Image Enhancement and Corrosion Detection for UAV Visual Inspection of Pressure Vessels

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Abstract The condition of a pressure vessel is normally checked by human operators, which have health and safety risks as well as low working efficiency and high inspection cost. Visual inspection for pressure vessels can be done by an Unmanned Aerial Vehicle (UAV) with the sensing module. Image enhancement techniques and image processing techniques are vital in the UAV inspection of pressure vessels. However, there are several issues to be overcome in the UAV visual inspection of pressure vessels. The images captured by the UAV are of low quality under the cluttered environment due to poor lighting, noises and vibrations caused by the UAV. In this research, a system is developed for UAV visual inspection of pressure vessels using image processing and image enhancement techniques. In the developed system, the input image is captured by the UAV first. Next, efficient image enhancement techniques are applied to the images in order to enhance image qualities. After that, the corrosion part is detected and the percentage of the corrosion area in the entire image is measured. The proposed system has the potential to be implemented for the autonomous correction detection with the image enhancement techniques in UAV visual inspection for the pressure vessels.

Keywords: Image enhancement, Corrosion detection, UAV, Pressure vessel

1 Introduction

Nowadays, human operators are always needed to check the conditions of pressure vessels. However, when carrying out this work, human operators may face healthy and safety risks in addition to human-errors, low working efficiency and high inspection cost etc. To solve this problem, the visual inspection of pressure vessels can be done in a safer and efficient manner by utilizing a UAV with a high-quality sensing module.

In the UAV visual inspection of pressure vessels, image enhancement techniques and image processing techniques play important roles. However, there are several issues with the visual inspection of pressure vessels using UAV. The first issue is about the inspection of the internal coating, linings for signs of breakdown, crack detection of connecting welds to shell with high accuracy and good performance under the

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confined space for UAV. There is also an issue about the part in the inner pressure vessels where the access is limited and lighting condition is poor. The images captured by UAV are of low quality under the challenging environment due to the poor lighting, noises and vibrations caused by UAV [1–3]. As a result, it is difficult to detect the corrosion in these low-quality images. Therefore, the images quality needs to be enhanced to increase the detection accuracy.

The illumination is important for the sensing module of UAV, which has been discussed in many research works [4–6]. To provide a required illumination level, the lighting device and its installation need to be considered carefully. When the lighting device and its installation are fixed, it requires the developed algorithm to be robust in the harsh environment especially for its lighting conditions. For example, when the light intensity level is too high (over 1000 lux), it will result in the glare and contrast issues. On the other hand, if the light intensity level is too low, the visual inspection will be difficult. In image enhancement, there are both traditional techniques and the state-of-the-art techniques such as deep learning [7, 8]. As the deep learning based techniques need lots of computing resources, it requires a powerful UAV onboard platform. In this paper, therefore, the traditional techniques for image enhancement are focused on, such as histogram equalization and morphological operators [9, 10]. The morphological operators can be used to correct the non-uniform illumination. The histogram equalization can be used to enhance the image contrast for both grayscale images and RGB images [9]. After the images are enhanced with the image contrast, the corrosion part can be detected using the colour information in the image with higher accuracy. On the other hand, as the images are captured by a UAV when it is flying, the blurred images are caused by the vibrations of the UAV. A blurred image will affect the performance in detecting the accurate corrosion area. As a result, some techniques need to be applied to deblur these images. Wiener deconvolution can be useful to deblur the images when the point-spread function (PSF) and noise level are either known or estimated [9, 11, 12]. The PSF is used to describe the response of an imaging system to a point source or point object. Due to the relative motion between the object and the video camera, the obtained image is blurred in the image acquisition process. In order to deblur the motion-blurred images, the PSF needs to be estimated. After that, the Wiener deconvolution can be used to deblur the images for achieving better performance. In summary, by applying the image enhancement techniques, the image quality and the performance of corrosion detection will be improved.

In this paper, a system is developed for UAV visual inspection of pressure vessels using low computational image enhancement techniques. Within the developed system, the input is the image captured by the UAV first. Next, the image enhancement techniques are applied to these images. After that, the corrosion part is detected and the percentage of the corrosion in the entire image is measured. The system is designed for UAV's visual inspection without ideal lighting condition.

This paper is organized as follows. Section 1 has a general overview of the paper. Subsequently, the procedure of the system is introduced in Section 2. Section 3 to Section 5 describes the image enhancement techniques, contour detection techniques and corrosion detection techniques, respectively. Finally, a brief and key conclusion is made in Section 6.

2 Overview of the system

In the research, there are several steps for image enhancement and corrosion detection as shown in Fig. 1. The techniques have been combined and applied for images and videos of a real pressure vessel with the industrial scale.

To begin with, the input is the image captured by the UAV first. Next, the image enhancement techniques are applied to the obtained images. These image enhancement techniques are used to enhance the image contrast, correct the non-uniform illumination and de-blur the images which are caused by the UAV vibrations.

After that, the corrosion part is marked with yellow colour using colour based corrosion detection techniques shown in Fig. 1. Also, the percentage of the corrosion area in the entire image is measured. Finally, the contour of the corrosion part is detected after the corrosion detection is performed. The image is finally converted into a gray scale image for contour detection.

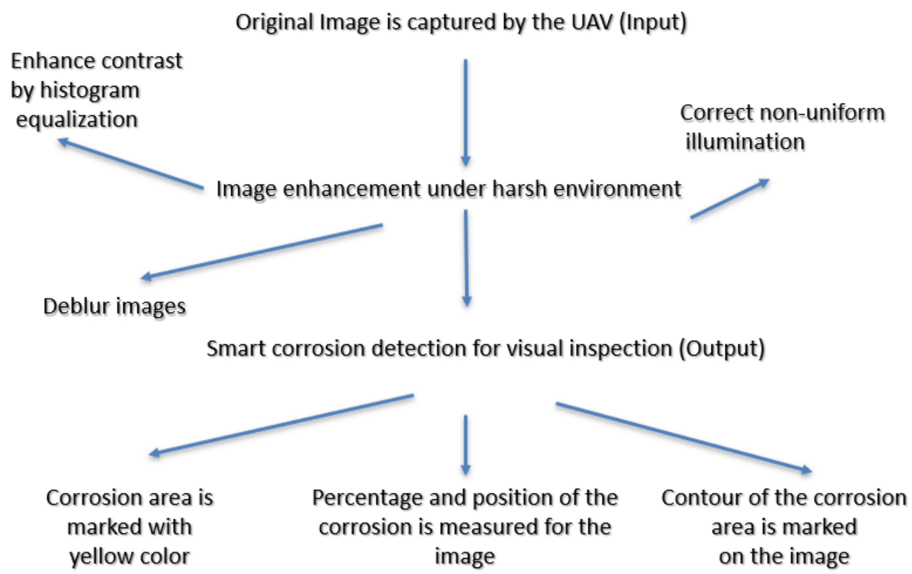

Figure 1. Overview for the system

3 Image enhancement

Image enhancement techniques are used to enhance the image quality and contrast before further image processing is conducted. Currently, the image enhancement techniques with Histogram equalization (HE) and Contrast Limited AHE (CLAHE) are adopted due to their low computational requirements. They can be applied to the RGB images for image enhancement [13–15]. The major idea of the HE is discussed in the following.

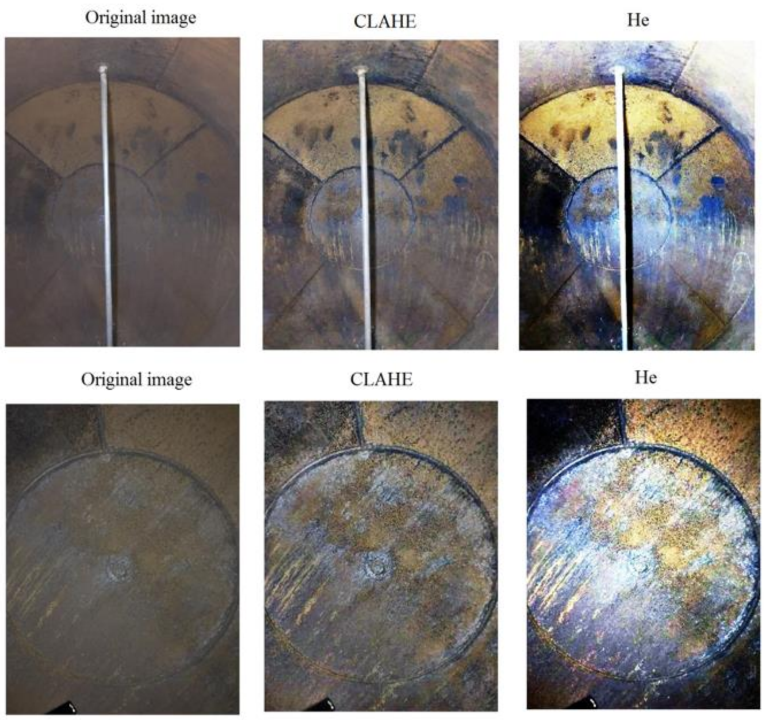

Figure 2. Samples of image enhancement

In a discrete grayscale image$\{x\}$, n_s is the number of occurrences of gray level I [16]. The probability of an occurrence of a pixel for I can be represented by $p_x(s)$:

$$p_x(s) = p(x = s) = \frac{n_s}{n}, 0 \ll s < L \quad (1)$$

In (1), L is the total number of gray levels, n is the total number of pixels. $p_x(s)$ is the image's histogram.

Let $\mathrm{cd}f_x(s)$ be the cumulative distribution function (CDF) to p_x:

$$\mathrm{cd}f_x(s) = \sum_{t=0}^{s} p_x\,(x = t), \quad (2)$$

For a new image$\{y\}$ which has a flat histogram, it has a linearized CDF:

$$\mathrm{cd}f_y(s) = sK \quad (3)$$

Using the properties of the CDF, a transformation can be done:

$$\mathrm{cd}f_y(y') = cdf_y(T(k)) = cdf_x(k) \quad (4)$$

Also, the following transformation needs to be applied to the result:

$$y' = y \cdot (\max\{x\} - \min\{x\}) + \min\{x\} \quad (5)$$

The experiments were carried by using different internal pressure vessel images. In the current stage, the UAV is not ready for capturing the images of pressure vessels and the images captured by humans are used to carry out the experiments and evaluate the feasibility of the developed image enhancement and corrosion detection system. The experiment results are shown in Fig. 2. The original image is shown on the left. The enhanced images using the CLAHE technique and HE technique are shown in the middle and on the right, respectively. It demonstrated that the image using the CLAHE has improved the visual texture of the original image.

4 Contour detection

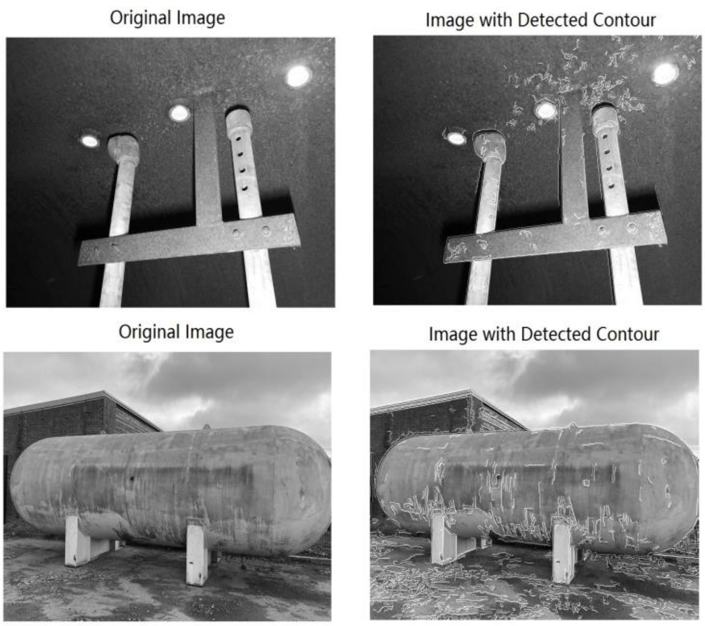

Figure 3. Samples of contour detection

Contour detection is a process that finds a curve joining all the continuous points along with the boundary that has the same colour or intensity. The contours are very useful for shape analysis, object detection and recognition. There are many contours detection techniques such as the Combination of Receptive Fields model (CORF), Gabor function model, multiple-cue inhibition operator [17–19]. The performance of various computational models in contour detection tasks has not been quantified and they have not been compared in complex visual tasks.

The Gabor filter is a linear filter for texture analysis in image processing [20]. Its mechanism in image analysis is similar to the perception in the human visual system. Given the point or region of analysis in an image, it is used to essentially analyze whether there is any specific frequency content in specific directions in the localized image region. The Gabor filter is particularly suitable for the purpose of texture representation and discrimination.

The details for the CORF model can be referred to [19]. In the CORF, the response *R* is defined as the weighted geometric mean of all the sub unit responses which belong to the specifications determined by the set *D*:

$$R_D(x, y) = (\prod_{i=1}^{[D]} (D_{\delta_i,\sigma_i,\rho_i,\varphi_i}(x, y))^{\omega_i})^{1/\sum_{i=1}^{[D]} \omega_i} \quad (6)$$

$$\omega_i = exp^{-\frac{\rho_i^2}{2\alpha'^2}} \quad (7)$$

$$\alpha' = \frac{1}{3} \max_{i \in \{1 \ldots [D]\}} \{\rho_i\} \quad (8)$$

In (6), $\delta_i, \sigma_i, \rho_i, \varphi_i$ stand for the polarity of the sub unit, the scale parameter, the radius and the polar angle, respectively.

The experiment results with the CORF are given in Fig. 3. In the research, the CORF technique is used to detect the contours of the images taken from both the external and internal pressure vessel. The original image was converted to a gray scale image first and the parameters were carefully tuned to improve the performance. In Fig. 3, the original images are on the left and the image with the contour detected are on the right. It is shown that most of the contours have been detected successfully.

5 Corrosion detection under cluttered environment

Corrosion detection is an important part of visual inspection for pressure vessels. The proposed algorithm needs to detect the corrosion with high accuracy, short time and low cost under the cluttered environment such as poor lighting situations. In this part, the experiment is carried out to test the performance of the corrosion detection for the images of internal pressure vessels in the cluttered environment.

In the experiment, the RGB value is used to detect the corrosion in the image. From the training images, the range of RGB value of the corrosion area can be found. The range of RGB value is used to find the corrosion part in the testing images. The experiment result is shown in Fig. 4. The original images are shown above and the images with the detected corrosion in yellow points are shown below.

The proposed method can also be used to detect the corrosions from a video which can be considered as a series of continuous image frames. The experiment results on the corrosion detection from a video are shown in Fig. 5 and Table. 1. The experiment was carried out on several continuous video frames. The interval between the two frames is 0.33 second. In the figure, a1 to a10 represent the original images of the video frame and b1 to b10 represent the images that show the detected corrosion area in yellow colour. In Table 1, the first column gives the order of the video frames and the second column shows the percentage of the corrosion area detected in the entire image in each video frame.

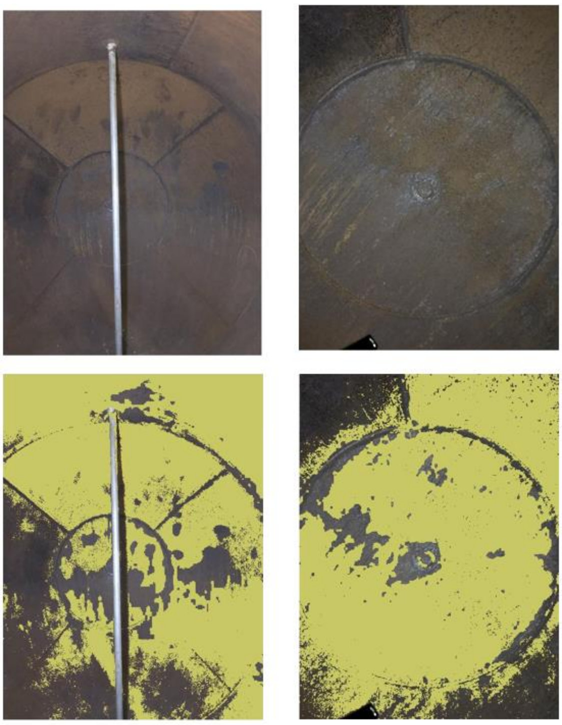

Figure 4. Samples of corrosion detection under cluttered environment for pressure vessel

Table 1. Area of corrosion detected in a video

– Order	– Percentage of corrosion area detected (%)
– 1	– 69.7
– 2	– 72.8
– 3	– 78.9
– 4	– 79.0
– 5	– 81.5
– 6	– 83.7

– 7	– 82.6
– 8	– 82.2
– 9	– 75.2
– 10	– 68.7

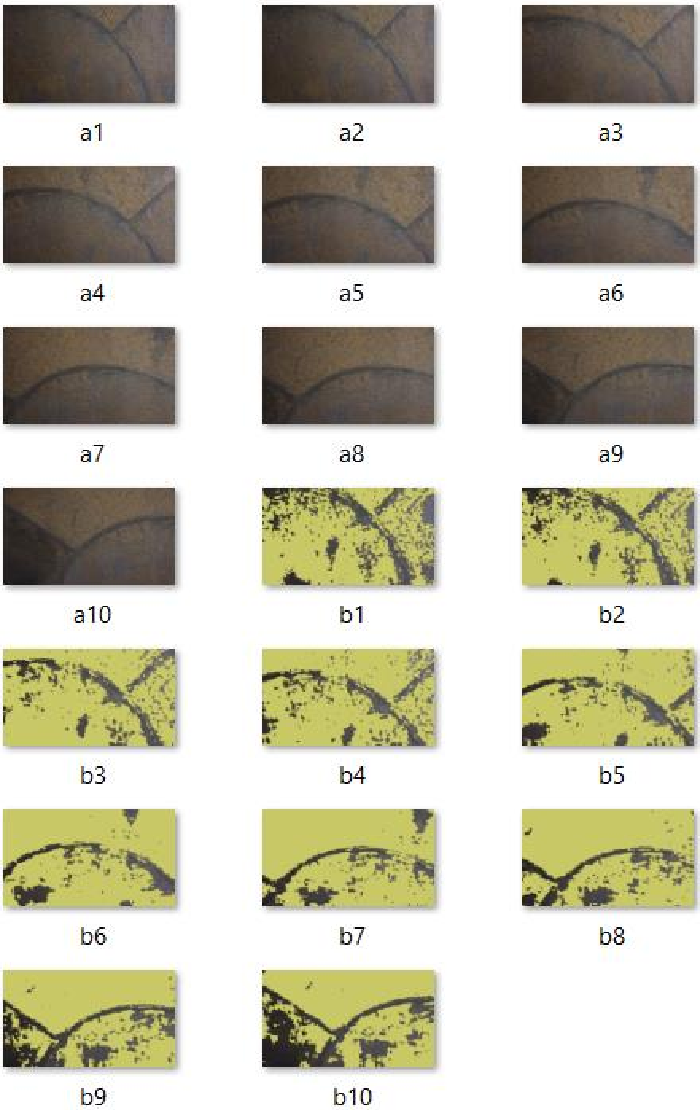

Figure 5. Samples of corrosion detection in a video

6 Conclusion

This paper has presented a system that was developed for the UAV visual inspection of pressure vessels. It has been mainly focused on image enhancement and corrosion detection to address the challenging issues in the cluttered environment.

Within the developed system, the UAV is used to capture the videos from pressure vessels. The Histogram Equalization techniques are mainly applied to the images to enhance the contrast of the image under poor lighting condition in the internal pressure vessel. After that, the corrosion part is detected by using the image's colour information and the percentage of the corrosion in the entire image is measured. The experiments were carried out to evaluate the performance and demonstrate the feasibility of the developed system.

Though a good performance was demonstrated in the lab-based experiments, there are some limitations and future work. First of all, to complete the sensing and image processing module, a lighting system is required to install on the UAV to provide suitable illumination, which will be solved in future work. Also, the current experiments only tested the images captured manually. In future work, the image processing module needs to be integrated and tested with the images taken by the flying UAV in the internal pressure vessels. In addition, the CLAHE technique was used only in this paper as the image enhancement technique. Therefore, the other more efficient image enhancement techniques need to be tested and evaluated in future as well to identify the most suitable image enhancement techniques for the UAV visual inspection of pressure vessels in engineering practice.

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