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Context-Aware High-Rise Structure Cracks Image Monitoring System Using Unmanned Aerial Vehicles

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Abstract

As the methods using UAV (unmanned aerial vehicles) are being sought in multipurpose surveillance and monitoring technologies such as saving lives, the collection of weather information, forest fire prevention, etc, active research has also been under progress in various areas. In this paper a miniature UAV was used to provide an image processing system of the structure cracks situational awareness for the safety inspection of the structure. With the structures for seasonal changes greatly depending on the time each day, the problem is a difficulty in checking for damage. Using a context-aware image processing system for the images are suspected of having cracks, it is possible to find out whether the structure gets damaged and take an immediate action if necessary. Ultimately, it could contribute to risk reduction. A context-aware crack image processing system processes the image that seems to have cracks and analyzes the data sent by a number of sensors, so as to establish an optimal condition. Then the proposed system provides an appropriate service that deals with the situation autonomously. The proposed system enables to accurately detect the defects occurring at the surface of facility and contributes to saving of time and efforts effectively.

Keywords*: UAV, Context-aware, Crack Images, Monitoring System*

1. Introduction

Recently, small, unmanned aerial vehicles (UAV) have been used for the safety inspection of high-rise structures in domestic and international industries. Structural safety inspections should be conducted on a regular basis for good maintenance [1-3, 7, 9]. For high-rise facilities, however, inspection may be dangerous and difficult because the inspector needs to carry testing equipment in person when conducting the inspection. In the case of deteriorated old high-rise facilities, the lack of maintenance causes additional threats, and it is not easy to fix the problems due to lots of restrictions. The high cost necessary for repairing and renovating is another obstacle to overcome in this situation. Therefore, it is required to develop a system enabling to collect and transmit images and sensor data, and analyze the gathered data using small UAVs in safety inspection for such a facility, which could result to shortening the inspection duration and saving maintenance cost [4, 10, 11, 12].

This paper proposes a context-aware image processing system using small UAVs for structural safety inspection. For implementing the context-aware structure crack image processing system, the use of context-aware image processing algorithm is suggested. This system enables the user to precisely detect the defects of the facility by means of context-aware service with the specific algorithm, so that it can help save maintenance costs.

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2. Image Recognition Algorithm for Identifying Cracks on the Structure

In order to recognize cracks on the structure from the image, there are several kinds of algorithms that can be used as follows: knowledge-based approach, feature-based approach, appearance-based approach, and template matching. In this study, corner detection method using CornerHarris was taken from the feature-based algorithm. Figure 1 shows an image recognition process for detecting cracks on the structure.

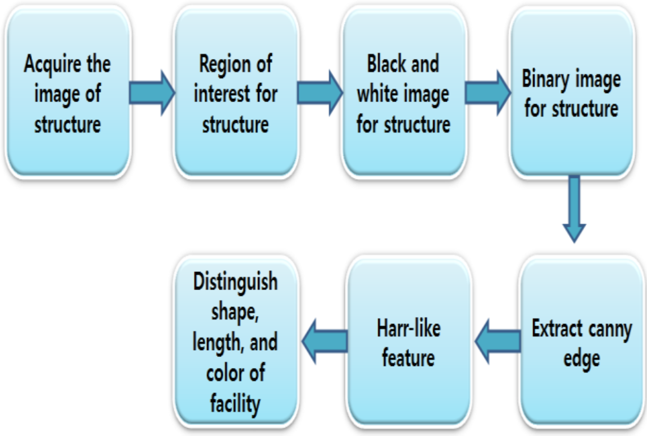

Figure 1. Process of Structure Crack Image Information Analyzing

Haar-like feature is useful in representing the feature values easily by using simple image. The feature values can be taken by moving the window over the input image. Depending on position, shape, and size, lots of variations can appear as shown in Figure 2. 1(a) of Figure 5 shows that the Harr-like feature prototype is capable of producing up to 43,200 distinct cases via 24*24 windows by scaling up the size at varying position and proportion. The feature value can improve recognition rate for cracks on the structure due to its simple operation [5, 6, 8].

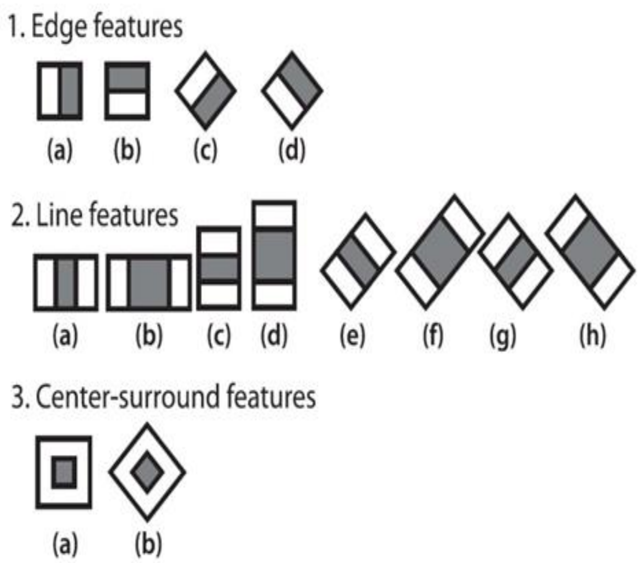

Figure 2. Harr-Like Feature Prototype

$$ii(x, y) = \sum_{x' \le x, y' \le y} i(x', y') \quad (1)$$

In equation (1) ii(x, y) is integral image, ii(x′, y′) is the brightness value of the initial image. Point 4 (x, y)'s value can be obtained by all cumulative pixel values on the horizontal x coordinate, and on the vertical y coordinate. In Figure 3, the sum of the pixels within rectangle D can be computed with four array references. The value of the integral image at location 1 is the sum of the pixels in rectangle A. The value at location 2 is A + B, at location 3 is A + C, and at location 4 is A + B + C + D. The sum within D can be computed as 4 + 1-(2+3).

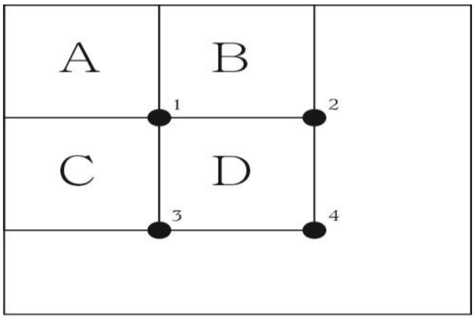

Figure 3. Rectangular Regions of an Integral Image

In the pre-processing stage, the color image will be converted to a gray color-based black and white image. Additionally, histogram equalization is applied to the resulting image in order to enhance the recognition rate for the black and white image. Histogram equalization redistributes the pixels residing in a narrow region to a wider region of the image so that it can enhance the image having more equalized distribution of contrast values. Region ration is then used to extract the fine crack image from the region of interest recognized by Haar-like feature. The process to detect feature point is divided into two modules: (1) binary module and (2) contrast ratio calculation module. The binary module converts the input image to two level images with only 0 and 1 in accordance to threshold value. There are several methods to set the threshold for the image, such as global threshold setting, block binary method, adaptive threshold setting, and iterative threshold setting method. This study makes use of an adaptive threshold setting method which finds out an appropriate threshold automatically in accordance to the contents of the target crack image [13, 14].

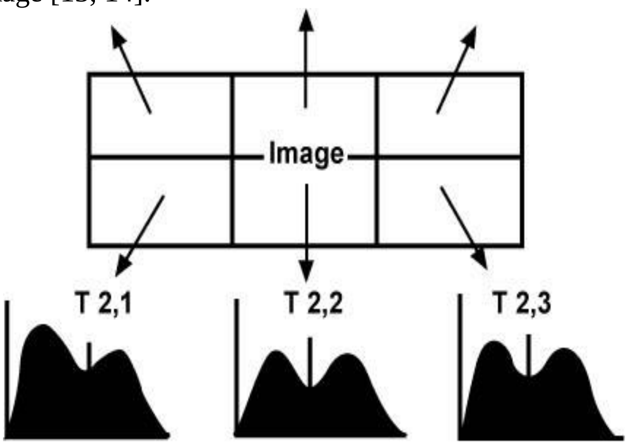

Figure 4. Adaptive Binarization Method

The adaptive binary method is a method that obtains the threshold value only for the part of the image using the partial image's histogram data rather than using the entire image's histogram. Figure 4 shows the division of the original crack image into m*m sub-images. For each of the sub-images, histogram will be investigated. Then the threshold $T_{ij}(1 \leq i, j \leq m)$ for the sub-image will be determined.

```
  for x= 0 to Nx {
    for y= 0 to Ny {
       mean = 0, count =0;
    for i= 0 to size
    for j= 0 to size {
       mean +=i[ x + 1 - (size/2)][y + j – (size/2)
];
       count++;
  }
       mean=(mean/count ) -con;
  if(i[x][y] > mean)
      B[x][y] =255;
  else
      B[x][y] =0;
  Endif
```

Figure 5. Binary Algorithm to Recognize the Crack

Figure 5 shows how to set the threshold value for the specific part of the image. For the input image, it grabs the block with size of size*size. Then it calculates the average value of the pixels in the block and sets the threshold to the average value. Binary processing is then carried out using this value. Contrast ratio calculation module triggers to run the binary module in order to convert the region where crack appears to two level images.

```
public Point2D<float> GoodFeaturesToTrack(
int maxFeaturesPerChannel,
double qualityLevel,
double minDistance,
int blockSize,
double k
)
public void FindCornerSubPix(
PointF[][] corners,
Size win,
Size zeroZone,
MCvTermCriteria criteria
)
```

Figure 6. Corner of the Crack Detection using EigenVal and Harris Algorithm

In Figure 6, contrast ratio is calculated for the binary image with crack by accumulating contrast values in the target region and dividing it by the total pixel value of the entire region. Subsequently, a decision is made after comparing this value with the threshold value, which was pre-specified through the experiment. The size of the region of interest can be obtained by calculating the difference in pixels between top marker and bottom marker. The highest number can be found using for loop. Then the average value is computed for the length. With the use of average value, more accurate size can be determined. Figure 7 is an algorithm used for calculating the length of the region of interest.

```
calcSize[calcCount] = (int)cornerSize;
int calcSizeTmp = 0;
for (int i = 0; i < calcSize.Length - 1; i++)
{
calcSizeTmp += calcSize[i];
}
int calcSizeFin = calcSizeTmp /
calcSize.Length;
i_cornerSIze = (int)calcSizeFin;
```

Figure 7. Algorithm used for Obtaining Length of the Region of Interest

3. Context-Aware Image Processing System Using Small UAV For Recognizing Cracks on High-Rise Structure

Context-aware computing is a technology that recognizes and analyzes the state or the context of the user, and offers the useful service automatically in accordance to the recognized context. Using context-aware service in small UAVs, the quality of the service will be much higher than ever before. Furthermore, the user's effort necessary to recognize and control service will be effectively reduced. The approaches to develop the context-aware service can be categorized as follows: (1) data-based model, (2) developer-driven model, and (3) user-driven model. This paper presents the system that provides the image of user's interest through context-aware service using small UAVs.

In order to investigate cracks and distortions that might occur at the inside and outside of the large facilities, this study developed a monitoring system and installed it at small UAVs. The monitoring system was designed to monitor both high-resolution 3D images and thermal images. A number of sensors were also installed on the small flying vehicle. They would be useful to check whether the facilities get damages or not even in different seasons and different times during one day. The proposed system assists to conduct the safety inspection for crack and distortion on the inside and outside of the high rise building by analyzing the high resolution 3D image and thermal image sent by the camera installed at the small UAVs. To obtain necessary data for the screen, this paper uses a Haar-like feature detection method. In the proposed method, only the information that the users want would be transferred in users' preferred format, which enables the users to acquire a more accurate image of their interest. Therefore, the safety inspection for the facilities can be achieved with high precision. The data sent by the sensors are collected, processed, and translated. Based on the analysis of the data, the system produces the optimal condition for inspection. Consequently, the system is capable of dealing with the data autonomously by cooperating with the sensors. The proposed system can extract extremely fine cracks occurring at the surface of the facilities. In addition to this, the system also offers the useful functionalities including capturing and storing the image fetched by the user.

To easily transmit the image data sent by image cameras and thermal image cameras installed at small UAV, IEEE 820.1x was used as wireless communication technology. The context-aware service compresses the original image into motion JPEG format data. The compressed data is transmitted in a speed of 20-30fps with 4CIF/2CIF resolution. Owing to the advanced technology, the transmitted service including context-aware service provides its service accurately. Figure 8 shows the overall architecture of the context-aware image processing system using small UAVs for identifying cracks on a facility.

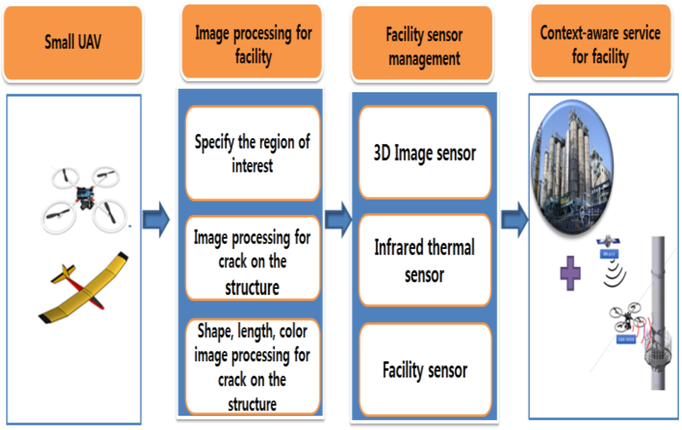

Figure 8. Architecture of the Context-Aware Image Processing System for Identifying Cracks on Facility

4. Conclusion

This paper presents an image processing system using small UAVs for inspecting cracks on facilities. The proposed system can be applied to the safety inspection for facilities. The optimal safety inspection is achieved by specifying the region of interest periodically. Based on the specified region, the system distinguishes the shape, length, and color of the crack using binary image processing, canny edge detecting and CornerHarris. Crack image can be presented in lots of forms depending on its position, shape, and size. A Haar-like feature is used for identifying the region of interest that is suspected of having cracks. Then the feature points for the region that needs to be extracted. To do this, image recognition processes are carried out in a step-by-step manner. After checking whether damages occur or not correspondingly at each season and at a certain time of a day, inspection using the sensors installed at small UAVs is carried out for the structure. Therefore, efficient management for the facility is made possible. This study proposes a service that enables to autonomously handle the situation by cooperating with each other, specifying/processing the region of interest and analyzing data sent by a number of sensors in accordance to the context-awareness so that it can establish the optimal condition for maintenance of the facility.

In the future, this system can be extended to deal with the inspection of cultural artifacts located in steep cliffs or vessels staying at port. Furthermore, the future system can evolve to be widely utilized for safety inspections across the industries.

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