation (1):

$$\frac{P_P}{O} = \frac{\pi r^2}{2\pi r} = \frac{1}{2} r = z \qquad (1)$$

The change from the BGR model to the HSV (Hue, Saturation, Value) model is imposed by easier determination of the parameter values that will define the range of desired colors in the image segmentation process. The HSV system is one of the models commonly used in machine vision. It is distinguished by way of recording color coordinates, which corresponds to the method by which the human eye perceives colors (Jankowski, 1990).

Image segmentation is based on the verification of each pixel and checking whether its color is within the range of colors defined by the user. If so, the cell has a value of 255, otherwise the value is set to 0. Thus, three masks are created, each for one of the defined colors. ROIs (Region of Interest) are areas in the image that are then analyzed to determine the color of the PAPI unit. Their location and dimensions are obtained through an earlier stage of contour searching. The color of the PAPI unit is verified by counting the cells whose value is 255. This process is performed for each of the three masks, in the defined ROI areas. If the number of cells with the value 255 is greater than the threshold value defined by the user as a percentage, the program visualizes it to the user by displaying the text above the given unit.

7. Trials and analysis of the results

The tests were performed using two recordings: in night and day conditions, which were then cyclically repeated for calibration and verification of the tests. The reason is the negligible number of recordings of PAPI units from the drone and the assumption that tests should be performed based on real system indications.

Nighttime recordings

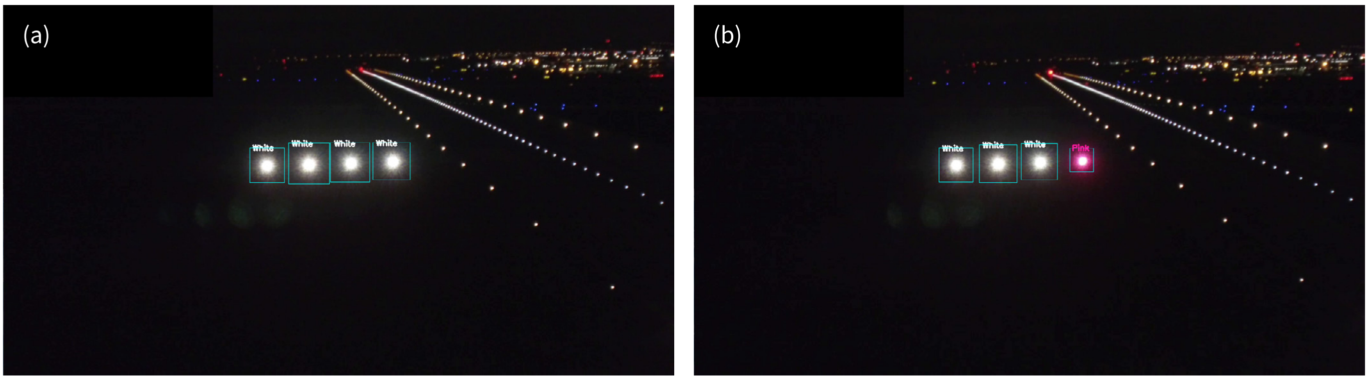

Figure 7. Windows clippings of the program; Visualization for a nighttime film record

In Figure 7 (a), the program image fragment is shown while the algorithm detected all four lights of the PAPI system, surrounding them with a white frame while correctly verifying the white color for each of the lights. Figure 7 (b) shows a section of the image when the vision system detected three white light sources and one pink light source. The pink color is created by overlapping the white and red colors. Thanks to this phenomenon, it is known that the PAPI unit lights perpendicular to the vision system. Having data from the GNSS receiver, we can determine the current angle of illumination of each unit of the system, the light color of which is pink.

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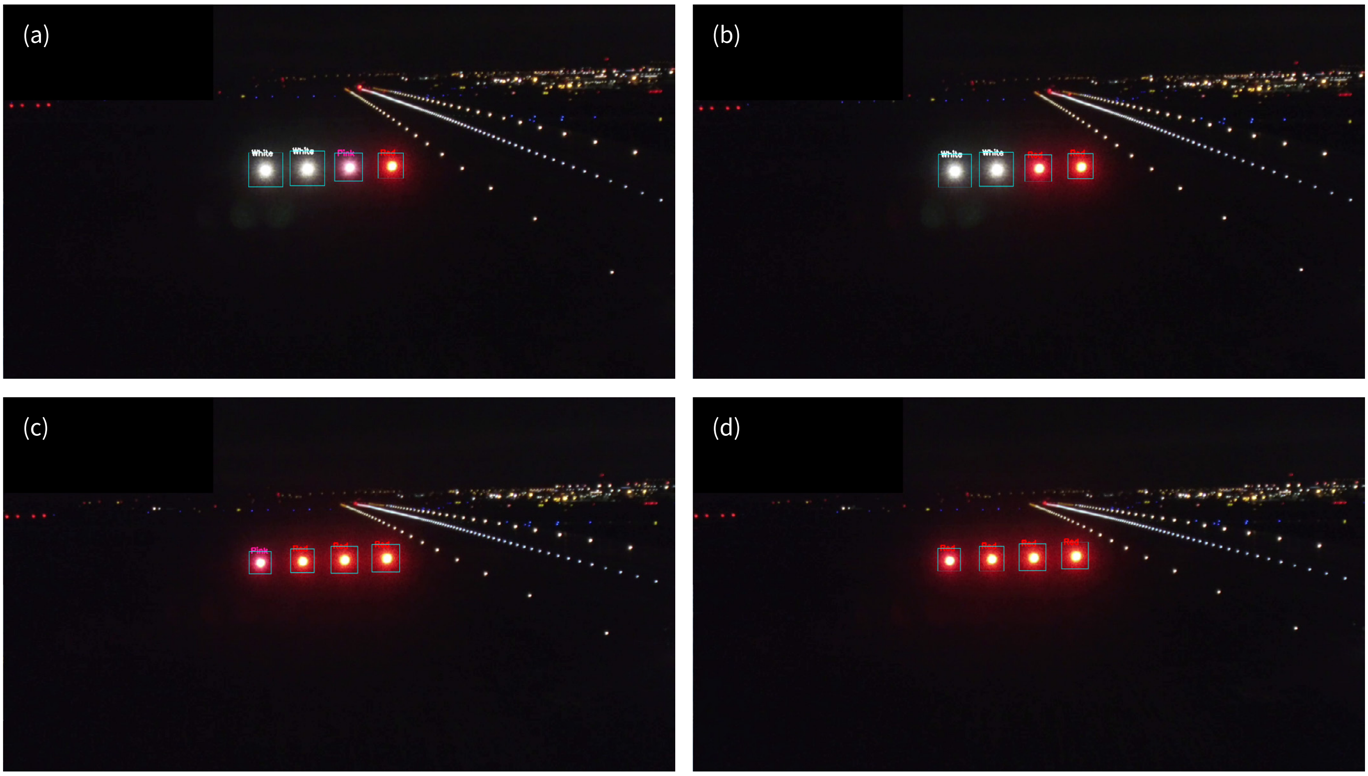

Figure 8. Windows clippings of the program; Visualization for a nighttime film record

Figure 8 presents selected program images to show the algorithm's correct operation in the remaining cases of the PAPI system indications. There may be a case where the algorithm detects more than one color as shown in Figure 9.

Figure 9. Window clipping of the program; Visualization for a nighttime film record

Figure 9 shows a situation where the algorithm detected two colors for one unit of the system. It shows it in the form of the text 'Calib R-P', which means that the red and pink colors have been detected. If the cases are present for a very short period, no additional modifications are necessary as these may reduce the algorithm's color detection performance. Otherwise, the range of parameter values that define the limit of recognizability of a given color should be changed.

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Daytime recordings

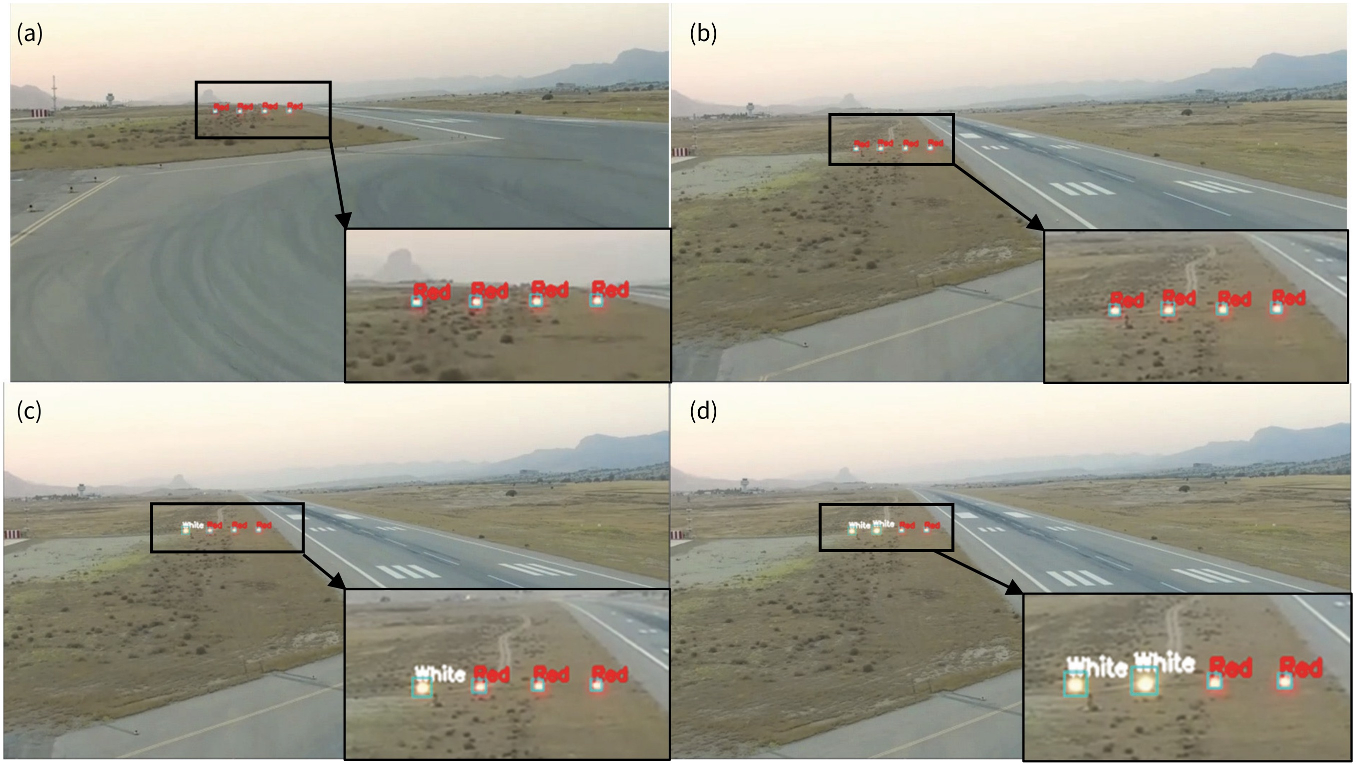

Figure 10. Windows clippings of the program; Visualization for a daytime film record

Figure 10 shows the operation of the program for recording in daytime conditions. As you can see, the algorithm is able to correctly locate the light sources despite the high ambient luminance, which adversely affects the quality of the algorithm. The part of the program responsible for color verification correctly detects white and red colors, while pink is not detected due to the very rapid transition from red to white.

8. Conclusion

The results and conclusions from the analysis of the conducted research confirm the thesis that it is possible to use unmanned devices with appropriate equipment to perform the PAPI system control. The proposed technology and the measurement logic used in the application work well in practice, and it can be assumed that the solution is suitable for wider implementation as a basis for at least periodic PAPI systems control. As already mentioned, recordings were used for research purposes, which are subject to errors due to lack of knowledge of, among other things: the specifications of the test apparatus used and the brightness setting of the PAPI units. The variety of recordings makes it necessary to calibrate the settings of the algorithm so that it can correctly recognize the units and the colors of their lights. Due to the need to certify the method for general use (which is a long process), the solution can only be used as a local tool to recognize PAPI indications in terms of correct operation and to detect possible discrepancies in the operation of the device. In the case of identifying incorrect indications or suspicions that the PAPI devices are de-calibrated, the method will be helpful when commissioning a review in accordance with applicable standards. Thanks to the use of the proposed technology in practice, airport management gains an additional tool that affects the safety of flights. The program has a development potential.

Declaration of interest
The authors declare that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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