# Feature-less Stitching of Cylindrical Cable for Surface Inspection of Cable-stayed Bridges

Kehui Zhang[1], Langming Zhou[1], and Xiao Changyan[1*]

[1]College of Electrical and Information Engineering, Hunan University, Changsha 410000, Hunan, China
[*]xcy19722@hotmail.com

**Abstract.** Cable surface inspection based on vision is of great significance for the scientific management and maintenance of cable-stayed bridges. In this paper, a set of automatic multi-view cable surface image acquisition system is designed in which images from four fixed cameras are wirelessly transmitted to a service computer, and then stitched together on the service computer. Clustering segmentation and histogram matching are used to enhance the collected images, and a new cylindrical objective image stitching algorithm is designed to obtain the distorted unwrapping cylindrical image from the 360° capture of the cable. The precise location and measurement of the damage can be achieved quickly by combining with the prior geometric dimensions of the cable.The tests on several groups of bridge data show that the proposed algorithm can solve the problem of feature-less cylindrical cable surface and the problem of complex background conditions, which is of great significance for quickly determining the position and distribution of cable surface damage.

**Keywords:** Cable Inspection, Cylindrical back-Projection, Image Stitching.

## 1 Introduction

Cable-stayed bridge has become the main type of long-span bridges, and the number of cable-stayed bridges rapidly increased[1]. Cables are the most important load-bearing components in cable-stayed bridges, are exposed to the air, wind, rain and sunshine for a long time. The polyethylene (PE) pipe is the protective layer for the cable. With age, the PE pipe will meet with fatigue, corrosion, and their coupled effects[2]. The long-accumulated damage causes internal steel wires to break, causing serious traffic accidents such as the collapse of the can tho bridge in 2007. The conventional inspection method of the cable is mainly to inspect the surface of the cable by using a lifting vehicle or a lifting trolley. This method has strong subjectivity, low detection efficiency, and is dangerous to the inspectors[3-5]. Therefore, it is crucial for developing an automatic image-based surface damage detection system to assess the conditions of the cables[6].

Nowadays, many tunnel inspection systems using computer vision have been developed to improve the efficiency and scientific management. [6] presented a damage detection algorithm which combines image enhancement techniques with principal component analysis (PCA) algorithm. They developed an image enhancement method together with a noise removal technique. Then the images are projected into PCA subspace to identify and localize damage in cable surface of cable-stayed bridges. [7] developed the imaging and inspection of the Deep Tunnel Sewerage System (DTSS). They created cylindrical images captured by a novel 360° revolving camera system and developed a geometrical relationship to combine the camera trajectory with scene geometry to automatically create a panoramic view of the tunnel. [8] proposed an modified scale-invariant feature transform (SIFT) algorithm for stitching defect images from multiple perspectives.

According to these research, we design a set of automatic multi-view cable surface image capture and process device. The cables' surface images are completely captured by four cameras and then transmitted wirelessly to principal computer. Next, due to the collected data has the characteristics of less surface texture and complex background environments, clustering segmentation and histogram matching are done with the data to enhance image quality in the principal computer. Thereafter, we use cylindrical back-projection to unwrap cylindrical surface images and stitch them.

In summary, we make the following contributions:

- We develop an efficient segmentation algorithm combined clustering segmentation with histogram matching to separate the background from the stay cable.
- We infer a geometric relation between 2D captured cylindrical image and unwrapped image.
- We propose an image stitching algorithm aimed at some feature-less objects like stay cable, tunnel, bridge deck and so on.

## 2 Related work

### 2.1 Image Segmentation

Image segmentation is a basic and key technology in the field of image processing. Its purpose is to separate the object from the background and provide a basis for subsequent processing such as object detection and accurate positioning. Some current methods are edge detection segmentation, region-based segmentation, clustering segmentation, etc[9]. We use clustering segmentation and edge detection segmentation in this paper. Edge detection segmentation segments an image by detecting the edge of different areas. The edge are often detected by derivative operations, and derivatives are calculated using differential operator, like the Roberts gradient, Sobel operator, Laplacian, etc[10]. Then is the clustering segmentation. Clustering is to divide the data set into several subsets according to the similarity among the elements. Clustering segmentation is an unsupervised statistical method, which does not require training samples and plays an important role in the application of image segmentation [11-15].

### 2.2 Cylindrical Back-projection

For some cylindrical or spherical objects that are consisted of surface, distortion of surface texture will occur in the process of imaging. The solution to this problem is to project the image texture onto a two-dimensional plane that to convert the cylindrical projection into a plane projection, which is a process of cylindrical back-projection. [16] proposed a universal back-projection formula for all curved objects. Other recent methods [17,18] were proposed by adding auxiliary rectangles, applying to the recognition of cylinder QR code.

### 2.3 Image Stitching

Image stitching is to use image processing technology to find overlapped parts in the images with overlapping areas, match the images, and then merge into an image. Feature-based registration method is the mainstream of image stitching algorithm. Image features can include corners, outlines, textures, or other special structures. Harris corner[19], FAST[20], SIFT[21], and SURF[22] features are often used in feature registration. There are two chief problems in stitching of cylindrical cables : registration of feature-less data under different four viewpoints.

## 3 Method

In this paper, the cable surface images of cable-stayed bridge captured by four CCD cameras are stored in the computer. For the stored images, we firstly separate the cable surface from the background, and then rectify the distorted cable surface. Lastly, we present an algorithm based on grid partitioning to stitch them. Fig.1. is shown the process of cable surface stitching.

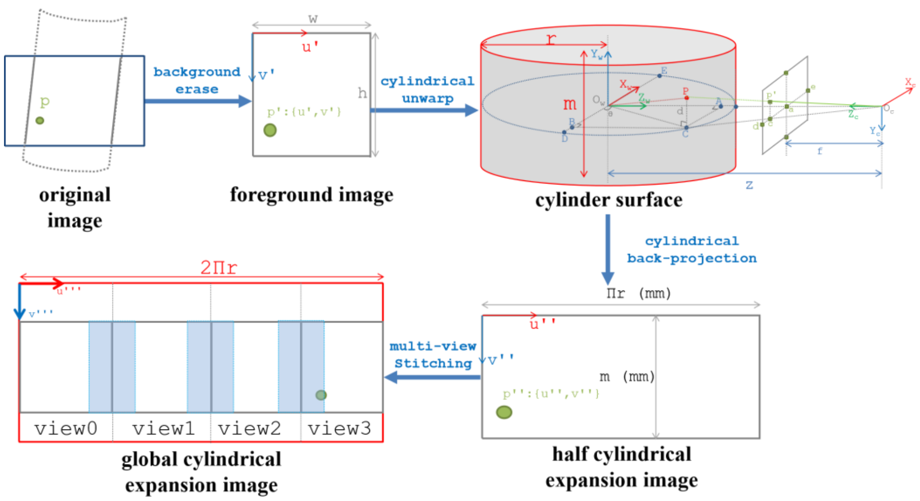


**Fig. 1.** The process of cable surface stitching.

### 3.1 Cable Surface Segmentation

In the acquisition images of bridge cables, all images are in the scene having parallax with the cable surface foreground and background. If only a single global transformation is used for modeling, it is easy to cause image distortion. Fig.2. shows the result of feature matching under parallax. Therefore, it is necessary to separate the cable surface from the background in our image processing.

In the segmentation between the cable surface and the background, it is prone to errors if the method of line-segment detection is simply used on account of the possible existence of rubber drainage tubes on the surface of the cable and complex background .If the images are segmented by the method of line-segment detection, some of which will segment the rubber drainage tubes and the background.

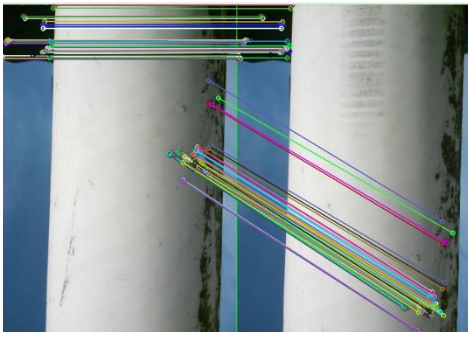

**Fig. 2.** The result of feature matching under parallax shows different homography.

Therefore,the clustering segmentation and Flood Fill algorithm are selected to background segmentation,which can reserve the shape information of cable surface and remove its background.In image processing, starting from a starting node, the adjacent nodes are extracted or filled with different colors. After the segmentation, the brightness of four images from four cameras is different due to the parallax of the four cameras, which is adjusted by histogram matching. The specific algorithm steps are as follows:

(1) Pre-segment images by mean-shift and flood fill.
(2) Get edges from pre-segmented images and original images by Canny operator.
(3) Detect lines by using Line Segment Detector (LSD) algorithm.
(4) The outer rectangular bounds are employed to fit lines.
(5) Erase background.
(6) Adjust brightness by histogram matching algorithm.

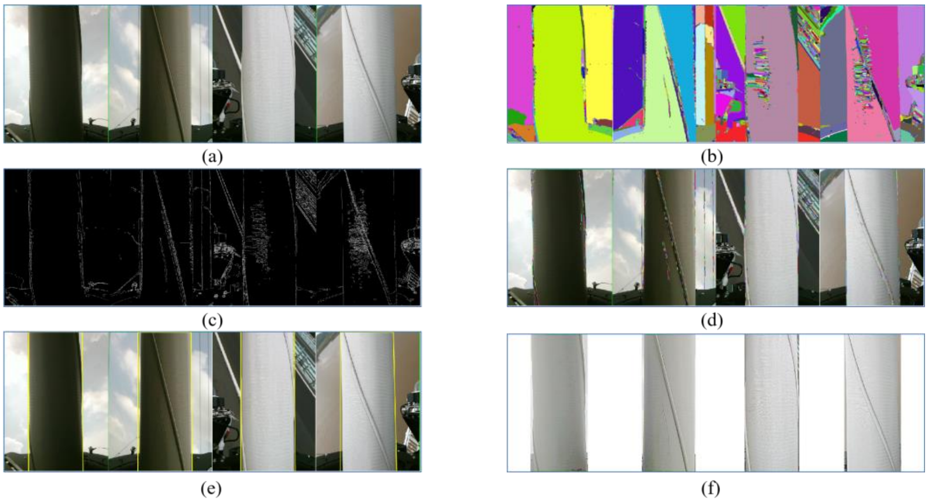


**Fig. 2.** The process of cable surface segmentation: (a)original image; (b)pre-segmentation; (c)edge detection; (d)line-segment detection; (e)border fitting; (f)background erase and color harmony.

### 3.2 Cylindrical Back-projection

The image of cable surface acquired by CCD digital cameras is cylindrical surface image. In order to meet the requirements of subsequent image stitching, the cable image needs to be expanded into a plane image. We first build an ideal cylindrical back-projection model, assuming that the image of cable surface is an ideal cylindrical image, and is expanded along the direction of the generating line.

The imaging geometric relationship is shown in Fig.3.:

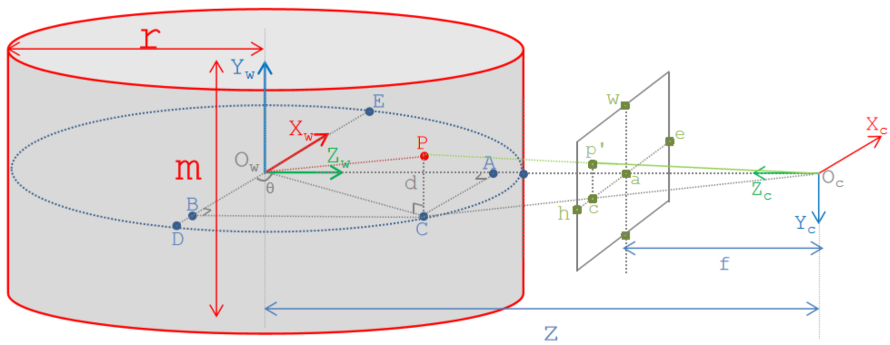


**Fig. 3.** Cylindrical back-projection: A 3D point $P(x, y, z)$ in a cylinder with known radius is projected onto a planar image as a point $p'(u, v)$.

A 3D point $\mathrm{P} = [x, y, z]^{\mathrm{T}}$ can be projected into a 2D pixel of a planar image, $p' = [u, v]^T$, using some known parameters: cylinder's radius, $\mathrm{r}$, focal length, $\mathrm{f}$, the distance from camera's optical center $O_c$ to the center of the cylinder, $\mathrm{z}$. This 3D point can be calculated as follows:

$$\begin{bmatrix} \mathrm{x} \\ y \\ z \end{bmatrix} = \begin{bmatrix} r\cos\theta \\ d \\ r\sin\theta \end{bmatrix} \tag{1}$$

where angle, $\theta$, and height of the point, $\mathrm{d}$ are two parameters in cylinder. Based on similar triangle theory, we can derive the following equations in the condition of the center of the cylinder locates at the center of the image:

$$\frac{\mathrm{m}}{h} = \frac{2r}{w} = \frac{z}{f} \tag{2}$$

$$\frac{\mathrm{PC}}{p'c} = \frac{AC}{ac} \tag{3}$$

The following formula is derived by Eq.(2) and Eq.(3):

$$v = \left\{ \frac{h}{2} - \frac{zd}{2r(z - r|\sin\theta|)} w \right.$$

$$u = \begin{cases} \frac{w}{2}\left(1 - \frac{z|\cos\theta|}{z - r|\sin\theta|}\right), & \theta \geq -\frac{\pi}{2} \\ \frac{w}{2}\left(1 + \frac{z|\cos\theta|}{z - r|\sin\theta|}\right), & \theta < -\frac{\pi}{2} \end{cases} \tag{4}$$

An example of the result of cylindrical back-projection is shown in Fig.4.:

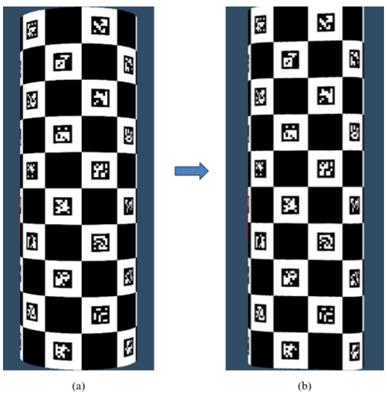


**Fig. 4.** (a)2D cylindrical image. (b) unwrapped image after cylindrical back-projection.

### 3.3 Image Stitching

In order to obtain a complete cylinder image, we need to stitch the acquired image. However, the image features are relatively simple and there are few local similar regions so that we choose SIFT algorithm to accurately extract key points and realize image matching through feature point description. SIFT feature extraction is very time-consuming and difficult to achieve real-time computing speed, so the SiftGPU, namely to achieve real-time calculation is obtained by using the graphics acceleration rate, aimed at 400 x 300 size of image point extraction can be achieved with the same speed of 4 frames per second, basically guarantee the real-time positioning effect, can complete the processing of large amount of data in a short time.

In addition, the key to the success of stitching is to obtain uniform matching points. However, due to the lack of features and uneven distribution on the cable surface, the SIFT feature matching algorithm guided by global homography cannot obtain uniform matching points.We use the following methods to solve this problem: first, the cylindrical back-projection formula in 3.2 is used to expand the cylindrical image to obtain more features; Second, APAP(As Projective As Possible) algorithm[27] is used to divide the image into multiple local image blocks by mesh, and the uniformity of each local image block is obtained to make the matching points more uniform and more dense. Fig.5. is shown the the comparison between two different feature matching methods.

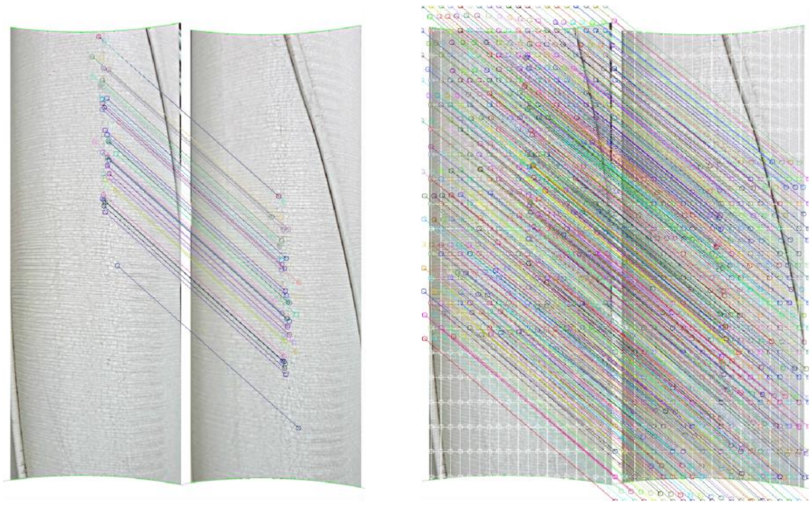


**Fig. 5.** (a)SIFT feature matching algorithm guided by homography. (b)feature matching algorithm guided by local homography with meshing.

## 4 Experimental Results

To verify the key parts of the above, we tested several groups of data collected from a cable-stayed bridge in Kaifu district, Changsha city named Hongshan Bridge as shown in Fig.6.. Hongshan Bridge is the world's largest span cable-stayed bridge without back cable pylon, and the only concrete pylon bridge with a height of more than 100 meters[24].

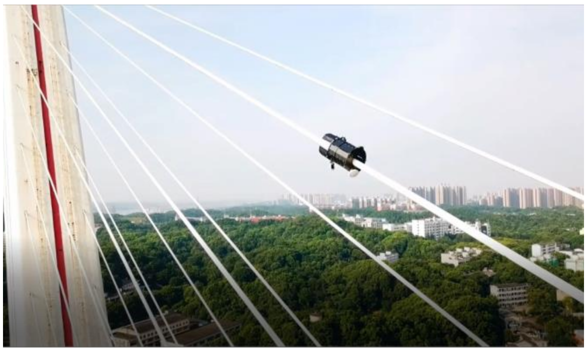

**Fig. 6.** The data collection in Hongshan Bridge.

The experimental result is shown in Fig.7., demonstrating that the proposed algorithm are suitable for cable detection.

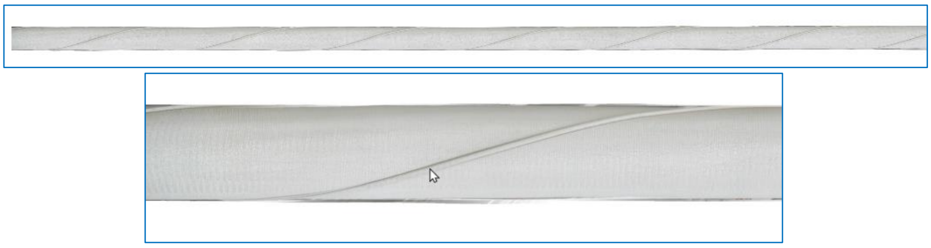

**Fig. 7.** The result of stitching.

## 5 Conclusion

In this work, we conduct digital image processing on the damage detection of cable surface. The core work is the splicing of the cable surface with few features to obtain a complete cable image. The preliminary work is to extract the cable area from the complex background accurately, then we use the derived cylindrical back-projection formula to rectify it. Finally through a series of feature extraction and matching, stitching, we obtain a complete cylinder image. The experimental results show that the system can be applied to actual cable detection.

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