NRC Publications Archive
Archives des publications du CNRC

Inspection of a helicopter blade using drone-based active thermography

Pant, Shashank; Genest, Marc; Ibarra-Castanedo, Clemente; Avdelidis, Nicolas P.; Valdes, Julio; Deane, Shakeb; Zolotas, Argyrios; Maldague, Xavier

This publication could be one of several versions: author’s original, accepted manuscript or the publisher’s version. / La version de cette publication peut être l’une des suivantes : la version prépublication de l’auteur, la version acceptée du manuscrit ou la version de l’éditeur.
For the publisher’s version, please access the DOI link below./ Pour consulter la version de l’éditeur, utilisez le lien DOI ci-dessous.

Publisher’s version / Version de l'éditeur:
https://doi.org/10.1117/12.2665495
Thermosense: Thermal Infrared Applications XLV, Proceedings of SPIE, pp. 1-7, 2023-06-12

NRC Publications Archive Record / Notice des Archives des publications du CNRC :
https://nrc-publications.canada.ca/eng/view/object/?id=d4bb3aa9-3678-4644-81bb-10cafe5b2d79
https://publications-cnrc.canada.ca/fra/voir/objet/?id=d4bb3aa9-3678-4644-81bb-10cafe5b2d79

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at
https://nrc-publications.canada.ca/eng/copyright
READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L’accès à ce site Web et l’utilisation de son contenu sont assujettis aux conditions présentées dans le site
https://publications-cnrc.canada.ca/fra/droits
LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D’UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n’arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research Council Canada
Conseil national de recherches Canada

Inspection of a helicopter blade using drone-based active thermography

Shashank Pant, Marc Genest, Clemente Ibarra-Castanedo, Nicolas Avdelidis, Julio Valdes, et al.

Shashank Pant, Marc Genest, Clemente Ibarra-Castanedo, Nicolas P. Avdelidis, Julio Valdes, Shakeb Deane, Argyrios Zolotas, Xavier P. Maldague, "Inspection of a helicopter blade using drone-based active thermography," Proc. SPIE 12536, Thermosense: Thermal Infrared Applications XLV, 125360T (12 June 2023); doi: 10.1117/12.2665495

Event: SPIE Defense + Commercial Sensing, 2023, Orlando, Florida, United States

Inspection of a helicopter blade using drone based active thermography

Shashank Pant[a]*, Marc Genest[a], Clemente Ibarra-Castanedo[b], Nicolas P. Avdelidis[c,b], Julio Valdes[a],
Shakeb Deane[c], Argyrios Zolotas[c], and Xavier P. Maldague[b]

[a]National Research Council Canada, Ottawa, Ontario, K1A 0R6, Canada.
[b]Computer Vision and Systems Laboratory, Department of Electrical and Computer Engineering,
Laval University, Quebec City, Quebec, G1V 0A6, Canada.
[c]School of Aerospace, Transport and Manufacturing, Cranfield University, Cranfield, MK43 0AL, UK.

ABSTRACT

A drone-based inspection system that can move “freely” around an aircraft to perform the inspection of all the areas of interest in a fast and effective manner can have significant impact in reducing inspection time and cost. However, active thermography inspection using drone is challenging because the drone carrying the optical and thermal cameras is subjected to vibration and undesired motion. Since active thermography relies on the pixel temperature evolution over time, an unstable thermal video from a flying drone can cause error in the output results as any movement between the acquired images will affect the pixel position in the successive frames and thus disrupt the monitoring of the temperature evolution. This paper presents the outcome of experimental runs, where a commercially available drone equipped with both thermal and optical cameras was used to inspect a helicopter Main Rotor Blade (MRB) in a laboratory environment.

Keywords: Drone based inspection, active thermography, video stabilization, aircraft structure

1. INTRODUCTION

The use of drones for the remote inspection of large and/or difficult to access areas have significantly grown in the last few years. Constant technological improvements have contributed to making drones more affordable and easier to deploy. Technological developments have also had a great impact on development and improvement of variety of drone mounted sensors, which are now smaller, lighter and with improved performance. Infrared Thermography (IRT) sensors have witnessed drastic changes in terms of cost and miniaturization. IRT can be used for contactless survey of thermal differences between the background and the article of interest, and when combined with drones it makes a perfect match for rapid survey of wide and hard to access areas. The use of drone based IRT systems have been explored for numerous applications such as: precision agriculture (monitor nutrients levels or lack of water in crop fields [1]; building inspections (poor insulation, air leakages, moisture) [2]; quality assessment of large structures (inspection of photovoltaic panels farms, wind turbines) [3]; for surveillance applications (conservation, law enforcement, military) [4]; inspection of industrial sites [5], etc. In most of these cases, the passive approach has been employed, i.e., the observation of thermal phenomena without the use of external energy stimulation, with the assumption that the features of interest (animals, plants, buildings, etc.) will naturally produce thermal gradients that can be clearly distinguished from the background. A different approach is needed when the features of interest are at approximately the same temperature as the background. This is the situation encounter for the inspection of aircraft structures during production or in-service, where typical anomalies can be difficult to detect visually (e.g. cracks, impact damage) and/or can be hidden inside the materials (e.g. delaminations, internal damage, water ingress). In such cases, an active thermography approach is better suited to thermally stimulate the structures to be inspected with a controlled energy source. In an active thermography technique, a sample is heated using an external thermal source such as a flash or heating lamp, while a thermal camera is used to capture the thermal response of the sample over a short time period, which typically

Thermosense: Thermal Infrared Applications XLV, edited by
Nicolas P. Avdelidis, Proc. of SPIE Vol. 12536, 125360T
© 2023 SPIE · 0277-786X · doi: 10.1117/12.2665495

spans from a few to several seconds [6]. The acquired time-lapse thermal images are then processed in time domain, frequency domain or using other techniques such as principal component analysis, wavelet or others [7]. Pixels that appear different than the surrounding areas in the processed thermogram (sequence of thermal images) are identified as features of interest and potential anomalies. The active thermography technique works well for a stationary and robotic setup, where the thermal camera is held steady or can be moved in a pre-defined trajectory. For in-service inspection, the ideal situation would be to inspect an aircraft without the need of removing any component. Therefore, a drone based active thermography system that can move "freely" around the aircraft performing the inspection of all the areas of interest in a fast and effective manner can have significant impact in reducing inspection time and cost. Therefore, this work presents results of drone-based active thermography technique to inspect helicopter blade in an indoor laboratory environment.

2. EXPERIMENTAL SETUP

In this work, an out of service Main Rotor Blade (MRB) of a Bell 412 helicopter was inspected using a drone-based active IRT system. The blade is fabricated out of different materials, which include: composite skin, honeycomb core, metal leading edge, etc. The IRT setup consists of a stationary pulsed thermal IRT system to thermally excite the structure using two 2400J Xenon flash lamps. For acquiring thermal and visual image streams, an off-the-shelf DJI Mavic 2 Enterprise Advanced drone [8] was used. The drone was navigated manually by a pilot in an indoor facility by maintaining a height of approximately 0.5 meters above the specimen while acquiring the thermal and optical footage. The experimental setup along with a typical frame extracted from the drone's optical and the thermal cameras is shown in Figure 1. Thermal and optical videos were acquired at a resolution of 640x512 and 1980x1020 pixels, respectively with 30 frames per seconds acquisition speed and saved in an .MP4 format [8] for further processing. Scene range setting was set to high gain, which allowed monitoring thermal features from -20 ℃ to 150 ℃ [8]. Since the drone IR camera, when used in the video mode is not radiometric and only provides RGB value from an MP4 video, a grayscale colormap was selected in the drone IR camera setting for ease of post-processing and to ensure a known color scale (i.e. -20 ℃ corresponding to black, and 150 ℃ corresponding to white). Auto level and auto range features from the IR camera were disabled so that the color scale remained constant for the entire acquisition duration. For comparison purposes, infrared images were also acquired from a stationary IR camera with a sensitivity of 0.02 ℃ and a spatial resolution of 240x320 pixels. There was no synchronization between the thermal excitation and the data recording using the drones' camera. Thus, the recording from the drone's camera was started manually a few seconds before the thermal excitation. The acquired thermal sequences were trimmed to remove any unwanted images, based on the spike in temperature corresponding to the point of flash excitation.

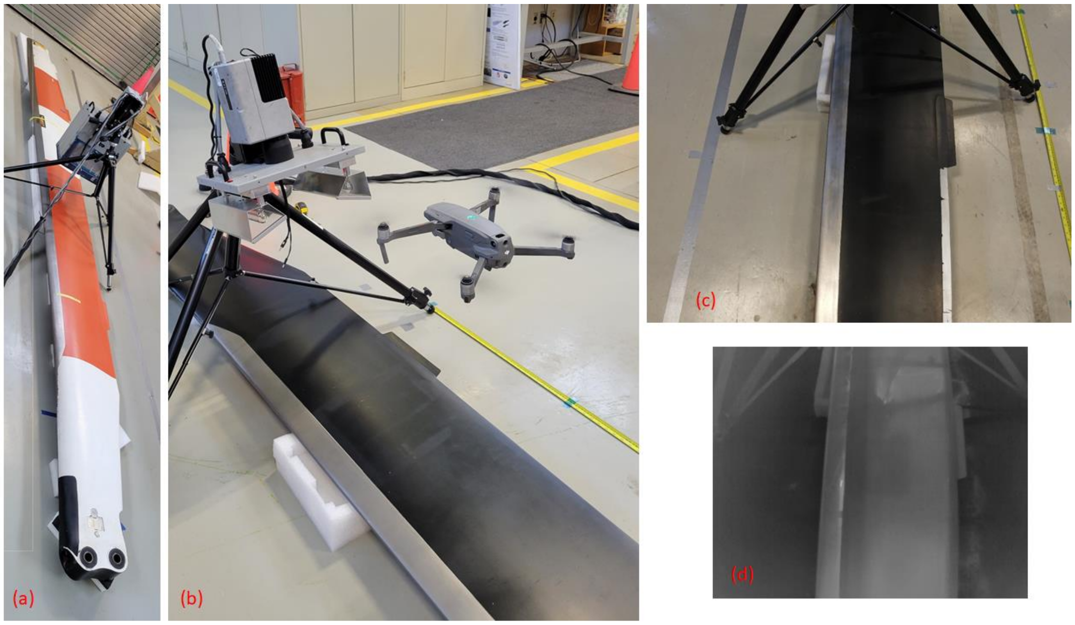


Figure 1: (a) Entire blade, (b) experimental setup, (c) optical image, and (d) thermal image acquired from the drone's camera.

3. ANALYSIS, RESULTS AND DISCUSSIONS

Active thermography relies on analyzing thermal evolution over time; therefore, any undesirable motions can disturb the pixel-wise alignment of consecutive frames adding to noise. Drones are inherently unstable, thus any videos acquired from a drone's camera will have some degrees of undesired motion even with on-board stabilization and gimbals. A quick study was performed to witness the effect of undesired motion on the final thermographic results. Sequences of thermal images acquired by a stationary thermal camera were randomly translated and rotated at varying degrees before processing. The post-processed results are shown in Figure 2, where the effect of random motion can be clearly seen. Even with a random motion of only ±5 pixels and ±5 degrees, as shown in Figure 2(c) it is difficult to perform any damage sizing. Therefore, video stabilization is required as a first step to minimize/mitigate any undesired motions prior to the application of signal processing technique especially for a drone based active thermographic system.

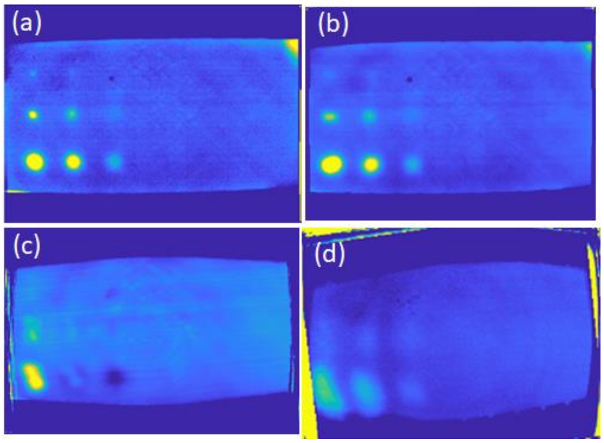


Figure 2: Results of thermographic analysis using sequences of thermal images that are: (a) steady, (b) randomly shifted by ±1 pixel and rotated by ±1 degree, (c) randomly shifted by ±5 pixels and rotated by ±5 degrees, and (d) randomly shifted by ±10 pixels and rotated by ±10 degrees.

For stabilizing the videos acquired from the drone, a previously developed procedure by the authors [9] was used with an addition of z-direction (zoom) for complete stabilization. The stabilization algorithm works on finding the motion between two consecutive frames by tracking user defined features, as shown in Figure 3. Feature selection is performed in two steps, first the algorithm finds all the features in the image, after which the user is asked to select the features with the highest concentration for improved tracking. A global trajectory is then found by compiling all the inter-frame motions. Finally, the difference between the original and the stabilized trajectory is used to shift, rotate, and scale the frames for stabilization. Optical video was used to track the features and extract the global trajectory, which was used for stabilizing both the optical and thermal image sequences.

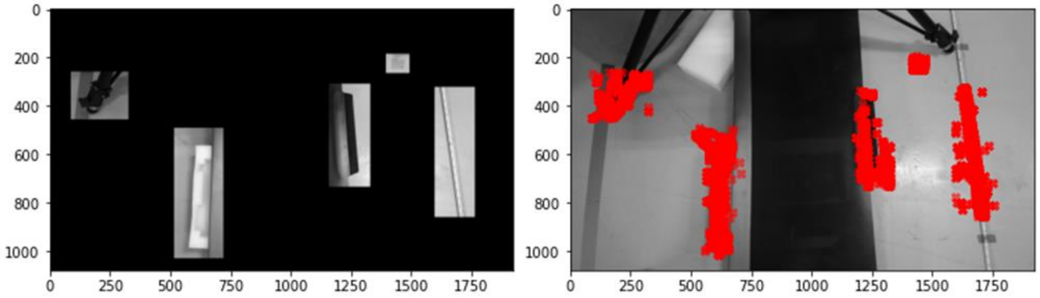
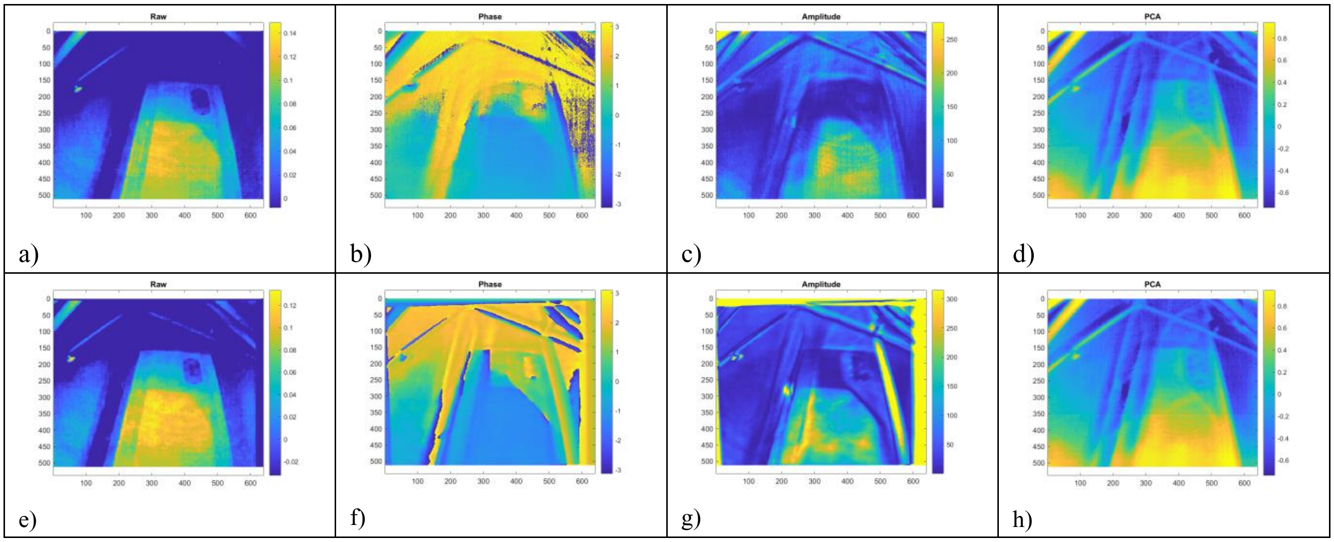


Figure 3: Example of user defined feature selection for improved tracking.

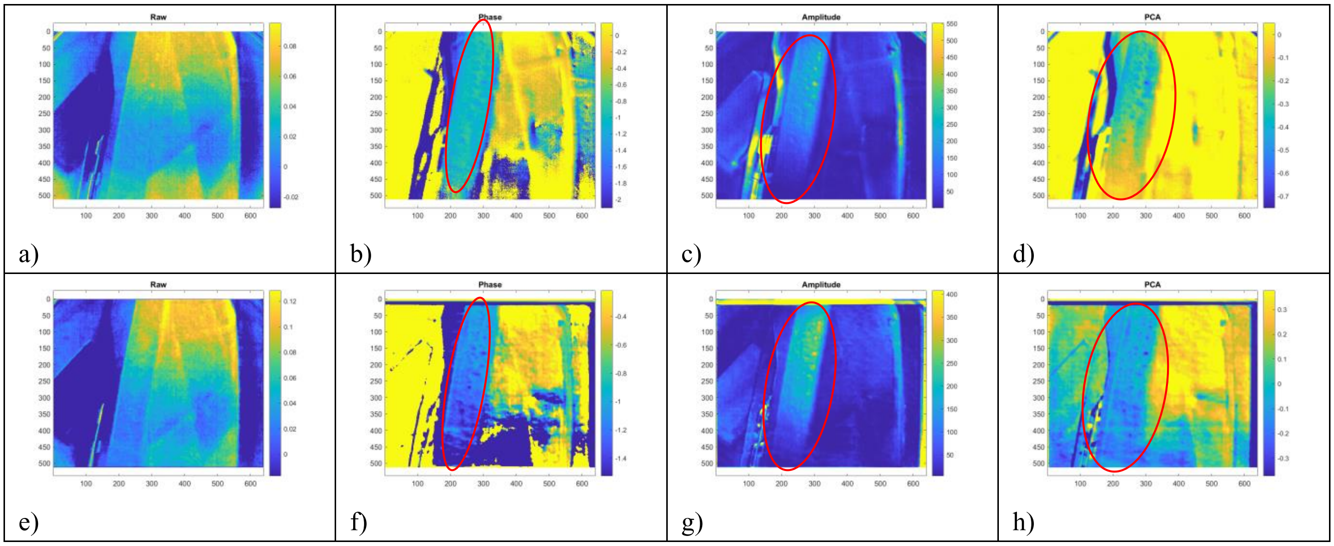
The thermal sequences were processed using typical signal processing techniques used in pulsed thermography such as pulsed phase thermography (PPT) [10] and principal component analysis (PCA) thermography [11]. Although thermographic signal reconstruction (TSR) [12] and TSR combined with 1st and 2nd derivative signal processing [13] were not employed in this study, the stabilization algorithm would also be beneficial for these techniques. Stabilized and unstabilized (original) sequences were processed using the PPT and PCA to highlight the benefits of the stabilization algorithm. Figures 4 to 6 present examples of raw and processed thermal images taken at different locations along the helicopter blade, which were arbitrarily chosen to illustrate the impact of sequence stabilization. The images are presented using Matlab Parula default colorscale instead of grayscale for purely esthetical and ease of viewing purposes.



a) b) c) d)

e) f) g) h)

Figure 4: **Unstabilized top-row:** a) raw image of a single frame, b) phase image, c) amplitude image, d) PCA first component; **stabilized bottom-row:** e) raw image of a single frame, f) phase image, g) amplitude image, h) PCA first component.



a) b) c) d)

e) f) g) h)

Figure 5: **Unstabilized top-row:** a) raw image of a single frame, b) phase image, c) amplitude image, d) PCA first component; **stabilized bottom-row:** e) raw image of a single frame, f) phase image, g) amplitude image, h) PCA first component.

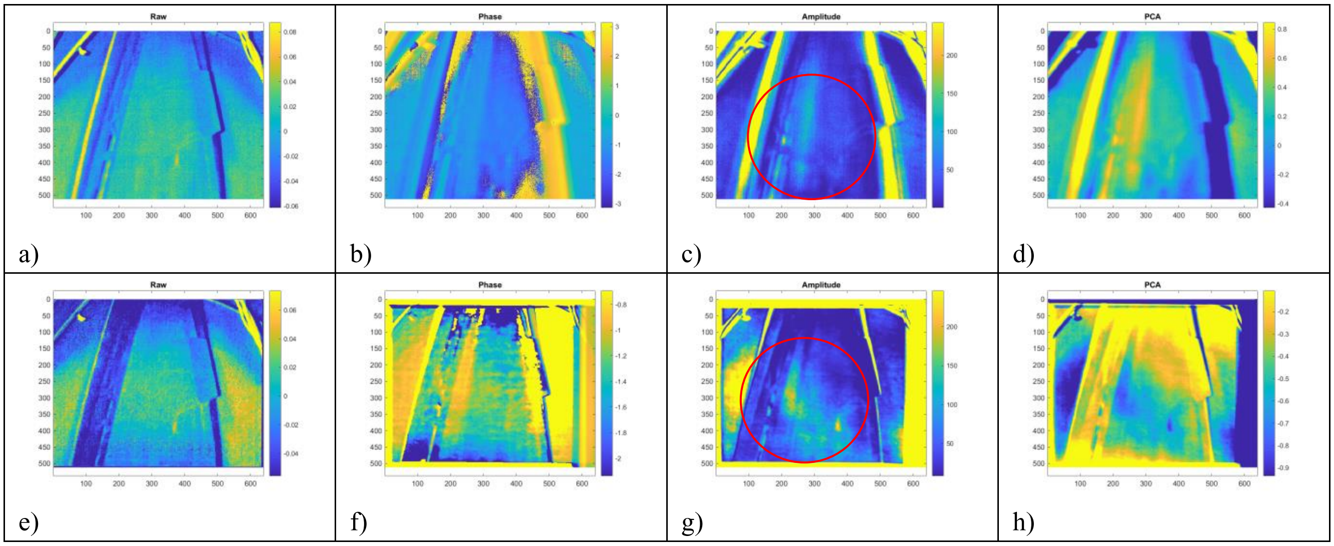


Figure 6: **Unstabilized top-row:** a) raw image of a single frame, b) phase image, c) amplitude image, d) PCA first component; **stabilized bottom-row:** e) raw image of a single frame, f) phase image, g) amplitude image, h) PCA first component.

In the figures above, it can be seen that raw unprocessed thermal data can be used to see shallow and large thermal anomalies from the structure. For deeper anomalies and features with faint thermal signatures, the stabilized version resulted in much sharper edge definition and better overall detection as compared to the unstabilized version, which are observable in Figure 5 and Figure 6. In Figure 5, more voids or access adhesive pockets, at the leading edge of the MRB (area circled in red), are discernable in the stabilized version. Whereas, in Figure 6, deeper anomalies were better seen in the stabilized sequence as highlighted by the red circle. Due to the different field of view between the drone IR camera and the stationary IR camera, a direct comparison between the stationary sequence and the drone captured sequence cannot be performed at the exact same location. Nonetheless, Figure 7 presents some examples of raw and processed thermal images obtained using the stationary setup at approximately the same areas as shown in Figures 5 and 6, where similar thermal patterns can be observed.

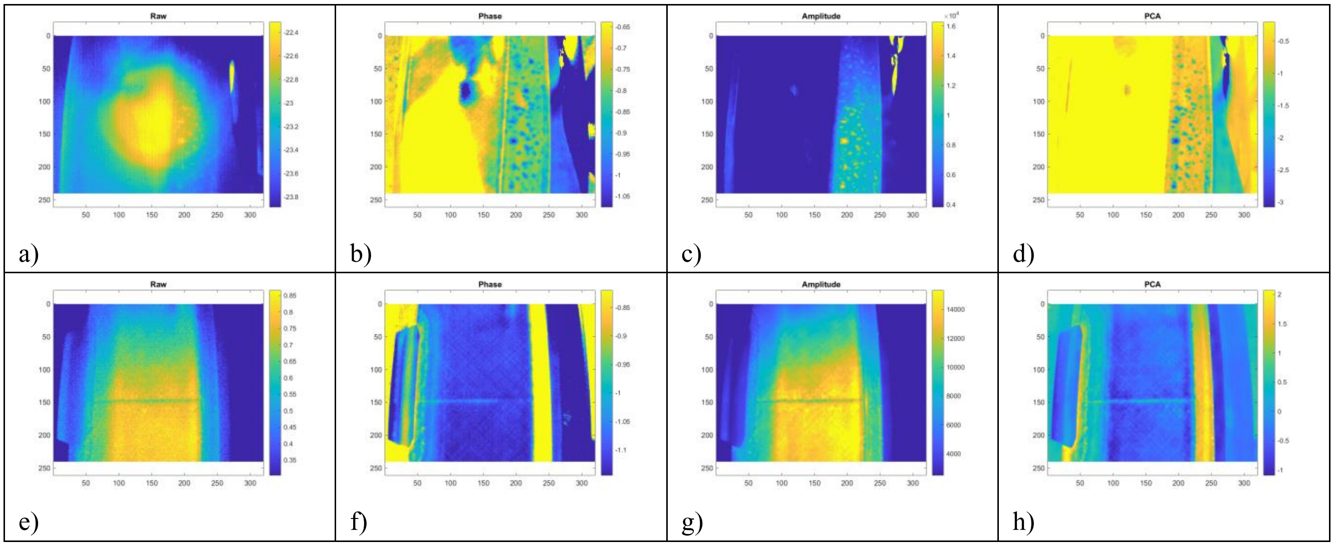


Figure 7: **Stationary sequence 1:** a) raw image of a single frame, b) phase image, c) amplitude image, d) PCA first component; **stationary sequence 2:** e) raw image of a single frame, f) phase image, g) amplitude image, h) PCA first component.

In Figure 7, it can also be noticed that the signal contrast is much better on the stationary system and the thermal features are more discernable. This was to be expected due to the higher thermal sensitivity of ±0.02 ℃ using a cooled detector as compared to grayscale images from the drone's camera using an uncooled detector. It is also believed that the position of the flash was better suited for the field of view of the stationary IR camera than that for the drone IR camera, even though the distance between the camera and the target was more or less the same. To further improve the results or if exact temperature values are needed it would be possible to perform an external calibration of the drone's IR camera to obtain the MP4 colorscale values. Although, the commercial IR system does evidently provide better results, the drone based active thermography approach presented in this work was able to detect the surface / sub-surface anomalies, which could not be seen in the optical and raw thermal images. Therefore, this work demonstrated the possibility of drone based active thermography inspection. However, further development such as: incorporating powerful heating source on-board the drone to provide ample thermal gradient without affecting or blocking the field of view [14] and autonomous capabilities are required for full utilization of this novel technique. Finally, a fully dynamic configuration in which the drone carrying the cameras and the heating source would scan the inspected component surface at constant speed while recording visible and thermal sequences, would also constitute an interesting approach worth of further research.

4. CONCLUSIONS

A drone based active thermography approach is demonstrated to detect sub-surface damage / anomalies in a Bell 412 helicopter blade in an indoor environment. It was found that image stabilization is required despite the drone had built-in stabilization to stabilize the drone, as well as, a gimbal to stabilize the camera. The raw and unprocessed infrared (IR) images from the drone mounted IR camera can be used for some quick observation of surface anomalies. However, for detecting deeper anomalies and those with faint thermal signatures, stabilized thermal sequences with advanced signal processing techniques such as: pulsed phase thermography, principal component analysis thermography, etc. are required. It was also shown that radiometric data is not required to perform the analysis and that using an MP4 video without exact temperature value provided sufficient information to detect surface and sub-surface anomalies, which could not be seen in the optical images. Overall, the possibility of using an off-the shelf drone equipped with thermal and optical cameras for active thermography inspection is demonstrated.

REFERENCES

[1] Tsouros, D. C., Bibi, S., and Sarigiannidis, P. G., A Review on UAV-Based Applications for Precision Agriculture, Information, Vol. 10 (11), 2019.

[2] Ortiz-Sanz, J., Gil-Docampo, M., Arza-García, M., and Cañas-Guerrero, I., IR Thermography from UAVs to Monitor Thermal Anomalies in the Envelopes of Traditional Wine Cellars: Field Test. Remote Sens, Vol. 11, 2019.

[3] Kim, D., Youn, J., and Kim, C., Automatic Fault Recognition of Photovoltaic Modules Based on Statistical Analysis of UAV Thermography," International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 42(2w6), pp. 179–182, 2017.

[4] Vacca, A. and Onishi, H., Drones: military weapons, surveillance or mapping tools for environmental monitoring? The need for legal framework is required, Transportation Research, Vol. 25, pp. 51-62, 2017.

[5] Nooralishahi, P., Ibarra-Castanedo, C., Deane, S., López, F., Pant, S., Genest, M., Avdelidis, N.P., and Maldague, X. P. V., Drone-Based Non-Destructive Inspection of Industrial Sites: A Review and Case Studies. Drones, Vol. 5(4), 2021.

[6] Avdelidis, N. P., Hawtin, B. C., and Almond, D. P., Transient thermography in the assessment of defects of aircraft composites, J. NDT & E International Vol. 36 (6), pp. 433-439, 2003.

[7] Ibarra-Castanedo, C., Piau, J. M., Guilbert, S., Avdelidis, N. P., Genest, M., Bendada, A., and Maldague, X. P. V., Comparative study of active thermography techniques for the nondestructive evaluation of honeycomb structures, J. Research in Nondestructive Evaluation, Vo. 20, pp. 1-31, 2009.

[8] DJI, "Mavic 2 Enterprise Series", (2 February 2023). Mavic 2 Enterprise Advanced - Specs - DJI

[9] Pant, S., Nooralishahi, P., Avdelidis, N. P., Ibarra-Castanedo, C., Genest, M., Deane, S., Valdes, J. J., Zolotas, A., and Maldague, X. P. V., Evaluation and Selection of Video Stabilization Techniques for UAV-Based Active Infrared Thermography Application. Sensors, Vol. 21, 2021.

[10] Ibarra-Castanedo, C. and Maldague, X. P. V., Pulsed phase thermography reviewed. Quant. InfraRed Thermogr. J. Vol. 1, 47–70, 2004.

[11] Rajic, N., Principal component thermography for flaw contrast enhancement and flaw depth characterisation in composite structures. Compos. Struct. 58, 521–528, 2002.

[12] Shepard, S. M., Lhota, J. R., Rubadeux, B. A., Wang, D., and Ahmed, T., Reconstruction and enhancement of active thermographic image sequences. Opt. Eng. 42, 1337–1342, 2003.

[13] Martin, R. E., Gyekenyesi, A. L., Shepard, S. M., Interpreting the results of pulsed thermography data. Mater. Eval. 61, 611–616, 2003.

[14] Deane, S., Avdelidis, N.P., Ibarra-Castanedo, C., Williamson, A.A., Withers, S., Zolotas, A., Maldague, X.P.V., Ahmadi, M., Pant, S., and Genest, M., Development of a Thermal Excitation Source Used in an Active Thermographic UAV Platform. Quantitative InfraRed Thermography Journal, 1–32, 2022.