Track check in Helicopter using Image processing

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***Abstract*—Helicopters inherently exhibit various types of vibrations that can result in crew discomfort, structural fatigue, and safety concerns leading to potential accidents. Vertical vibrations, often stemming from blade misalignment or ”out of track” conditions, pose a significant challenge. This project aims to track vertical vibrations during blade tracking through image processing. The proposed approach offers a cost-effective and straightforward alternative to existing methods in the industry.**

The method comprises several key steps, including image filtering, image thresholding, precise blade tip position determination, and the conversion of pixel distances into real-world measurements. Ultimately, the study calculates the deviations between the tips of each blade relative to a reference blade. Experimental results substantiate the effectiveness and accuracy of the proposed methodology.

***Index Terms*—blade tracking, rotor tracking, rotor track and balance, vertical vibrations in Helicopters**

I. Introduction

Helicopters are widely used in modern aviation for their ability to hover and perform vertical takeoffs and landings. However, helicopter rides are often uncomfortable due to the significant levels of vibrations they produce. These vibrations can lead to structural issues and even accidents. There are two main types of vibrations in helicopters: vertical and lateral. Vertical vibrations, in particular, are caused by the rotor blades being out of alignment, as illustrated in Figure 1. This type of vibration makes the helicopter bounce up and down during flight. It occurs because one of the blades lifts the helicopter during one part of its rotation but loses lift in the remaining quadrants.

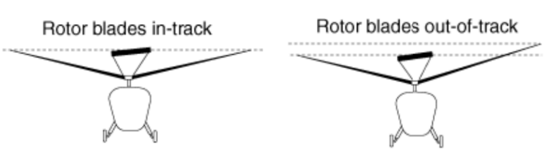


Figure 1: In-track and out of track b blades

Blade tracking is a critical process used to manage vertical vibrations. It involves calculating and adjusting the vertical position of each blade's tip based on its position in the air. Typically, one blade is selected as a reference, and the position of the other blades' tips is measured relative to this reference blade. If the difference in blade tip position falls within a certain threshold (usually around 20 mm), the blades are considered to be in track; otherwise, they are deemed out of track or misaligned. This threshold may vary for different helicopter models. Blade tracking can be performed both in-flight and on the ground.

Various methods have been employed in the past for blade tracking. The oldest method is known as flag tracking, where each blade is painted with a different colored wet paint, and an operator holds a flag near the rotating blade tips. When the blades touch the flag, marks are left on it, and the out-of-track values are determined from these marks. The drawbacks to this method are obvious. It was dangerous, restricted to ground only, and did not allow for track measurements in flight. The use of static rotor balancing devices is not applicable to some aircraft.

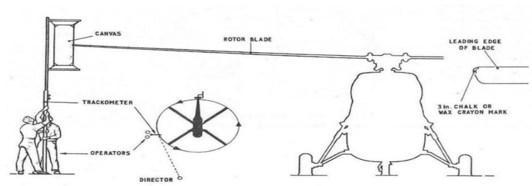


Figure 1: Tracking Balancing Helicopters - Evolution in equipment

Over the past few decades, various methods have been explored for blade tracking in helicopters. One approach involved radar systems like the Micropower Impulse Radar (MIR), which offered exceptional accuracy but came with a high cost and complexity.

Vibration sensors mounted at specific locations on the airframe were another avenue of development. While these sensors helped reduce vertical vibrations, they didn't ensure perfect blade alignment.

Several optical methods also emerged for obtaining blade tracking data without attaching targets to the blade tips or visually estimating rotor blade positions from a distance. However, a drawback of these systems was that the influence coefficients used in the software varied from one aircraft to another of the same make and model.

All the previously employed techniques had their limitations, and the ones without drawbacks were often expensive. Therefore, a simple blade tracking technique is proposed to address these issues. The objectives of this technique include:

1. Reducing vertical vibrations.

2. Designing a system suitable for indoor/outdoor use and in-flight/on-ground operation.
3. Developing a system that requires no modifications to the blades like attaching sensors to blade tips.
4. Creating an affordable system.

This approach utilizes image processing techniques and is divided into several steps, including image filtering, image thresholding, precise determination of each blade's position, and conversion of pixel distances into real-world measurements. This method aims to provide accurate results while overcoming the drawbacks associated with previous techniques.

II. PROPOSED METHODOLOGY

The implementation of the proposed work leverages computer vision and is structured into two distinct steps.
The first step centers on blade tracking. In this phase, images of the tips of the helicopter's rotor blades are captured and subjected to image processing techniques. The primary objective here is to analyze these images to determine the extent to which the blades are out of alignment or "out of track." By comparing the positions of the blades in the images, the system calculates the degree of misalignment between them. This information is valuable for assessing and addressing any issues related to blade tracking and alignment.

The second step involves calibration, which entails the creation of a reference table that establishes the relationship between pixels and distance. This calibration process is carried out by capturing images of a known rectangular shape, allowing for the calculation of the pixel-to-distance ratio. This table becomes a crucial reference point for mapping pixels to real-world distances in subsequent stages of the process.

A. Calibration Process

The purpose of this process is to determine how many pixels correspond to a specific rectangular shape at varying distances. The below table shows the relationship between the number of pixels and the corresponding distances. This table is crucial for the subsequent step.

The calibration process involves a camera, a piece of paper with a printed rectangular shape, and a movable holder on a scaled bench. The rectangular shape on the paper has a known length of 3.86 centimeters. The paper is attached to the movable holder, which is initially positioned 10 centimeters away from the starting point on the optical bench. The camera is placed at the 0-centimeter mark on the bench, aligned to capture the rectangular shape.

A simple program is developed to capture an image of the paper and determine the number of pixels that make up one row of the 3.86-centimeter-long rectangle. These pixel counts are recorded in a table alongside their corresponding distances. The holder is then moved in 5-centimeter increments along the bench, and new pixel counts are recorded and added to the table. This process is repeated until the maximum scale on the optical bench is reached. Table 1 provides the initial values, showing how many pixels are needed to represent a 3.86-centimeter line when viewed from various distances.

TABLE-I:CALIBRATION DATA

Distance(cm)	**No of pixels**
10	a1
15	a2
20	a3
25	a4
30	a5

Then the coefficients of a polynomial p(x) of degree n are calculvcted which fit the first column of Table 1 to the second column of the table (i.e. distance to number of pixels), in a least squares sense.
The calibration process is complete here. The coefficients calculated here are stored in the form of an array and will be used later in the next step.

III. BLADE TRACKING

The next step involves creating an experimental setup that mimics the configuration of a helicopter. Subsequently, a program is developed to detect the degree of misalignment between the blades' tips within this experimental setup. To understand this process better, we'll provide an overview of the equipment involved and some fundamental helicopter concepts.

In helicopters, a magnetic pickup is typically affixed to the non-rotating shaft of the main rotor. This pickup is utilized to measure the rotor's speed of rotation, expressed in revolutions per minute (RPM). The working principle of a magnetic pickup is straightforward: it comprises a coil and a permanent magnet. When a piece of metal passes through the magnetic field created by the pickup, it disrupts the magnetic flux, generating a pulse signal. As the rotor starts to rotate, a metal target on the rotor blades periodically interrupts the magnetic field, generating signals at the output of the magnetic pickup.

In the experimental setup described in this work, a photogate is used instead of the magnetic pickup. The photogate operates in a similar manner to the magnetic pickup, producing a pulse signal whenever a rotor blade passes through it.

To gain a more comprehensive understanding of the implementation of this program and the experimental setup, further details and results are provided in Section 3. However, it's important to note that this brief introduction outlines the equipment and principles involved in this process.

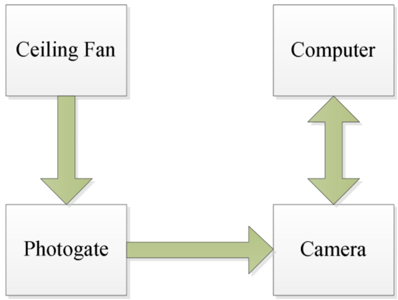


Figure 2: Diagram of experimental setup

A. Blade Tracking

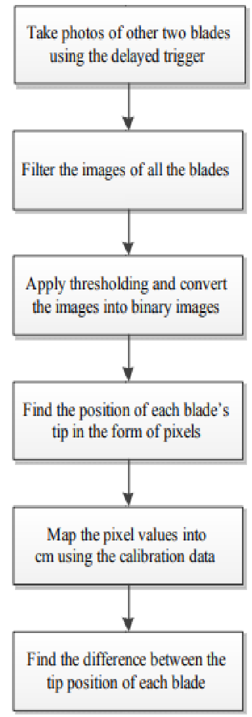
The subsequent phase involves creating an experimental setup that closely resembles the configuration of a helicopter. Subsequently, a program is designed to identify the degree of misalignment between the tips of the blades within this experimental setup. To comprehend this process better, it's essential to provide an overview of the equipment used and some fundamental helicopter concepts.

In conventional helicopters, a magnetic pickup is typically affixed to the non-rotating shaft of the main rotor. This magnetic pickup serves the purpose of measuring the rotor's speed of rotation, expressed in revolutions per minute (RPM). The operational principle of a magnetic pickup is remarkably straightforward: it comprises a coil and a permanent magnet. When a piece of metal passes through its magnetic field, it disrupts the magnetic flux, thereby generating a pulse signal. As the rotor begins to rotate, a metal target on the rotor blades intermittently cuts through the magnetic field, leading to the generation of signals at the output of the magnetic pickup [8].

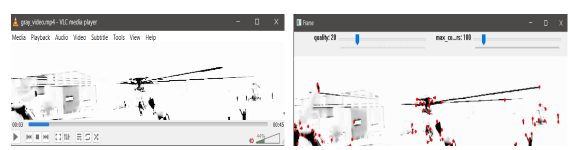
In the experimental setup described within this work, a photogate is employed in place of the magnetic pickup. The photogate operates in a similar manner to the magnetic pickup, producing a pulse signal whenever a rotor blade passes through its path.

B. Blade tip detection

Blade tip detection and vertical tracking can often be achieved through traditional computer vision techniques and algorithms



1. **Image Processing Techniques:** Depending on the quality and characteristics of your helicopter video or images, you can apply image processing techniques such as edge detection, contour detection, and geometric analysis to locate the blade tip and track its vertical position.
2. **Thresholding:** You can use thresholding techniques to isolate the helicopter blades from the background. This can be effective if the background is relatively uniform.



3. **Edge Detection:** Apply edge detection algorithms like Canny or Sobel to detect the edges of the helicopter blades. Once you have the edges, you can find the blade tip by identifying the highest point along the detected edges.

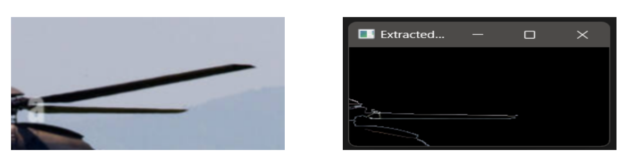


Figure 1: Edge detection of sample blade image

4. **Contour Analysis:** Utilize contour analysis to find the blade's contour, and then calculate the center or tip of the contour. This can work well for well-defined blade shapes.

Figure 1: Corners detection of sample helicopter video

5. **Template Matching:** If the helicopter blades have distinct shapes or patterns, you can use template matching to locate them in the images.
6. **Optical Flow:** Optical flow techniques can be used for tracking the movement of the blade tip over consecutive frames in a video.
7. **Kalman Filtering:** Implement Kalman filters or other tracking algorithms to estimate the vertical position of the blade tip over time. This can help smooth out noisy measurements.
8. **Camera Calibration:** Ensure that your camera is calibrated correctly to accurately convert pixel coordinates to physical measurements.

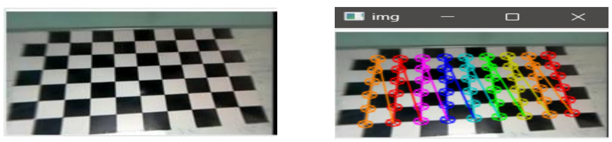


Figure 1: Camera Calibration

9. **Finding Blade Tip Positions:** In our research, we needed to find the position of the tips of the rotor blades in the images. To do this, we took images of the helicopter rotor where the blades appeared flat (horizontally aligned). The tip of each blade looked like a straight line in the image. We used a computer program to identify this straight line edge, which represented the tip of the blade. We also measured the X-position (horizontal position) of the tip of each blade in relation to a reference blade (we called it Blade A). This helped us calculate how far each blade was from the reference blade.
10. **Mapping Pixels to Distance:** After finding the positions of the blade tips in pixels, we needed to convert these pixel values into real distances (in centimeters). We used a mathematical formula that involved a polynomial coefficient to do this mapping accurately. This step allowed us to know the actual distance between the blades.
11. **Calculating Blade Differences:** to be done

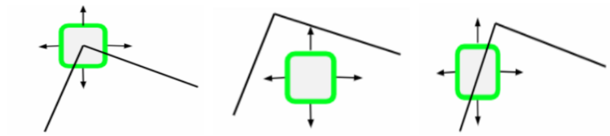
C. Corner Detection

The corners of an image are basically identified as the regions in which there are variations in large intensity of the gradient in all possible dimensions and directions. Corners extracted can be a part of the image features, which can be matched with features of other images, and can be used to extract accurate information.

D. Harris Corner Detection

Basic intuition is that corners can be detected by looking for significant change in all direction. We consider a small window on the image then scan the whole image, looking for corners. Shifting this small window in any direction would result in a large change in appearance, if that particular window happens to be located on a corner.

1) Flat regions will have no change in any direction.
2) If there's an edge, then there will be no major change along the edge direction.



E. Mathematical Overview

For a window(W) located at (X, Y) with pixel intensity I(X, Y), formula for Harris Corner Detection is –

$$f(X,Y) = \sum (I(Xk,Yk) - I(Xk + \Delta X, Yk + \Delta Y))^2 \tag{1}$$

where (Xk, Yk) ϵ W
According to the formula:
If we're scanning the image with a window just as we would with a kernel and we notice that there is an area where there's a major change no matter in what direction we actually scan, then we have a good intuition that there's probably a corner there.

Calculation of f(X, Y) will be really slow. Hence, we use Taylor expansion to simplify the scoring function, R.

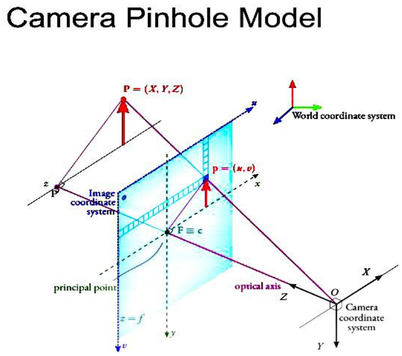
$$R = min(\lambda 1, \lambda 2) \tag{2}$$

F. Camera Calibration

In order to use the camera as a visual sensor, we should know the parameters of the camera. **Camera Calibration** is nothing but estimating the parameters of a camera, parameters about the camera are required to determine an accurate relationship between a 3D point in the real world and its corresponding 2D projection (pixel) in the image captured by that calibrated camera.

We need to consider both internal parameters like focal length, optical center, and radial distortion coefficients of the lens etc., and external parameters like rotation and translation of the camera with respect to some real world coordinate system.

The process of camera calibration involves using chessboard images captured from different angles and positions. OpenCV's functions are employed to detect the corners of the chessboard within the images. These detected corners are then used to calculate crucial parameters, including the camera matrix, distortion coefficients, rotation vectors, and translation vectors.



1) Parameters:

1. **Distortion:** Cameras introduce distortion due to lens imperfections. The two main types are radial distortion (straight lines appear curved) and tangential distortion (image appears skewed). These distortions can significantly affect image analysis and 3D reconstruction accuracy.
2. **Intrinsic Parameters:** Intrinsic parameters are camera-specific properties, including focal length (fx, fy) and optical centers (cx, cy). They form the camera matrix and help correct distortions. A common representation is the pinhole camera model.
3. **Extrinsic Parameters:** Extrinsic parameters involve rotation and translation vectors that position the camera's coordinate system relative to a world coordinate system. These parameters are crucial for 3D scene reconstruction.
4. **Calibration Pattern:** A known pattern (e.g., chessboard) is placed in front of the camera. The pattern's 3D coordinates and corresponding 2D image coordinates are used to calibrate the camera.
5. **Re-projection Error:** After calibration, re-projected image points are compared with detected image points. Lower re-projection error indicates more accurate calibration.

2) Mathematical Formulations::

1. **Radial Distortion:** Radial distortion is approximated using a polynomial expression:
$$x_{distorted} = x(1 + k_1 r^2 + k_2 r^4 + k_3 r^6)$$
$$y_{distorted} = y(1 + k_1 r^2 + k_2 r^4 + k_3 r^6)$$
2. **Tangential Distortion:** Tangential distortion is caused by lens misalignment:
$$x_{distorted} = x + [2p_1 xy + p_2(r^2 + 2x^2)]$$
$$y_{distorted} = y + [p_1(r^2 + 2y^2) + 2p_2 xy]$$
3. **Camera Matrix:** The camera matrix combines intrinsic parameters and maps 3D points to 2D image coordinates:
$$Distortion\ coefficients = (k_1 \quad k_2 \quad p_1 \quad p_2 \quad k_3)$$

$$camera\ matrix = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$$

Done

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Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include Acknowledgments and References and, for these, the correct style to use is "Heading 5". Use "figure caption" for your Figure captions, and "table head" for your table title. Run-in heads, such as "Abstract", will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

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TABLE I
TABLE TYPE STYLES

Table Head	Table Column Head		
	Table column subhead	***Subhead***	***Subhead***
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[a]Sample of a Table footnote.

Fig. 1. Example of a figure caption.

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References

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