UAV–Based PAPI Measurement - Post Processing Method As An Alternative For Flight Check

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ABSTRACT

Unmanned Aerial Systems (UAS) have recently begun to establish a strong position as a viable alternative to the traditional flight inspection systems for either NAVAIDS or Visual Aids. Aside from the need to develop the regulatory framework, the actual application is still limited by the perceived exclusivity of conventional inspection methods. The proposed paper explores a novel approach to Unmanned Aerial Vehicle (UAV)-based post-processing methods, for the measurement of Precision Approach Path Indicator (PAPI) lights in accordance with ICAO 9157 standards. It discusses various existing solutions, including conventional aircraft-based flight checks and semi-automated UAV-based inspections, where inspectors manually trigger measurements in real-time upon the detection of transition events and other relevant parameters. By challenging the relevance of conventional flight checks for visual aids, the paper underscores the potential limitations of these methods for accurate and reliable assessments. Additionally, it critically examines the reliability of real-time and in-flight assessment through a case study approach. Through this analysis, the paper highlights the importance of the regulatory framework ensuring the rules for consistency and accuracy of assessments to meet the upcoming technological evolution. Measurement techniques must continue to evolve and focus on contributing to the improvement of operational performance and safety standards in the aviation industry.

INTRODUCTION

Modern civil and military aviation relies on advanced navigational systems to ensure safe and precise approach procedures. One of the key elements in this process is visual aids, in particular Precision Approach Path Indicator (PAPI) systems. PAPI lights play a critical role in providing visual guidance to pilots during landing approaches, providing essential information about the descent path relative to the runway threshold.

Inspection and maintenance of such systems is essential to ensure their reliability. The inspection of PAPI lights is governed by international regulations, primarily outlined in ICAO Annex 14 [1] and ICAO Doc 9157 [2]. Annex 14 provides standards and recommended practices for the design and maintenance of aerodromes and details specific requirements for the installation and operation of PAPI systems. Doc 9157 provides guidance on acceptable methods for the inspection and maintenance of airfield lighting and emphasizes the need for periodic checks and calibrations to ensure compliance with specific operating parameters. Compliance with these regulations is essential to maintain aerodrome certification and ensure the safety of air operations.

One of the required inspections has to be performed in flight to replicate the pilot's perspective. Until now, the only way to achieve such a result was to use a specially equipped inspection aircraft. While an effective method, it is time consuming and expensive. In recent years, the rapid development of unmanned aerial systems (UAS) has opened up new possibilities for monitoring and inspecting aerodrome infrastructure, including PAPI lights. This approach has been incorporated into international regulations as an alternative method for PAPI lights measurement and is described in the latest edition of Doc 9157 (Fifth Edition, 2021). The use of UAS for PAPI inspections is also discussed in several studies and industry reports, highlighting their efficiency and effectiveness in maintaining airfield lighting systems [3-5]. The regulations only propose a framework for the methodology, not how to achieve the most efficient implementation. Many organizations have pioneered the use of real-time UAV-based measurements over traditional methods. This paper demonstrates the possibility of a slightly different concept that directly redesigns the inspection matter into a separate, independent process performed immediately after the conducted flight.

LEGAL FRAMEWORK

The framework for a measurement method of a PAPI using UAS is described in ICAO Doc 9157 Aerodrome Design Manual, Part 4 - Visual Aids. The available description briefly defines the outlines for both vertical and horizontal assessment.

The UAS must be strategically positioned at least 300 meters downwind of the PAPI system for the proposed operation. It is essential to obtain high dimensional accuracy for positioning in order to perform vertical scans or measurements. Measurements should allow the operator to determine the parameters h1 and h2, which represent the upper and lower boundaries of the red-to-white transition zone of a given PAPI unit (see Figure 1). Using these parameters, it is possible to calculate the setting angle ϴ of the light unit according to a defined formula.

$$\theta = \tan^{-1}\frac{(h_1 - h_2)}{2d}$$

where:

h_1, h_2 are the upper and lower limits of the transition zone; and

d is the horizontal distance of the UA from the PAPI.

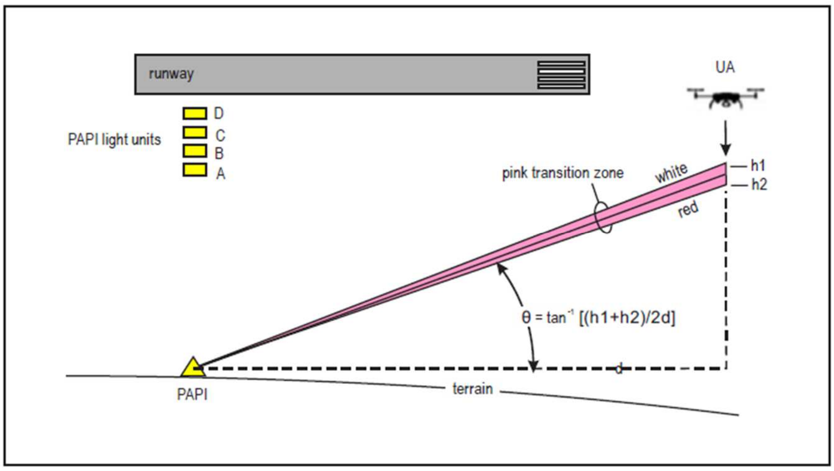

Figure 1. Determination of PAPI Setting Angles

The horizontal scanning process performed with the UAS allows the operator to define the lateral boundaries of the PAPI system. This is accomplished by detecting when the signals from units D and A are no longer visible. See Figure 2.

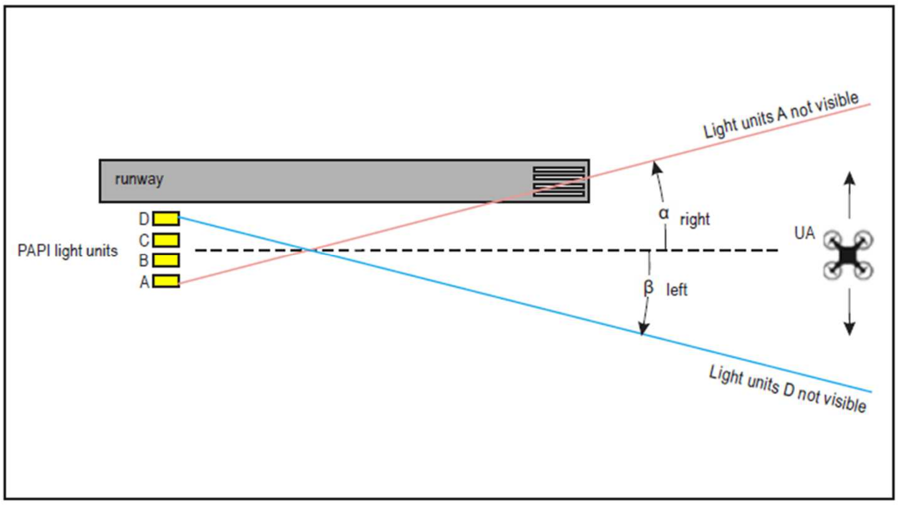

Figure 2. Determination of PAPI Azimuth Range

The use of a UAS provides a viable alternative method for evaluating PAPI settings. A typical UAS configuration includes an unmanned aircraft (UA), a control station or remote pilot station (RPS), and a communications data link (C2 link) that connects the UA to its control station/RPS for flight management. Additional components may include launch and recovery equipment and a ground processing unit for downloading measurement data.

The integration of a real-time kinematic (RTK) base station is often essential to ensure high dimensional accuracy. Data acquired by the UAS can be monitored in real time in the field and recorded for later analysis. This approach improves both the accuracy and efficiency of PAPI setting measurements.

Using an UAS for the measurement of PAPI angle settings may require obtaining special authorization from the relevant regulatory authority within the jurisdiction overseeing the aerodrome.

EVOLUTION OF VISUAL AIDS FLIGHT INSPECTION METHODS

The calibration and maintenance of navigational visual aids, such as PAPI systems, has evolved significantly over the years. In addition to the ground-based approach of ground surveys, lift platforms or checkboards, the evolution has also reached the flight check method. The bird's eye view in-flight assessment allows inspectors to evaluate the PAPI lights as they would be seen from the pilot's perspective. This ensures operational visibility and alignment. Over the years, the use of positioning and data processing systems has led to technological advances in aircraft-based flight inspection methods. Digital recording and automated data logging have streamlined the inspection process, reducing human error and increasing efficiency. However, conducting inspections in real time can still have some negative effects on the efficiency of the measurement process and the operational conditions at the airport. Time pressure on the inspector during approach, PAPI readjustments requiring unexpected go-arounds, or the possibility to impact on regular air traffic flow are just some of the implications. To solve such problems, the transformation process has reached another technological step, which includes UAVs as a potential alternative. In the last decade, several different solutions have been proposed as a reliable calibration tool for Visual Approach Slope Indicator Systems (VASIS). In general, the proposed concepts related to real-time measurements performed by dedicated UAV operators while supervising an automated flight in close distance to the inspected infrastructure. The proposed paper presents another possibility by performing a post-processing method related to the flight check of PAPI lights.

RESEARCH ON VISUAL AIDS POST-PROCESSING METHOD – AIROTEC DEFI

This paper discusses the results of a research project conducted by Airotec between 2021 and 2023. The aim of the project was to develop a UAV-based solution that could accurately measure PAPI lights. The main focus of the project was to ensure that the developed product complies with regulatory standards such as ICAO 9157 and to demonstrate its operational effectiveness through rigorous field testing. The project methodology was structured into several key phases, including concept development, including system architecture and inspection procedures, followed by implementation, operational testing, comparative analysis, safety analysis, and finally commercial services. The primary objective was to develop a universal UAV-based solution capable of accurately measuring the transition angle of each PAPI unit with minimal impact on traffic flow. The other objective was to provide a process for inspecting the remaining airport ground lights in accordance with safety procedures and the operating environment. The key parameters to be achieved were accuracy, reliability, time and cost reduction in relation to the highest safety and airport operational standards. The operational testing phase included extensive field tests at several Polish communication airports. These tests were designed to collect real-time data under fully operational airport conditions, to verify the measurement accuracy and to compare such a novel inspection method with traditional aircraft-based methods. With over 50 measurement flights for separate PAPI systems at several airports, the system was able to measure vertical settings for each PAPI unit with a maximum resolution of 0.018 degrees.Each complete vertical PAPI measurement took no more than 3 minutes. The total inspection time, including horizontal angular coverage and intensity control, was no longer than 12 minutes. To avoid disrupting air traffic, UAV flight time was kept to a minimum. Each inspection process required to calibrate the PAPI system was performed on the ground after the flight. This was done in a safe environment and without time pressure. The key achievement was the successful integration of a post-flight analysis approach on the ground and minimizing runway occupancy and human error. The conclusion was that with an appropriate level of automation combined with accuracy, such a solution can be very attractive for commercial use.

STEP BY STEP PROCEDURE OF CONDUCTING UAV-BASED PAPI FLIGHT CHECK

The complete post-processing UAV-based PAPI flight check can be divided into four phases: preparation, inspection, data processing and analysis. The pre-inspection phase requires the plan and mission preparation, safety analysis, equipment calibration and, in the case of regional European regulations, obtaining the necessary approvals from the competent authority. The pre-programmed mission is prepared once per infrastructure to be inspected and is executed fully automatically under the supervision of a drone operator. Each survey flight must comply with all safety procedures established by the UAS operator and the airfield operator. The drone must be thoroughly inspected prior to each flight. The camera has to be calibrated and then adjusted to specific light conditions and the type of PAPI (LED, halogen). The inspection process is carried out in cooperation with the airport technical staff and in constant communication with TWR air traffic control. The flight is automatic and can be performed either sequentially or separately for each inspection type: vertical, horizontal coverage or intensity control check. Upon completion of the inspection process, the UAV returns to a predetermined safe take-off point under the supervision of a dedicated pilot. Mission results are available immediately after the UAV lands at this safe location. The collected data is then subjected to post-processing using specialized software installed on a laptop computer. In the final phase, an on-site assessment is performed by a trained inspector in a secure environment. The inspector verifies the calibration of the PAPI unit or recommends any necessary adjustments. There are several commercial and operational advantages to this process, which will be discussed in detail later in this paper.

RELIABILITY ON MEASUREMENTS ACCURACY

The comparative analysis between UAV-based and traditional aircraft-based Precision Approach Path Indicator flight inspection reveals significant differences in methodology and operational efficiency while maintaining the highest accuracy. Traditional aircraft-based inspections involve a series of flight maneuvers in which an inspector in a highly equipped aircraft evaluates the angular settings of the PAPI lights during multiple approaches. During a sinusoidal flight, the inspector must capture transitions from white to red and vice versa, which are then processed to calculate the angular settings of each PAPI unit. This method requires multiple flights, significant coordination between air and ground crews, and quick adjustments to PAPI settings when deviations are detected due to the time constraints of keeping inspection aircraft in the air.

In contrast, the UAV-based post-processing method discussed here uses commercially available unmanned aerial vehicles (UAVs) such as the DJI Matrice 300 RTK or DJI Mavic 3 Enterprise. These UAVs are equipped with a professional camera, GNSS receivers, and RTK corrections. The UAV performs automatic flights, capturing images at defined intervals, which are then processed to determine the angle settings of the PAPI lights. The data processing is automatic, but the inspection itself is still the responsibility of the inspector. Based on the processed information, the inspector has the ability to evaluate the visual transition zone by defining its upper and lower limits. This approach is crucial because of the nature of the PAPI lights. They are navigational aids designed to be interpreted visually by humans, not by a computer program. There are several advantages to such an approach. Pre-programmed, automated data collection allows for repeatability and reduces flight time. Post-processing limits the potential for human error in a time-pressured, real-time in-flight measurement. Data acquisition independent of the calibration process reduces runway occupancy time, air traffic control workload, and simplifies the process if multiple adjustments of PAPI units are required. New possibilities for in-flight calibration are opened by analyzing the PAPI performance on the acquired data. It allows easier assessment of the transition zone spectrum and alignment, both in the vertical and horizontal planes for each unit inspected.

It is important to note that it is not meaningful to compare the results of a UAV-based method with those of an aircraft-based method in terms of a single measurement accuracy. Both methods conform to standards and can accurately indicate the angular position of a selected PAPI system. Given the resolution of one method described in this paper, which is 0.018 degrees, and the repeatability demonstrated by the low standard deviation between repeated measurements, the conclusions drawn are more focused on establishing credibility rather than promoting better accuracy over other methods. The main advantages of using UAVs and post-processing method lies in the reduced probability of human error, reduced workload for Air Traffic Control (ATC), reduced inspection time, and improved repeatability.

During the research, the project team conducted a series of validation tests at two main locations: Olsztyn-Mazury Airport (EPSY) and Wroclaw Airport (EPWR). For the purpose of comparison with the traditional flight inspection method, several flights were conducted on the closest dates to a commercial, full flight inspection performed by professional Flight Inspection Service (FIS) providers. At EPSY, the inspections were conducted in December/January 2022/2023 for both runway directions 01 and 19. At EPWR, inspections were conducted in March 2023 for runways 11 and 29. Each inspection included multiple flights to ensure comprehensive data collection for the vertical settings of the PAPI lights. All results are presented in Table 1.

Table 1. Comparison of Results Obtained During UAV-Based PAPI Flight Check and Aircraft-Based Flight Check

Date	PAPI	Type of inspection	Calculated vertical angle setting [°]				
			PAPI	A	B	C	D
Dec. 2022	EPSY 01	aircraft	2,97	2,42	2,70	3,23	3,53
Jan. 2023	EPSY 01	DeFI	3,12	2,51	2,74	3,50	3,70
Dec. 2022	EPSY 19	aircraft	3,47	2,96	3,29	3,65	3,97
Jan. 2023	EPSY 19	DeFI	3,58	3,04	3,35	3,82	4,08
Mar. 2023	EPWR 11	aircraft	3,04	2,51	2,86	3,22	3,55
Mar. 2023	EPWR 11	DeFI	2,98	2,44	2,82	3,14	3,49
Mar. 2023	EPWR 29	aircraft	3,05	2,51	2,87	3,22	3,56
Mar. 2023	EPWR 29	DeFI	3,04	2,47	2,89	3,18	3,57

To understand the logic of the results obtained, the nominal angles were as follows. In EPSY for runway 01, the nominal angles were set to 2.42°, 2.75°, 3.25°, and 3.58° for units A, B, C, and D, respectively. For Runway 19, the nominal settings were 3.00°, 3.33°, 3.67°, and 4.00°. For EPWR, the nominal settings for both runways 11 and 29 were identical: 2.50°, 2.83°, 3.17°, and 3.50°. The results are summarized in Table 2.

Table 2. The nominal angle settings of PAPI Light Systems at EPSY and EPWR

Airport	Direction	Nominal angle [°]				
		GP	A	B	C	D
EPSY	01	3,00	2,42	2,75	3,25	3,58
EPSY	19	3,50	3,00	3,33	3,67	4,00
EPWR	11	3,00	2,50	2,83	3,17	3,50
EPWR	29	3,00	2,50	2,83	3,17	3,50

To illustrate the variability in measurement accuracy for DeFI, across different units for specific PAPI systems, the most prominent metric was absolute and relative standard deviations.

Table 3. Absolute and relative experimental standard deviation

Series	Number of flights	Absolute standard deviation (°), Relative standard deviation (%)				
		Unit A	Unit B	Unit C	Unit D	Glide Path
EPSY 01 (3,0°)	6	0.0378°	0.0117°	0.0103°	0.0137°	0.0088°
		1.53%	0.43%	0.32%	0.39%	0.29%
EPSY 19 (3,5°)	4	0.0332°	0.0365°	0.0772°	0.0359°	0.0568°
		1.10%	1.09%	2.00%	0.88%	1.58%
EPWR 11 (3,0°)	5	0.0068°	0.0129°	0.0042°	0.0060°	0.0079°
		0.28%	0.46%	0.14%	0.17%	0.27%
EPWR 29 (3,0°)	5	0.0076°	0.0068°	0.0080°	0.0078°	0.0064°
		0.31%	0.24%	0.25%	0.22%	0.21%

As can be seen in Table 3, the relative standard deviation for most measurements is less than 0.5% and in the worst case does not exceed 2%. Due to the relatively small number of measurements, the research team decided to verify the variability with an extended experimental uncertainty. By including an extension coefficient, based on the assumption that the distribution of measurements may be more extensive than a normal distribution, it is possible to consider extreme cases that may occur in reality. In practice, the extended uncertainty provides a more conservative and realistic range within which the expected value of the measured quantity falls. The uncertainty has been increased to such an extent that it is likely to cover most of the possible outcomes of a measurement for a given true value. The calculation involved multiplying the resulting standard uncertainty by an appropriately chosen extension factor. The value of the factor depended on the chosen confidence level. Due to the small number of measurements, a t-Student distribution coefficient was used and the confidence level was set at 95%. For all the results obtained, the relative extended uncertainty did not exceed 3% (0.0851°), except for the single worst case where it did not exceed 5% (0.1646°).

KEY SPECIFICATION FEATURES

Each PAPI flight inspection method consists of unique features and offers several advantages over the other available methods. When comparing the post-processing method with the real-time UAV-based or aircraft-based flight check, the strong differences are visible in the commercial and operational results. Due to the specific purpose of PAPI, i.e. to be visually available for an aircraft during its approach, it's not necessary to have above-average measurement accuracy, but the ability to obtain reliable results. All the features described below have been observed and verified during real case scenarios.

Runway Occupancy Time

The most significant advantage is related to runway occupancy time. The PAPI flight check duration is calculated from the time the ATC clears the drone for takeoff. The starting point is the grass or technical road around the threshold at a safe distance from the runway. According to ICAO 9157, the UAS must reach a point at least 300 meters from the PAPI system. In this case, it should take approximately 18-20 seconds to reach the inspection start point. The vertical angle data acquisition process depends on the defined resolution required to obtain reliable results during the analysis. The inspection time varies from 2:52 to 3:00 minutes. In order to minimize the impact on air traffic, the UAS must exit the runway and return to the starting point as quickly as possible. This can be accelerated by allowing the operator to manually take control of the drone and fly back at full speed. This process should take no more than 20 seconds. The starting point for the vertical alignment inspection is the same for the horizontal and intensity control inspections. The time to collect data for the horizontal check follows the same rules as the vertical check. The time required for a complete mission is also approximately 2:50 minutes.Intensity control, on the other hand, requires the involvement of a dedicated operator in the control tower, ATC or other authorized personnel. In this case, the inspection time depends on the effectiveness of cooperation and communication with the person changing the intensity of the PAPI lights from 1% to 100% and back. The proposed process includes a delay of approximately 5 seconds between each intensity setting change. The time is calculated from the time the UAS reached the point and the tower was requested to begin the change process. It stops when the tower communicates that it has returned to the primary setting. This entire process can take anywhere from about 55 seconds in a best case scenario to as long as 2 minutes in a scenario where there is poor engagement on both sides. It is important to note that each check can be performed separately or in sequence. The entire process should take no more than 8-9 minutes in a worst-case scenario, from the initial request for takeoff to the UAS on the ground. A single part of the flight check, i.e. the vertical inspection, should take no more than 3:40 to 4 minutes. All presented time values have been defined during true-case scenarios during commercial services on the 24-hour controlled airport of EPWR or EPKK. The use of such an approach makes it possible to perform the inspection between arriving or departing aircraft and to keep the air traffic flow undisturbed. UAV-based flight inspection also eliminates the need to book a slot for an over runway flight and makes it much easier to manage air traffic without taking into account the inspection aircraft performing multiple go-arounds. The timeline of the UAV-based PAPI flight check is shown in Figure 3.

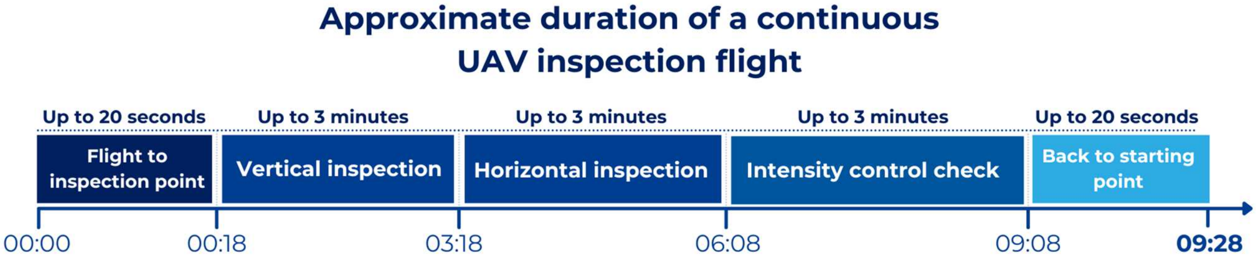

Figure 3. The timeline for the duration of continuous UAV- based PAPI Flight Inspection

PAPI Adjustment Process

The flight inspection crew, together with dedicated airport personnel, shall make adjustments to the infrastructure that is out of acceptable tolerance. The adjustment is performed on site and based on the obtained result immediately after the measurement during the ongoing inspection. Within the post-processing method, two major differences can be observed that provide the beneficial advantages. First, the precise repeatability of the inspection flight and second, the direct proof of the required correction type. Thanks to RTK technology, the automated flight can be precisely repeated several times. Each frame of acquired data will be from the same location in relation to the previous calibration flight, allowing easy verification of each adjustment made to the specific PAPI unit. There may be situations where not one, but several adjustments are required. In such a case, existing flight check methods may cause a discrepancy due to the need for a human to determine the moment of transition in real time. Analyzing the PAPI setting under no time pressure and on the same data set allows to provide more reliable correction range and type. Below, there's a table summary of a 5-time PAPI adjustment process during the same night of flight inspection performed at the controlled airport EPSY. The complete process started after sunset, around 17:39, and was completed at 20:04. The average flight time for the acquisition of data for the vertical inspection did not exceed 3:05 minutes.

Table 4. Measurement results of a EPSY PAPI 01 setting during a UAV-based flight inspection

Vertical setting						
PAPI 01	Nominal	Measurement 1	Measurement 2	Measurement 3	Measurement 4	Measurement 5
A	2,42	2,28	2,28	2,42	2,42	2,40
B	2,75	2,75	2,86	2,74	2,72	2,75
C	3,25	3,49	3,49	3,39	3,34	3,25
D	3,58	3,66	3,65	3,57	3,56	3,55
GP	3,00	3,12	3,17	3,07	3,04	3,00
						Result

The infrastructure to be inspected was a halogen PAPI and required several major adjustments. Due to a lack of technical knowledge on the part of the airport staff, the entire process took longer than planned. The ongoing adjustment process can be seen in Figure 4.

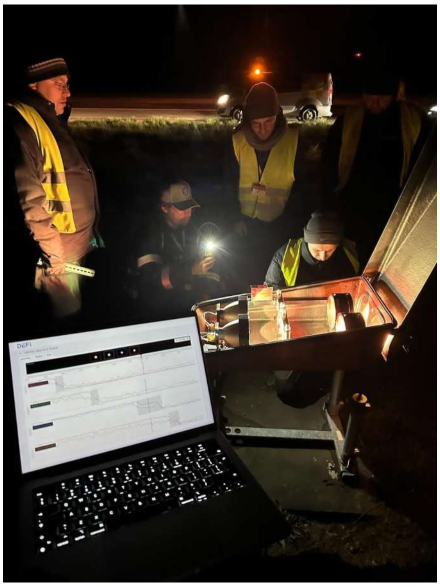

Figure 4. On-site assessment of obtained results and real-time adjustment process of PAPI Light Unit

Figure 5 shows the graphical representation of the results obtained during the first inspection before any adjustments, and Figure 6 shows the results obtained during the flight check performed after the final adjustment. The post-processing allows to easily detect the misalignment of a specific unit in vertical and horizontal planes. The selected area defines the visual transition zone of a specific PAPI unit, and the location of an area on the X-axis provides an overview of the registered angle setting. Looking at the unit A from the top chart (Figure 5), the setting is between 2.17 and 2.39 with a transition zone of 0.22 degrees, set at angle 2.28 in relation to the nominal value of 2.42. This particular unit is misaligned in both the vertical and horizontal planes.

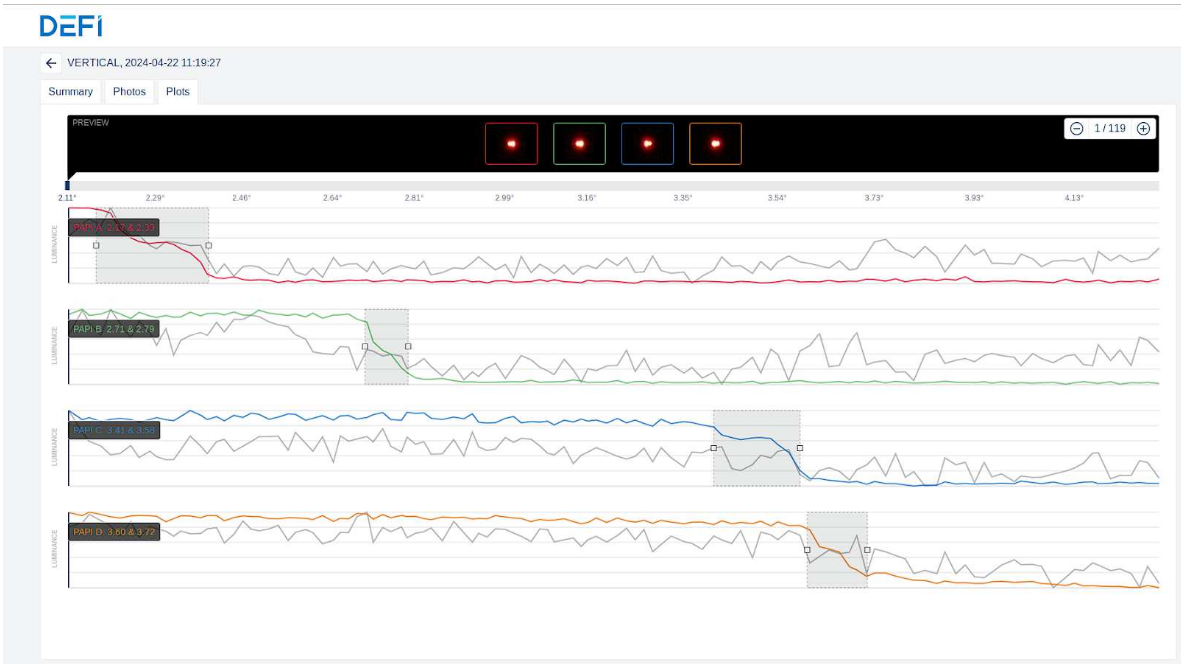

Figure 5. Transition zone assessment on the processed data after the first inspection (before any adjustments)

Another inspection possibility is to verify the performance of each unit in time by previewing the processed data. Thanks to the resolution achieved, it is even possible to verify the performance of each lamp inside the unit. For this specific example, unit C, visible on the 3rd chart in Figure 5, operates in an inverted transition, from right to left in relation to each other unit in the PAPI system, while observed from below to above the glide path. Such a feature may not be observed when simply checking the transition angle, or may simply not be visible from a greater distance, especially from the aircraft perspective during an approach. The graphical representation allows for an easier comparison of the calibration efficiency in the field between the preadjustment and the final measurement. The graph in Figure 6 shows the final effect of the adjustments. Compared to the previous results, the transition zone of each unit is relatively similar and doesn't overlap with any other unit. The sharpness of each unit could be steeper, but since this is a visual assessment and not a photometric test, there's no need for such a restrictive technical requirement.

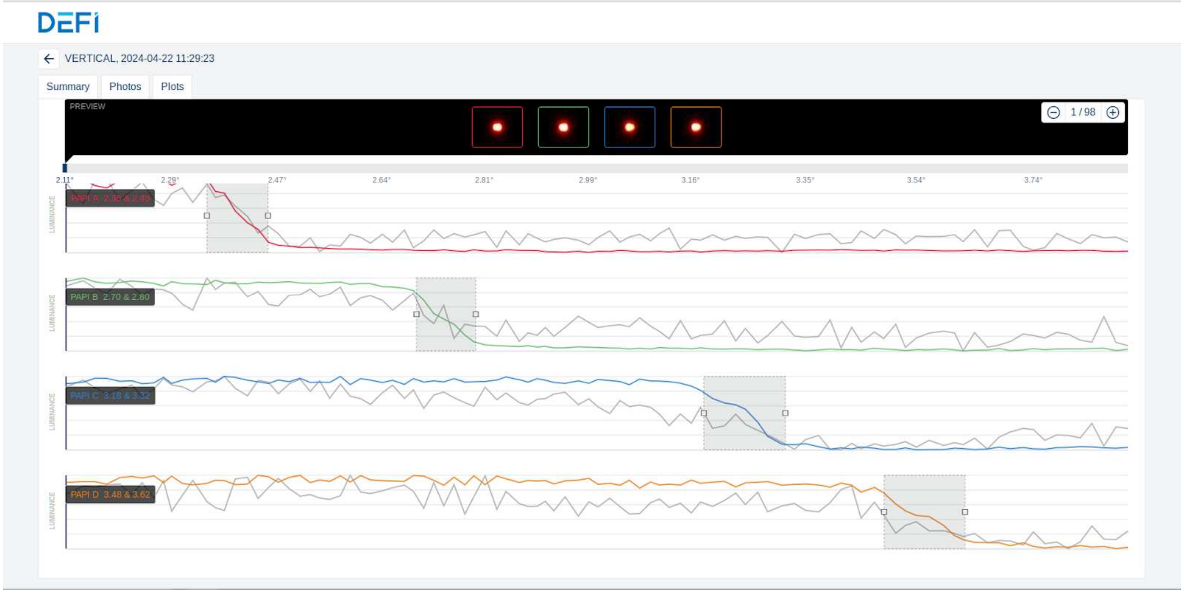

Figure 6. Transition zone assessment on the processed data after the final adjustment

Additional features provided by the post-processing method include the ability to specify which corrections should be applied to the specific PAPI unit. For example, it is possible to automatically determine the exact number of screw turns for a particular leg to align both the vertical angle and the area of the visual transition zone. This could be done by knowing the positioning guidelines, including the type of thread, that might be available in the technical documentation of the installed PAPI. Such a case is another step of the described research planned by the authors of this paper.

HUMAN FACTOR

Any inspection method, real time UAV-based, aircraft-based, or even the discussed post-processing method, requires a dedicated person to perform the evaluation. The transition zone of the PAPI unit could be evaluated automatically by the computer program, but at the same time it is crucial to take into account the subjective perspective of visual interpretation. Traditional approaches and most of the proposed concepts are based on real-time measurements. The inspector however, is not involved in the flight process itself and should only focus on observing and evaluating the PAPI performance. Either aircraft-based or UAV-based real-time methods exclude inspectors from the flight process to minimize possible errors. Yet, the evaluation process is still under time pressure and responsibility for making a mistake. Both can lead to measurement error, misinterpretation, or flight time extension, which can directly or indirectly affect air traffic flow, safety, or service costs. The post-processing method allows analysis to be performed under safe conditions when the UAV is already on the ground and off the runway. Thanks to the short duration of the pre-programmed data acquisition missions, the flight can easily be performed between flight operations. All decisions regarding PAPI adjustments can be made without time pressure and can be discussed with airside personnel, who may also have access to the results. The human inspector is indispensable in the flight control process due to the essential purpose of the PAPI system or even the entire airport lighting infrastructure. Until the technological breakthrough allows fully autonomous flight operations, visual aids will be an integral part of a safe approach procedure. Until then, any innovation in visual inspection must focus on simplifying the process and ensuring the reliability of results while maintaining the highest safety standards and minimizing the impact on air traffic flow.

CONCLUSIONS

The UAV-based approach to PAPI angle setting measurements has a number of significant advantages over traditional in-flight inspection methods. Not only does it achieve comparable accuracy, but it also improves operational efficiency by reducing costs and mitigating risks associated with manned inspections. The automated data collection and post-processing capabilities of UAVs contribute to their reliability as an alternative solution, especially when integrated into a robust regulatory framework that ensures consistent and accurate assessments.

Key benefits of the UAV-based approach include optimizing the PAPI adjustment process, minimizing runway occupancy time, and maximizing accuracy by reducing human error. The automated nature of the mission allows inspections to be conducted without the need for extensive runway occupancy, thereby increasing operational efficiency. Furthermore, the automated flight and mission preparation process is the only relevance of the UAV platform. The post-processing method relies solely on the acquired footage to carry out the flight inspection. The independence of the UAV platform ensures its versatility and adaptability to a variety of inspection scenarios.

It is important to note that all UAV-based flight inspection methods inherently reduce workload compared to traditional methods. The impact and workload reduction may vary depending on the availability of unmanned traffic management (UTM) systems. Specific UAV flight check procedures should not be confused with other drone operations near airports. These flight checks are complex, professionally executed services performed by authorized and experienced teams. Every action, from communication to movement on airport premises during the pre-flight and flight phases, is conducted in strict accordance with applicable operational standards and safety procedures.

In addition, this UAV-based method provides a great benefit as a pre-flight check prior to the traditional PAPI commissioning flight inspection. This is where such a method would not be approved by relevant regulatory authorities. By performing preliminary assessments with a UAV, potential primary setup issues can be identified and quickly addressed, thereby limiting the subsequent manned flight check process to a single operation. This pre-flight application further underscores the utility of UAVs in improving overall inspection cost efficiency and accuracy.

Overall, the UAV-based post-processing method presents a compelling case for its adoption in PAPI inspections, offering improvements in accuracy, cost-effectiveness, and operational safety. Future work should focus on refining regulatory standards and further enhancing the technological capabilities of UAV systems to solidify their role in aviation safety and efficiency.

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