Project

of

Image Based Crack Detection of Concrete Surface

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Abstract

Concrete health checking for infrastructures is rapidly becoming a new hot topic national wide. The traditional crack detection method are often expensive and dangerous. With the UAV (drone) and evolution of image processing technologies, imaged based crack detection on surface of concrete is becoming possible. The project is to design a system which aims efficiency and accuracy of crack detection for practical use. A few algorithms are used and testing accuracy reaches 92%.

Background

With modern cities and communities growing, health checking of concrete for infrastructures is rapidly becoming a new hot topic national wide. The traditional approach to examine cracks costs hundreds of thousand dollars per remote controller (Fig. 1) and in many times, they are frustrated to get access into certain spots because of the limitation of their size and weight. In addition, the operator needs to be very careful when working, still some accidents are inevitable (Fig. 2).

Figure 1 The price of a bridge detecting machine (XZJ5311JQJ18) is approximately $620,000 [1]

Figure 2.1 Operators examining cracks with danger[2]

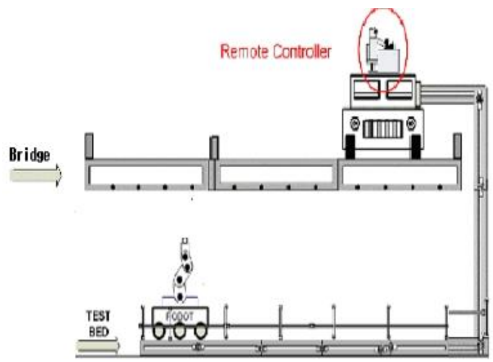


Figure 2.2 General view of traditional device to examine cracks[2]

Figure 2.3 Traditional bridge detecting machine [3]

With technological innovation, people start to think about other more economical and efficient approaches, which are also expected to bring a safer working environment to the operators.

Especially, after the introduction of Unmanned Aerial Vehicles (UAV), the suitability and efficiency get incredibly improved. By using this kind of aircrafts mounted with HD camera and laser distance-detector (Fig. 3), to examine every corner and seam in detail becomes possible. Besides, the expense of structural detection will be largely reduced comparing UAV with traditional detecting machines (Fig. 4).

Figure 3 UAV with HD Camera[4]

Figure 4 Price of UAV in Amazon, approximately $455[5]

At meantime, it brings up a new challenge, with huge amounts of image based data produced by UAV, many professionals are forced to get in to filter up the data to get valuable images with crack part.

System design

1. **Purpose of design**
   This system is used to detect whether there's cracks in the image taken by UAVs. It's not hard to measure the width of the cracks or figure out maintaining methods after the cracks are detected. However, it's hard and time-consuming for detectors to check every place of the structures. For instance, if detectors are detecting a bridge with a length over 1000 meters, it may take them a few months to finish their jobs, which also means they will stay in the dangerous traditional detecting machines for months.
   It's meaningful to use UAVs to detect the concrete cracks and equip it with an accurate system. The only job of this system is to figure out whether there's cracks. It's simple but it will be enough and save a huge amount of detectors' time.
2. **Design ideas**
   The detecting problem is a practical problem. Many cases should be considered. We not only need to distinguish cracks from those images without cracks, but we should also consider cases like "there's some useless background in the image" or "there's stains on the surface". Cases as showed in Fig. 5:

a) **Cracks** b) **No cracks** c) **With useless background** d) **With stains**

Fig. 5 Different practical cases of images

The first step of our system should still be image preprocessing. To begin with, we need to convert BGR images into grayscale images to reduce the complexity. Furthermore, we only care about cracks which have darker color. We do not care about the background of the surface which mainly has a lighter color, so we can binarize the image. A threshold can be picked. Colors darker than it will be turned into black and colors lighter than it will be turned into white. In addition, there’s still a lot of noise after binarization and we need to reduce them. A convolution kernel can be designed to lighter the color of noise. After another binarization, most of the noise can be reduced.

The next step of our system is to retrieve images with cracks. In this part, we also need to cross out cases like c) or d) in Fig. 5. We choose to use K-Means to realize this and the reasons will be mentioned in the part of approach.

3. **Flow chart of the design**

Fig. 6 is the flow chart of our train of thoughts:

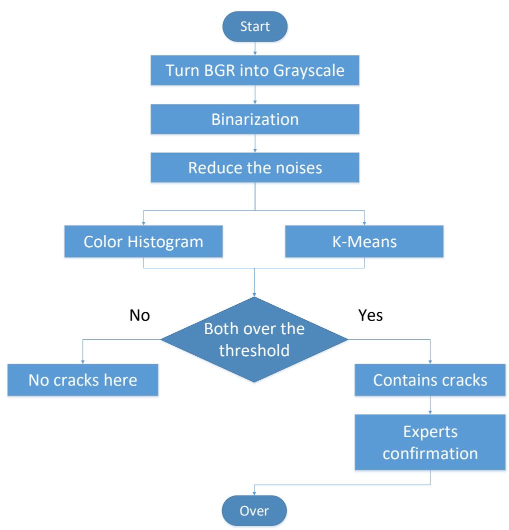


Fig. 6 Flow chart of train of thoughts

Approach:

To realize our design, algorithms below are needed. They aim to process RGB images into grayscale images, binarize the images, reduce the noise around cracks and distinguish cracks from informal cases.

1. **Reducing color dimensions of all the images**

To reduce the complexity of the system, we need to reduce color dimensions of all the images. Generally, grayscale will be enough for crack images. So before processing cracks images we can first convert RGB color into a grayscale, by applying equation 1[6].

$$\mathrm{C}(x,y) = 0.2989 \times \mathrm{R}(x,y) + 0.5870 \times \mathrm{G}(x,y) + 0.1140 \times \mathrm{B}(x,y) \qquad (1)$$

In the equation, $\mathrm{R}(x,y)$ represents the red pixel value of an image; $\mathrm{G}(x,y)$ represents the green pixel value of an image; $\mathrm{B}(x,y)$ represents the blue pixel value of an image; $\mathrm{C}(x,y)$ represents the grayscale value of an image. Fig. 7 shows the example result:

a) **BGR images** b) **Grayscale images**

Fig. 7 BGR and grayscale images

Fig. 7 shows that after dimension reduction, the texture of the images will not be changed at all.

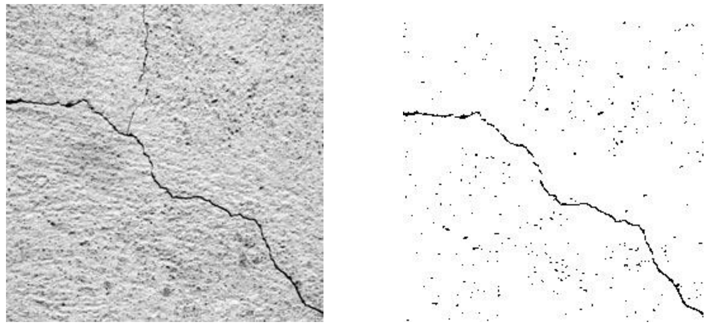
2. Image binarization

Cracks is the only thing within consideration. Background of the surface should be removed as much as we can because their existence may lower the accuracy. For this purpose, a ratio will be defined to change the value of every pixel into either 0 or 255.

$$\mathrm{G}(i,j) = \begin{cases} 0 & \mathrm{P}(i,j) < T \\ 255 & \mathrm{P}(i,j) > T \end{cases} \qquad (3)$$

$$\mathrm{T} = (P(i,j)_{max} - P(i,j)_{min}) \cdot ratio + P(i,j)_{min} \qquad (4)$$

$\mathrm{P}(i,j)$ represents the pixel value of (i, j); T represents the threshold, which is defined as equation 4 in our system; $\mathrm{G}(i,j)$ represents the pixel value of (i, j) after image binarization[7]. We refer to a threshold T to turn all the pixels into either 255 or 0. Fig. 8 shows the example result if the ratio is chosen as 0.3:



a) **Before binarization** b) **After binarization**

Fig. 8 images before and after binarization

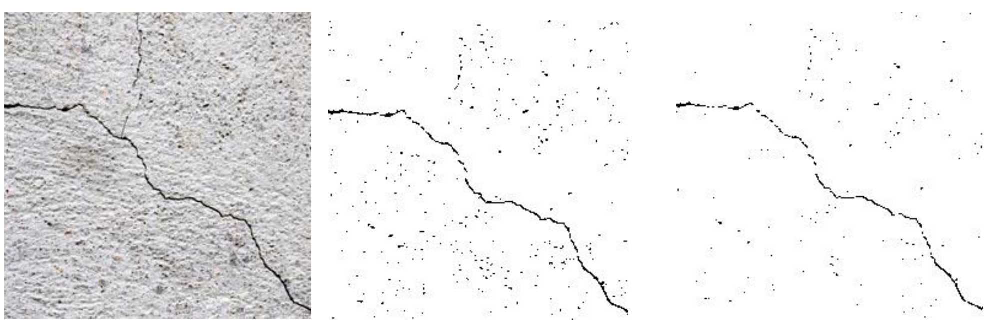
Fig. 8 shows that most of the background has been reduced but there’s still some noise that can’t be ignored.

3. Noise reduction

After binarization, there’s still some noise that can’t be ignored. Noise should be reduced otherwise it will have influence on the accuracy. In our system, convolution kernels as equation 5 are used to eliminate the noises.

$$\mathrm{f}(\mathrm{i},\mathrm{j}) = \sum_{(m,n)\in R} P_k(m,n)\cdot\omega_k \tag{5}$$

R represents the area of noise reduction; k represents the pixel id in this area; $P_k(m,n)$ represents the original grayscale; ω_k represents the ratio we define; $\mathrm{f}(\mathrm{i},\mathrm{j})$ represents the pixel value of (i, j) after noise reduction[2]. Fig. 9 and Fig. 10 show the example results:



a) **Original** b) **After binarization** c) **After reduction**

Fig. 9 images with cracks

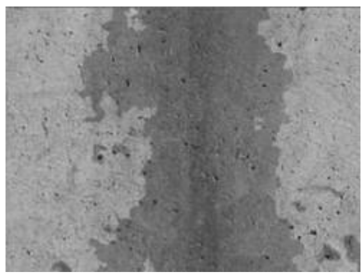
a) **Original** b) **After binarization** c) **After reduction**

Fig. 10 images without cracks

In Fig. 9 and Fig. 10, noise can be nearly ignored after noise reduction.

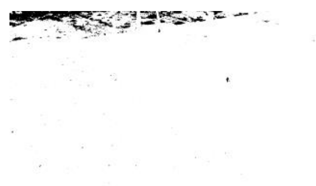
4. K-Means clustering

For common images, most of the noise will be reduced after reduction. After noise reduction, only black and white pixels are remained. After lowering the importance of white pixels which we do not care about, color histogram can have a good performance when retrieving images with similar amount of black pixels. However, there's still some cases should be considered as Fig. 11 and Fig. 12. They have similar amount of black pixels with images with cracks:



a) **Original** b) **After reduction**

Fig. 11 Case 1



a) **Original** b) **After reduction**

Fig. 12 Case 2

To cross out cases in Fig. 11 and Fig. 12, our system applied K-Means. K-Means is an unsupervised machine learning method to cluster points into k clusters. It takes iterations to minimize the distance of between points in a cluster and their centroids. Its function can be represented as:

$$J = \sum_{n=1}^{N} \sum_{k=1}^{K} r_{nk\|x_n - \mu_k\|^2} \quad (6)$$

J represents the sum of the squares of the distances of each data point to its assigned vector and $\{r_{nk}\}$ and $\{\mu_k\}$ should be found to minimize J.

The black points in the preprocessed images can be considered as the points to be clustered. The reason why we choose K-Means is that cracks are usually cluster of points with low density and stains or color blocks are usually cluster of points with high density. The average distance of the points of cracks to their centroid should be comparatively larger than other cases. It can easily been observed in Fig. 13:

a) **Stains** b) **with useless background** c) **with cracks**

Fig. 13 Examples of how the points can be clustered

Fig. 13 shows the examples that how the points in different cases can be clustered and if there's a line (crack) in the image, the average distance of the points to their centroid will be comparatively larger.

5. Retrieve images

After lowering the importance of white pixels which we do not care about, color histogram can have a good performance when retrieving images with similar amount of black pixels. Meanwhile, after comparing the average distance of points to their centroid, informal cases can be crossed out. Images with crack content will be retained.

Practical test and result:

In a selection of 25 images with mixed crack and no-crack content. 15 of them have crack content and 10 of them have no-crack content including useless background and stains. The accuracy of detection reaches 92% after optimizing the parameters.
One of our good result is that even images as Fig. 14 can be retrieved:

Fig. 14 Image with cracks and useless background

Fig. 14 means that even there's useless background, images with cracks will not be crossed out due to the large average distance in the cluster of cracks.
The 8% images with cracks are showed in Fig. 15

a) **Image 1** b) **Image 2**

Fig. 15 Images with cracks that have not been retrieved

Cracks in Fig. 15 are either thin or small, which means using particular parameters, our system has an accuracy limit.

Discussion

Fig. 15 reveals the drawbacks of our system. To get higher accuracy, the UAVs should be equipped with HD cameras to get more clear cracks.

Another interesting part is that, our system applies several parameters like the threshold for binarization, the parameter to lower the importance of white pixels, the cluster number, the similarity threshold for Color Histogram and the cross-out threshold for K-Means. Practically, detectors do not need to detect all the structures around them. For example, if a detector takes charge just one particular bridge, the images he needs to retrieve are all about this bridge. After few rounds of detection, he can get better and better parameters for his job and the accuracy will be higher and higher.

Reflection on preparing a presentation

We watch TED to learn how to perform a presentation. The main guideline of our presentation is using more visualized thing to demonstrate our key points. Figures are better than tables and tables are better than pure text.

Reference

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[3] 'Bridge Detecting Machine', Baidu Baike, https://baike.baidu.com/pic/%E6%A1%A5%E6%A2%81%E6%A3%80%E6%B5%8B%E8%BD%A6/10618050/0/79b1e936977ad2640b55a934?fr=lemma&ct=single#aid=0&pic=79b1e936977ad2640b55a934

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[7] http://www.cnblogs.com/zkwarrior/p/5805006.html