Application of remote sensing in airport runway crack detection using canny detection and morphological operations

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Abstract. With the tremendous growth of the aviation sector, aviation safety becomes increasingly prominent and generally worrisome. Aircraft safety issues exist not just during flight, but also during take-off and landing. Airport runway flaws like cracks and potholes, as well as runway foreign matter (FOD), provide significant concealed threats that risk aircraft take-off and landing, small dips on the runway might cause the aircraft to deviate, and foreign objects on the runway can puncture the tires, causing it to explode. Airport runway safety detection is critical. Remote sensing has a vital role in detecting and monitoring an area's physical qualities at a distance. It required high-accuracy cameras to acquire remotely sensed photos which are used in the detection of cracks on the runway surface. These cracks are one of the first signs of structural deterioration, which is crucial for maintenance, and used in upgrading the runway condition. Fracture identification on the surface of a runway by automated analysis of optical images. Firstly, canny edge detection is used to detect the cracks in the acquired images. Secondly, morphological operations were made to enhance the result of canny edge detection such as opening, closing, Skeletonization, Boundary extraction, and others. Thirdly, the analysis of the results was made to compare the length, average width, and area of the cracks to the manual detection of the visualized cracks. The proposed algorithm was found to be highly useful for analyzing surface fractures as well as classifying them, which gave high accuracy results of imaged edge detection.

Keywords: Remote sensing, Morphological operations, Canny operator, runway cracks detection, aerospace safety.

1. Introduction

Recently, air transportation had a vital role in the economic growth across the world. Aviation safety has become the most important concern. The major risk in the aviation sector is presented in the take-off and landing accidents accounted for 34% of all serious aircraft accidents [1]. The International Civil Aviation Organization demands that all aircraft that run out of runway be protected from damage. Nowadays, the global concern is about the pain and loss caused by aircraft disasters. A high majority of aviation tragedies happened when airplanes take off and land, while accidents caused by foreign object debris (FOD) account for a share of these disasters. FOD is an abbreviation for foreign substances, debris, or items that may cause harm to an aircraft, such as metal components, shattered stones, and runway pavement cracks. The maintenance of fractures in runway pavements became an important part of airfield care to achieve safe runway functions to accomplish cost-effectiveness in fracture repair and maintenance [2]. Pavement fractures are frequently prioritized for maintenance based on their severity levels in practice. The severity of fractures is judged subjectively by airport technicians based on their opinion and expertise. Generally, crack severity is determined by the diameter of the fracture. breadth, length, and density of cracks. The technique overcomes various shortcomings by methods of prioritizing that take into account the size and features of fractures (including fracture depth) and also landing and take-off rate by aircraft type, and statistical distributions of their landing and take-off wheel loads, and touch-down positions [3]. The cracks of airport runways can be detected in remotely sensed images [4]. Remote sensing is characterized by "the scientific knowledge of distant observation." As a result, it differs from in situ sensing. Currently, remote sensing is used in various sectors, including space exploration, medical (diagnostic and surgery), and manufacturing (product quality control) - as well as environmental research, which is our present focus that is used in runway crack detection. It is required high-accuracy cameras to acquire remotely sensed photos. The creation of high-speed picture capture systems is used for collecting information regarding pavement surface quality [5] as well as automatic image processing that is used for identifying and classifying defects [6].

Several fracture detection approaches are presented including automated crack. The main advantage of using the image-processing method in crack identification is that it is faster and less expensive than manual methods. A crack can be identified in two directions; destructive and non-destructive testing. Destructive testing is a kind of examination that examines how a component can respond when subjected to extreme pressure till it fails while, non-destructive testing evaluates an object's attitude without destroying it [7]. Images with high spatial and spectral resolutions generate massive volumes of data that must be processed quickly and efficiently to get the required information [8]. Correctly, processed data provide a trustworthy evaluation of the state of the runway. The deployment of asphalt pavement image analysis techniques presents certain problems, as it necessitates extensive data processing algorithms to address variations in pavement state and texture. A collection of image processing techniques for analyzing photos captured during airport runway surveys to automatically detect and describe runway fractures is the most prevalent kind of pavement surface flaw on the runway. According to the state-of-the-art crack identification and description, the suggested image-processing tool is the best tool for automated fracture identification and description. Rapid detection allows for the use of preventative actions to avoid harm and failure. The process of noticing a fracture in a structure by using processing techniques known as crack detection. For dependability, fractures must be reliably diagnosed by measuring their lengths. Surface condition deficits are determined using eye examination and surveying techniques [6].

This paper aims to determine the area, breadth, and length of cracks on the structural surface to reveal the runway pavement's early deterioration stage [9]. The main advantage of image-processing techniques, is that it gives a more accurate outcome than traditional manual techniques. The complexity of fault detection processing is dependent on image size. Recent digital cameras offer image resolutions that exceed 10 megapixels aiming to increase the resolution to take detailed photographs of pavement surfaces [10]. The classification of observed fractures is identified as block cracking, delamination, edge cracks, fatigue cracks, edge cracks, longitudinal cracks, potholes, and thermal cracks [11].

2. Edge Detection

Edge detection is a vital issue in image processing. It is a key tool in pattern identification and picture segmentation. Edge detector is just a pass filter that may be used to extract picture edge points. It is a concept used in image processing to describe techniques like feature selection and feature extraction fields as well as their vision. An edge detector takes a digital picture as inputs and outputs like an edge map [12]. Various detectors' edge maps offer express information about the location, strength, and direction of the edges, in terms of its design, and edge-detection techniques [13]. Many spatial edge detectors have been created over time. Edge detection is achieved by convolution with a collection of direction derivative masks [14]. The common edge detection operators, such as Roberts, Sobel, Prewitt, and canny are all specified on 3 by 3 pattern grid [15], making them efficient and simple to implement. In the next sections, different edge detection will be discussed briefly.

2.1 Roberts detector

One of the two kernels in Robert detector is displaced by 90° concerning the other. This edge detector quickly measures a 2D spatial gradient on an object image. The kernels are being utilized to assess the gradient's direction and magnitude in Roberts detector. Merits such as simple, straightforward calculations, and edges direction are identified. Besides, cons in which they are always more susceptible to noise. Edge detection is imprecise and less dependable.

2.2 Sobel detector

Several kernels could be used to determine the gradient's direction and magnitude. The primary use of Sobel edge detection is to locate edges in a picture along the horizontal and vertical axes. As a result, this edge detector attempts to recognize edges in both horizontal and vertical directions, which are then integrated like a single metric. Merits such as simple, straightforward calculations, and edges direction are identified. And cons in which they are always more susceptible to noise. Edge detection is imprecise, and Less dependable.

2.3 Prewitt detector

The Prewitt detector is quite similar to the Sobel operator. That has merits such as simple, straightforward calculations, and edges direction is identified. And cons as they are always more susceptible to noise, Edge detection is imprecise, and Less dependable.

2.4 Canny detector

Canny edge detection is the most convenient approach for detecting step edges. Canny designed his edge detector using three criteria. Initially, the reliable edge has a likelihood of missing actual edges and a high probability of identifying fake edges[16]. Secondly, the detected edges are as close to the genuine position of the edge as possible. Finally, there should only be one response to a single edge (thin lines for edges). This is equivalent to improving the signal-to-noise ratio [17], Image edge detection lowers data, eliminates extraneous information, and maintains crucial structural aspects of pictures. From the previous discussion, the canny edge detector used as the optimum edge detection method [10]. Edge detection is the technique of determining the borders of objects or textures in a picture. An edge is defined as a difference in intensity from one pixel to the next**.** Counted on these requirements, the canny detector begins by smoothing the picture to remove noise [4], Identifies the gradient picture to display locations with high derivatives. The algorithm monitors the regions with top derivatives to a tone pixel that is not at its peak (non-maximum suppression) [18]. The leftover pixels are further decreased by T1 and T2 which are two thresholds [19]. If the magnitude is less than T1, it has been set to zero (no edge). If it is more than T2, an edge was provided. If the intensity is within the two thresholds, it is set to zero unless otherwise specified. a route exists from this pixel to a pixel with a gradient greater than T2.

Step 1: Gaussian filter to eliminate noise

The initial stage in canny edge detection is to remove any noise from the source image before attempting to identify and detect any edges. The Gaussian filter is used to blur and eliminate undesirable detail and noise. The Gaussian smoothing may be achieved using the usual convolution approach by computing a sufficient 5 X 5 mask. The wider the Gaussian mask, the lower the detector's sensitivity to noise. The intensity of the noise is reduced or blurred when the standard deviation is increased. As an illustration in equation (1), consider the 2D Isotropic Gaussian equation:

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (1)$$

Step 2: Calculating the gradient

After smoothing the picture and removing noise, the following step is to determine the edge strength by calculating the image gradient; there are several methods and masks for calculating the gradient. One of these methods is to compute the difference in intensity between two successive pixels in both directions (x and y). When searching for edges, seek for the set drop as the steepest ascend since both imply a significant shift in picture intensity as shown in figure (1).

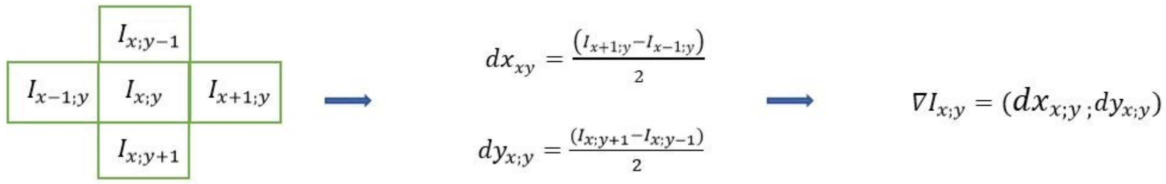

Figure 1. Explanation of gradient computation in canny detector.

1- Once obtain the gradient intensity for each pixel, we can calculate the magnitude and orientation of the gradient by doing the following in equation 2:

$$|\nabla I_{x,y}| = \sqrt{(dy_{x,y})^2 + (dx_{x,y})^2} \quad (2)$$

2-The main goal is to emphasize locations with large spatial derivatives. The following equation 3 is used to compute the edge's orientation:

$$\theta = \text{arc tan}\left(\frac{dy_{y,x}}{dx_{x,y}}\right) \quad (3)$$

3- Step 3: Non-Maximal Suppression.

This step uses the amplitude and orientation of the gradient at the pixel in question to generate one pixel-width edge as shown in figure 2.

- Interpolate the values of the pixels located in the vicinity of the location under consideration.
- A pixel with no removal of the local maximum gradient intensity.
- A The real pixel is compared to its neighbor's along the gradient's direction.

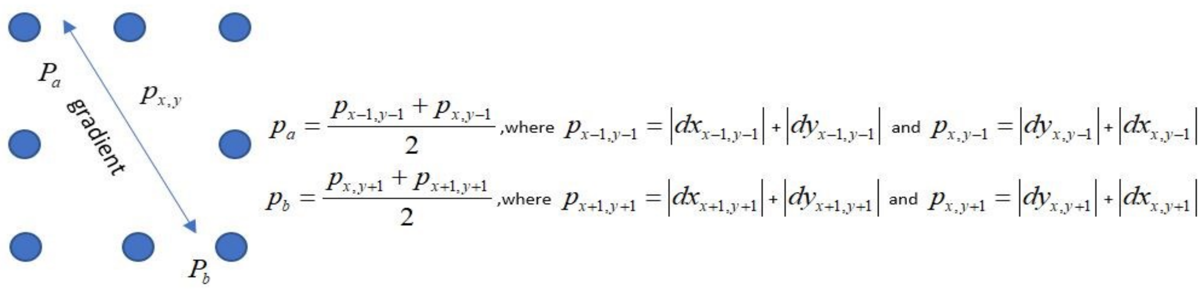

Figure 2. Non-Maximal Suppression procedure on image

4- Step 4: Hysteresis.

Currently, the issue is that some pixels, although representing a local maximum, may represent noise. Most edge detectors use a threshold technique at this level [20]. They set the threshold such that any pixel with a value less than the threshold is removed as shown in figure 3. Two thresholding levels are chosen: high threshold (TH) and low threshold (LT) (TL).

- If the gradient magnitude for a specific pixel is less than TL, it is set to zero unconditionally.
- If the gradient is greater than TH, the pixel is ignored.
- If the gradient between these two, it be set to zero unless a route exists from pixel to pixel with a gradient greater than TH.

(a) Canny detection in case TL=0.2 ,TH=0.6

(b) Canny detection in case TL=0.4, TH=0.8

Figure 3. Submitting hysteresis to canny edge map.

3. Methodology

This study's findings may be used to spot the first signs of pavement deterioration, or cracks, and speed up the repair process. Road damage may be detected by mobile apps employing smart algorithms and threshold functions, and with these applications in hand, policymakers can take immediate action to repair the road or perform routine maintenance. The Canny Algorithm was chosen as the edge detection method because it is considered a simple algorithm to be implemented in many different computer languages. The most notably and simple to be developed software is Java. Making usage of many different functions, most notably the threshold function. Most of the time, these assumptions can be applied to road cracks [9]. Using Terrestrial photogrammetry collects data from ground photos. It includes capturing many overlapping photos of an item or scene from various perspectives and stitching them together using specialist software to generate a 3D model. The model can measure distances, create maps, and evaluate topography. Surveying, engineering, and archaeological employ terrestrial photogrammetry. The picture was taken by a mobile camera with specifications such as includes a back triple-camera array with a 12MP main camera with Dual Pixel autofocus, a 12MP telephoto lens with 5x optical zoom and 50x Space Zoom, and a 108MP ultra-wide angle lens. Laser autofocus, and focal length is 26 mm. Figure 4 illustrates a fundamental architecture for fracture detection depending on image processing.

The following are the steps in the image processing algorithm:

- Take image of the structure that will be subjected to the fracture, using a camera or other sources.
- After a photograph has been taken, it undergoes pre-processing, during which techniques that are suitable for using in image processing
- As a result of the picture processing, the cracks have been found in the structure.

- Extracting fracture features involves categorizing fractures based on dimensions including length, width, area, and the direction in which expanded.

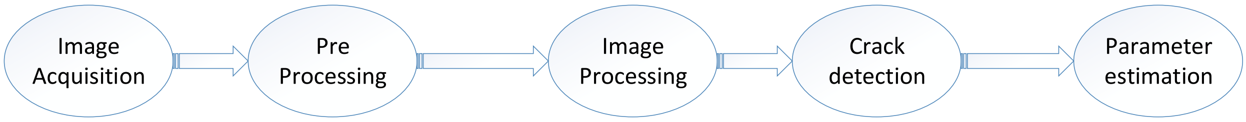

Figure. 4 The design of image processing-predicated flaws detection.

The principles of image processing techniques can be utilized to detect road cracks as follows:
1-Photometric Principle:

- The fracture pixels are darker than the pavement pixels.
- The gray-level patterns of pavement fracture and pavement surface are unrelated.

2-geometric principle:

- A fracture is a continuous thin item.
- A fracture is a collection of linked segments with varying orientations.
- A fracture does have a different breadth over its whole length.

3- Combining photometric and geometric principles:

- Image pre-processing: to minimize the impact of texture and maximize the contrast between the pavement surface and the fracture.
- Show the original image and transparency of the image Airport runway crack and the Classification of the crack.
- Apply a canny edge detector to detect edges.
- Remove noise from an image by morphology operations (opening and closing).
- Skeletonization and boundary extraction of the Airport runway crack was then applied Region fill holes of cracks to determine the area of the Airport runway crack of surface.
- The length, width, and surface of the Airport runway crack area were determined.

4. Experimental study

The experiment is designed to determine runway condition. This research is based on the section area of road that is similar to an airport runway to indicate pavement conditions, determining pavement cracks, early maintenance of road's section to increase airport runway conditions. Therefore, several images captured pavement runway sections to apply image processing by matlab software to determine pavement fault detection and get data from it as type and length of cracks [21]. Image processing is an important and rapid method in determining pavement condition to increase runway, taxiway, and roads in the airport quality. Therefore, apply image preprocessing, canny edge detection, and morphological operation on images to extract pavement cracks, and determine pavement condition.

5. Results and discussion

The case study area properties of dimension 1 x 0.5 m, after using the morphology operation and getting edge detection by using matlab software, that has several image analysis and modification features, making it a formidable image processing tool. It also can filter, segment, register, and extract features as shown in Figure 5. Therefore, calculating the number of the pixel, that indicates the length and area of airport runway pavement cracks. Comparing the image of the manual calculation of the length, average width, and area of cracks and after image processing including morphology image, crack detection as shown in figures according to the number of pixels as shown in table 1

Table 1. result of several pixels of cracks.

Image	Input image	Dimension	Output image	Dimension	percentage
Length	625 pixels	1.56 m	482 pixels	1.21 m	77.12%
area	16000 pixels	0.1 m^2	9220 pixels	0.058 m^2	62%
Average width	6 pixels	0.015 m	5 pixels	0.0125 m	83.333%

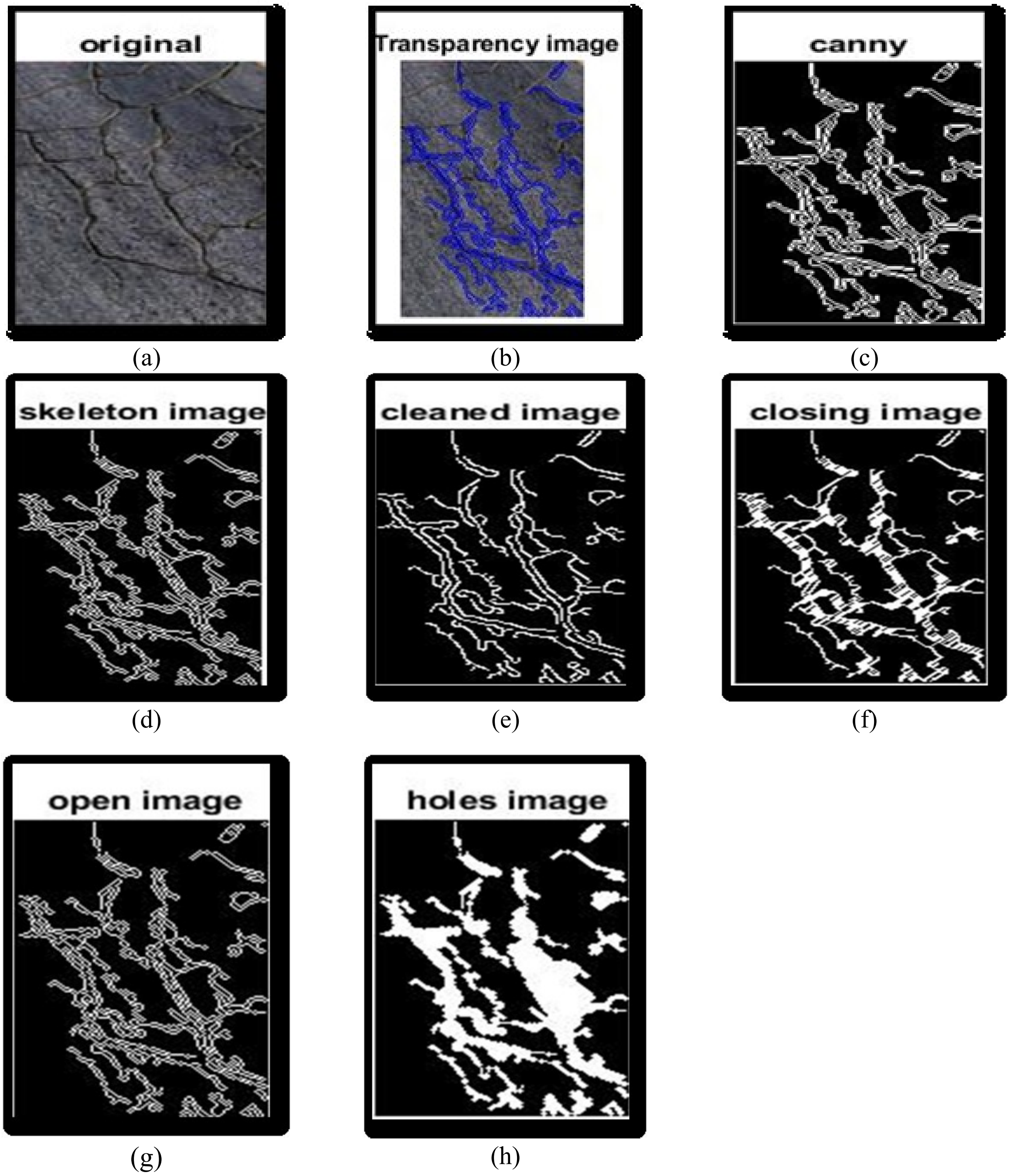

Figure 5. (a) Original image, (b) Transparency image, (c) Canny detection, (d) Skeletonization image (e) Cleaned image, (f) Closing image, (g) Opening image, (h) Fill holes image

6. Conclusion

This paper implements an image processing-based algorithm that automatically detects and calculates the length, width, and area of airport runway cracks in asphalt pavement. The edge detection algorithm used is Canny edge detector and some morphological operations. In this paper it was concluded that:

- Length of crack: 625 pixels before detection and 482 pixels after detection with an accuracy percentage of 77.12%.
- Area of crack: 16000 pixels before detection and 9220 pixels after detection with an accuracy percentage of 62%.
- The average width of the crack: 6 pixels before detection and 5 pixels after detection with an accuracy percentage of 83.333%.

The results were within an acceptable percentage promising that comparing images detection results crack with manual calculation before detection and morphology and after detection and morphology with highly useful in assessing and identifying surface cracks and stresses. The aim of this research in image processing technology whose objectives are airport runway crack length, fracture breadth, and crack propagation orientation were taken into account. Some approaches have high efficiency with low accuracy. Additionally, as a future research, the usage of alternative/additional characteristics for crack identification and conducting several algorithms for edge detection of road cracks.

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