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Design and research of pavement crack detection system based on image processing

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ABSTRACT

With the rapid development of China's economic construction, road traffic is playing an increasingly important role in national economic construction. The ensuing road pavement maintenance and management problems highlight increasingly, among them the damage detection of road pavement become one of the priorities of relevant road maintenance department. In addition, a number of early-constructed high-grade highways along enter long or overhaul period, in order to improve the service life of the road, obtain pavement damage data has become the important topic of pavement maintenance management department. At present, the way of road pavement detection still is mainly artificial detection, but the artificial detection method is of low detection efficiency, time-consuming and affects the normal traffic. Therefore, the study of pavement damage detection system has certain practical significance. This paper mainly expounds the research of pavement crack detection based on image processing technology. This paper first expounds the relevant pavement damage detection system. In this paper, the digital image processing methods are studied, including image enhancement processing, image edge detection and image segmentation technology. Digital image processing is the research emphasis of this article, and at the same time, it is also the core content of pavement crack detection technology. Finally, the road pavement crack image classification recognition is studied and several common methods of pattern recognition are introduced.

KEYWORDS

Pavement distress detection; Image enhancement; Image segmentation; Edge detection; Pattern recognition; Neural network.

HARDWARE DESIGN OF PAVEMENT CRACK DETECTION SYSTEM

Road information acquisition system relying on on-board system is different from general image acquisition system; it should gather the road image information when car at the speed of 30-70 km/h. How to collect clear images in the process of high-speed mobile and store them down in real time is the primary problem for considering[1]. Hardware selection is the starting point of building systems; it is directly related to the quality of the image and the image processing effect later. This chapter deals with image acquisition hardware choice and establishment.

Hardware structure design of pavement crack detection system

The purpose of pavement crack detection test system hardware structure design is to establish a rapid, accurate, high resolution image input platform. Record pavement cracks, and then further conduct image processing to achieve the purpose of the pavement crack detection. Pavement crack detection system hardware design mainly includes the choice of linear array camera and image acquisition card, camera choice, lighting design, the camera fixed bracket design. The following Figure 1 and Figure 2 are respectively hardware structure diagram and the flow chart of pavement crack detection.

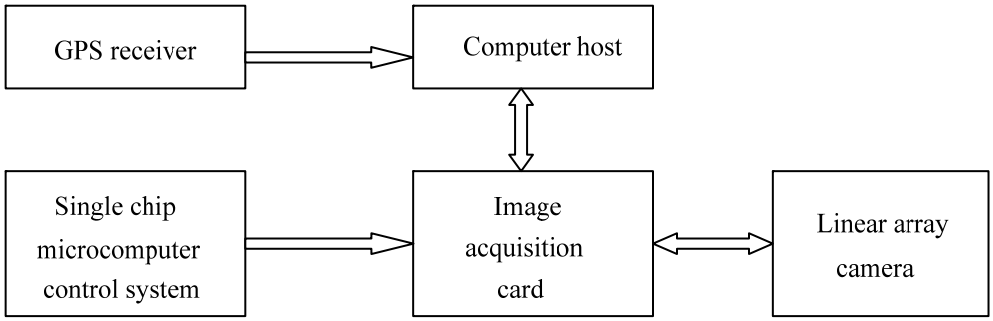

Figure 1 : The hardware structure diagram

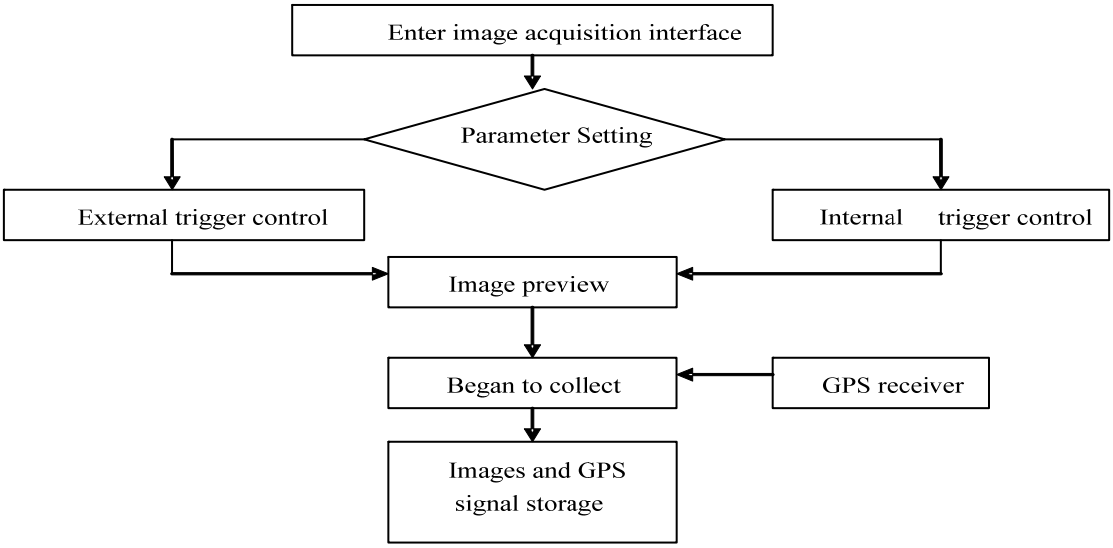

Figure 2 : The flow chart of pavement crack detection

Linear array camera selection

1) Working principle of linear array camera

Charge-coupled device (CCD) is consisted of diode units lined up on the silicon photosensitive; they are neatly arranged in a rectangular square, each light-sensing cells called picture element, when the phalanx of light rays onto silicon wafers, under the action of the in a certain energy photons each atom of the picture element, electrons escape from the atoms, forming a pair of free electrons and electron holes atom[2]. The stronger the light projected onto a photosensitive unit, more the more electron hole will be produced.

2) Analysis of linear array camera resolution and line scanning rate

Linear array camera resolution and line scan rate are two very important indicators of camera. Camera resolution is the image pixel points camera collected at every time, the higher the resolution, the more pixels means can be used, the clearer image is. Because this article uses the linear array camera, so we just need to consider level points. Image acquisition of this paper is conducted on the vehicle, therefore on the horizontal distance is a lane whose width is 3.7 m[3]. Because the system design goal is to detect the pavement cracks of 2 mm or more, the transverse distance resolution reaching 3.7/0.002 = 1850 is enough. On the way of actual measurement, we set the resolution of the linear array camera for 4080.

Line scanning rate refers to the rate that camera collect transmission images, for linear array camera it refers to the number of rows collected per second. The higher line scan rate is, the more images collected per second, the higher the performance of the camera is. Due to the sampling system is under the driving state, so under the vehicle speed to satisfy the detection of 2 mm or cracks. If the vehicle speed is between 36-72 km/h, then according to the formula

$$f = 1000 * V / 7.2 \quad (1)$$

The camera line scanning frequency can be calculated for 5 to 10 KHz. Only linear array camera that satisfies the above two conditions can be used in this system.

Auxiliary lighting design

In vehicle image acquisition, because road pavement materials are generally darker colors, usually in the form of asphalt or cement, while collecting images light from the lens may not be enough, so that the collected image brightness is not enough, the image is dark, increased a lot of difficulty for the subsequent image processing. So in the camera detection system must consider the design of auxiliary lighting to increase the light intensity, increase light entering the lens, thereby making a clearer image. Right light source choice will directly affect the whole test system.

The characteristics of the light source is one of the most important in lighting design, five important factors involved in the design of the light source:

1. Directions: controlling and regulating exposure to the object in the direction of the incident light is the most basic factors of system design[4]. It depends on the type of light source and location relative to the place of the object. Generally there are two of the most basic ways, namely direct light and diffuse light. All other ways extends out from the two methods.

2. Spectrum: light is composed of single or multiple components of the spectrum, such as the sunlight spectrum is made up of all spectrum from the infrared to the ultraviolet spectrum, the spectral range human eye can feel is between 380 mm to 780 mm, that is, from red to purple. Light color depends on the type of light produced by light source and camera lens of optical filter covering the light.

3. Polarization sensitivity: it is also called polarized light, a feature of the waves of light. Transmission light is volatile like electromagnetic wave. The light wave direction of general oscillation is indefinite, while the oscillation direction of the polarized light is in a certain plane, for example, the oscillation of the linear polarized light axis is vertical with transmission direction. The polarization resistance of light waves retained directional nature in the mirror reflection, but diffuse type of reflected light is lost.

4. Strength: the strength of the light will affect the camera exposure, insufficient light means that the low contrast, will need to increase the magnification, but may amplify the noise at the same time, also may make the aperture of the lens, but the depth of field; In turn, in the waste of energy intensity, and bring the cooling problem. Sometimes adjustment of the size of the light intensity will bring unexpected results.

5. Uniformity: the detection optical applications need uniform illumination. Because light intensity reduces with the increase of distance and angle of the light, the lighting will bring bigger problem for large object.

PAVEMENT CRACK IMAGE PROCESSING METHODS

Basic theory of digital image processing

With the progress of human civilization and the development of science and technology, the requirement of process information communication is more and more high, and image has become one of the main medium of information transmission[5]. Since it is intuitive, vivid and informative, image has become our important means to obtain information, awareness, and tools to change the world. Research shows that information gotten through the visual has accounted for more than 75% of the total amount of information, which shows the importance of image for humans. At present, the development and application of image processing becomes more and more wide, many technologies are maturing, and huge economic benefits generate. Image processing and its fusion with other fields becomes an indispensable tool for scientific research and our life.

In a broad sense, the image is the objective reflection of the natural scenery, is the important sources of human to know the world and the human itself. Photographs, drawings, film and television undoubtedly all belong to image; optical imaging on the camera viewfinder, microscope, or telescope is also image. In addition, Chinese character we use also can be classified as a kind of image, because Chinese characters originated from hieroglyphs, therefore it can be thought of as a special kind of painting; by extension, sensor signals by converting the image, such as electroencephalography, electrocardiogram can also be regarded as a kind of image. Image is the object of reflection or transmission of light distribution, it is objective existence. All in all, all information that human visual sensory can receive can be called image.

Image is obtained by using different observation systems in various forms and means of observation of the objective world, which are entities that can directly or indirectly act on the human eye and produce visual. Usually we will image roughly divided into two kinds: one kind is simulate image, such as photos, pictures and optical simulation image, the other kind is the digital image, namely bitmap images after the computer processing. Strict digital image is grid sampling after equidistance rectangular, 2D function of the amplitude of equidistance quantification[6]. And digital image acquisition is the process to change continuous image function into a discrete functions set. Digital image acquisition process is shown in Figure 3.

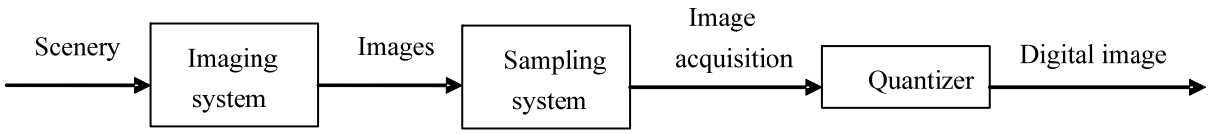

Figure 3 : The process of digital image acquisition

Pavement crack image preprocessing

Image enhancement processing refers to the image processing method that processed image is more suitable for a particular application for priority than the original image. Any picture of the original image without treatment has a certain amount of noise. Image quality is deteriorated by the noise, characteristics of the image is not clear, even cause image characteristics lost, bringing certain difficulty to late image analysis. Therefore, enhancement processing must be done to the original image of low quality. Image enhancement algorithms can be roughly divided into two categories: frequency domain and spatial domain methods. Spatial domain is also known as the image space. This kind of method mainly directly computes the image pixels in the form of matrix[7]. Frequency domain processing is based on Fourier transform of the image. Image enhancement has no general theory. Because the original image is processed for human visual sensory, deciding the different methods of treatment effect by different observers to judge, so the evaluation of sensory visual image is a very subjective process. So we need to define a standard to measure the performance of an algorithm.

"Spatial domains enhance" refers to reinforce individual pixels of the image; Spatial domains enhance processing process is to directly operate on these pixels. The process can be defined by the type1:

$$g(x,y) = T[f(x,y)] \quad \textbf{(2)}$$

Frequency domain method in the image enhancement refers to do specified processing operations on the transformation value of an image in the image frequency domain, and then change it into spatial domain. From the form, the method belongs to the indirect approach; Figure 4 describes the process of this method:

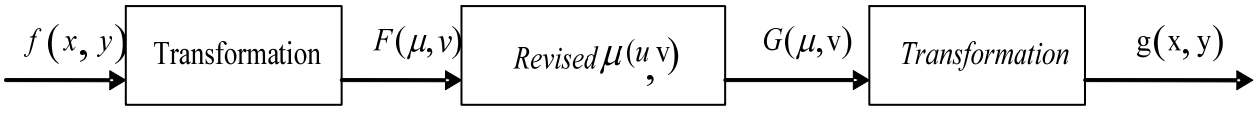

Figure 4 : The process of digital image acquisition

Its specific mathematical description is as follows

$$F(u,v) = \Im[]f(x,y) \quad \textbf{(3)}$$

$$G(u,v) = H(u,v) \cdot F(u,v) \quad \textbf{(4)}$$

$$g(x,y) = \Im^{-1}\{G(u,v)\} \quad \textbf{(5)}$$

IMAGE NOISE MODEL

Here are several types of the typical noise model, and image enhancement method according to different noise. Image noise can be categorized according to its nature, it should be pointed out that the noise is generally understood to be caused by some kind of or many uncertain factors. Often use the basic model for image processing

$$y = Hx + z \quad \textbf{(6)}$$

Image noise is mainly produced in the process of image acquisition and transmission, and most of them belong to the additive noise.

1) Gaussian noise

We can take it as the synthesis effect of a large number of small independent distribution factors, according to the central limit theorem; we can take advantage of the Gaussian distribution in probability and statistics, the form of the Gaussian distribution is as follows:

$$z \sim N(\mu,\sigma^2) = \frac{1}{\sqrt{2\pi\sigma}}\exp\left[-\frac{(z-\mu)^2}{2\sigma^2}\right] \quad \textbf{(7)}$$

In addition, the extent of Gaussian noise is generally expressed as the Rayleigh distribution. The probability density function is:

$$p(z) = \begin{cases} \frac{2}{b}(z-a)\exp\left[-\frac{(z-a)^2}{b}\right], z \geq a \\ 0, z < a \end{cases} \quad \textbf{(8)}$$

Numerical characteristics of Rayleigh distribution is as follows:

$$E(z) = a + \sqrt{\frac{\pi b}{4}}, \sigma^2(z) = \frac{b(4-\pi)}{4} \quad \textbf{(9)}$$

2) Quantization noise

In analog - to - digital converter (ADC) process, distortion caused in the process of quantifying the amplitude of the signal, referred to as quantization distortion[8]. Because this kind of distortion is similar to those thermal noise produced by the electronic components, they are referred to as quantization noise.

Distribution of the quantization noise can be obtained by computing. Assuming the signal density distribution function as $f(x)$, with symbol z as error caused by quantization:

$$f(z \mid x \in R_i) = fX(z + a_i)I(z + a_1 \in R_i) \quad \textbf{(10)}$$

Among them, $I()$ is the indicator function. By the full probability formula, we can get the density distribution function of z:

$$f(z) = \sum_{i=1}^{M} f(z \mid x \in R_i)P(\in R_i)$$

$$= \sum_{i=1}^{M} fX(z+a_i) I(z+a_i \in R_i) \int_{r \in R_i} fX(x)dx \quad (11)$$

Mean and variance are respectively:

$$E(z) = \sum_{i=1}^{M} \int_{x \in R_i} fX(x)[x - Q(x)]dx \quad (12)$$

$$\sigma^2(z) = \sum_{i=1}^{M} \int_{x \in R_i} fX(x)[x - Q(x) - E(x)^2]dx \quad (13)$$

3) Salt and pepper noise

Salt and pepper noise mainly describes the bipolar noise of the image. Namely, only a little picture element of image has noise, but the effect of this type of noise is different from previous simple additive noise. If take the original image pixels as x, salt and pepper noise as Z, image pixels polluted by salt and pepper noise as y, we can directly describe the effect of the salt and pepper noise:

$$p(y) = \begin{cases} \alpha, y = x \\ \beta, y = a \\ \gamma, y = b \end{cases} \quad (14)$$

Enhancing processing of crack image

Image acquisition system uses black and white CCD camera, so the original image the system adopts is gray image, so no need to do gray level transformation process of the image, can directly conduct subsequent image processing. Because the images may produce interference to the original image in the design of the hardware system, the formation of image signal and image transmission and storage process, namely, noise[9]. In addition, in the process of transmission and storage the original image generates impulse noise jamming signal because of electromagnetic disturbance. Weather, lighting and air dust are all likely to be of different degrees of influence on the image. Therefore, before the image processing, usually need to do certain pretreatment of original image, such as image filtering, image restoration, image sharpening processing. Image preprocessing usually can better improve the image quality, eliminate the noise pollution caused by various factors, and improve the accuracy of detection. According to the different principle of noise, different methods for processing are adopted. And obtain an ideal filter to enhance the image by comparing.

Image filter processing

Image filtering is also known as image smooth. Because the noise in the image and image signal are often intertwined, if improper filtering is not smooth correctly, it can cause the details of the image itself, such as edges and lines become blurred, causing a drop in the quality of the image. So in the image filter processing certain image detail may be sacrificed[10]. How to filter the noise in the image, but at the same time keep the details of the original image as much as possible become the key point of the image smooth.

Image gray-scale enhancement

Histogram equalization is also known as histogram equalization, referring change a given image histogram distribution into a balanced distribution histogram, it belongs to the gray enhancement algorithm. Histogram equalization processing is a very simple and practical method of digital image processing; it is used to represent the image of gray distribution of the statistical charts.

By random process mathematics theory the relationship between the distributions of image signal can be achieved. Due to the breakage of the cracks belongs to the random process, we can express it by using mathematical function, the variable of the function represent the image pixel distribution, so it is possible to define the following formula:

$$F_s(s) = \int_{-\infty} P_s(s)ds = \int_{-\infty} P_r(r)dr \quad (15)$$

Through mathematical theory relationship of the type can be derived, making the relationship between variables more clear, derivation:

$$p_s(s) = \frac{d}{ds}\left[\int_{-\infty} p_r(r)dr\right] = p_r(r)\frac{dr}{ds} = p_r(r)\frac{d[T^{-1}(s)]}{ds} \quad \textbf{(16)}$$

The cumulative distribution function, namely discrete gray level transformation function type is as follows:

$$s_k = T(r_k) = \sum_{i=0}^{k}\frac{n_i}{n}(0 \le r_k \le 1; k = 0,1,...,L-1) \quad \textbf{(17)}$$

SUMMARY

With the rapid development of road traffic construction in China, the transportation plays an increasingly highlighted role in national economic construction and people's livelihood. Among various forms of transportation, highway is mostly closely contacted with people's daily life. With the increase of highway mileage, the related road maintenance road maintenance problem increasingly becomes part of the important topics. At present, the traditional manual detection means can't meet the demand of road in our country, so the road diseases automatic detection technology research has become the important topics we need to be addressed. In this paper, the road pavement crack detection system based on image processing technology is studied, mainly complete the following several aspects work. First of all, the developing situation of the pavement disease detection system at home and abroad are simply introduced, the development trend of future research are given. Design and research are done on the pavement crack detection system; this paper introduces the hardware composition and working principle of pavement crack detection system. Pavement image acquisition system take pictures of pavement damage image of high quality and high resolution, then the computer processing system of image store and display. Because the image acquisition process belong to outdoor work, which has been affected by some factors of natural environment. The images usually contain factors that bad for the image processing such as noise, shadow part. To facilitate the classification of image recognition later, this article first do preprocessing to the original image, including image histogram enhancement, image filtering and sharpening, etc., and then extract the edge of the crack image through the edge detection operator.

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