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Application of the image and laser sensors based tunnel scanning system

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ABSTRACT: Degradation of tunnel concrete liner requires routine and repetitive inspection to increase the life cycle of the structures. The tunnel inspection task, however, is labor intensive and time consuming process. Hence a computer based inspection system needs to be developed. In this paper, applicability of a tunnel scanner based upon a laser and an image scanning system, called as opto-laser tunnel scanner, is discussed. The image scanner can capture detailed surface features of tunnel liner such as micro cracks and spall, and laser scanner can reproduce geometric characteristics of a tunnel liner. Both types of data set have their own application. In addition the combined data set show three dimensional features of tunnel liner. This application will extend the data usage so it can be applicable for tunnel management.

1 INTRODUCTION

Most tunnel concrete liners installed as a structural element to support tunnel loads undergo degradation process which causes loss of the material strength and increase of permeability mainly produced by generation of various types cracks. In consequence a routine and repetitive inspection is required to provide timely maintenance to increase the life cycle of the structure.

Previously, the tunnel inspection was mainly conducted by human, hence it took long time and efforts. Recently with aid of computers and IT technology, vision or laser based systems have been developed (Asakura and Kojima, 2003, Yu et al. 2007, Yoon et al. 2009). The vision based system uses Charge-Coupled Device (CCD) cameras or video camera to capture the surface images of concrete liner. From the image, location, shape and size of the cracks are found. Likewise, a laser based system uses laser sensor to measure distance from the sensor to a target. From the scanning process the spinning mirror mounted at the front of the sensor deflects the laser rays to a circumferential direction, and the sensor measures returned laser rays. This measurement includes the geometric and radiometric features of a tunnel. The geometric feature of a tunnel represents three dimensional characteristics of the tunnel, which represents dimensions and shapes of the tunnel and attachment at the concrete liner. The radiometric features represent surface characteristics of the concrete liner for example, wetness of the tunnel liner and shape, size and distribution of surface crack. A successful application of the synthesized radiometric and geometric data set has been shown to delineate the surface cracks and spalls of a concrete liner (Yoon et al. 2009). The combined image and laser based system has advantages, such as acquisition of image and laser data sets, which allowing the identification of dimensional and surface features. Hence the system is more versatile and has wide applicability. This paper discusses about the development of the synthesized image and laser scanning system, and shows system configuration, optimization and data display. In this paper the synthesized image and laser scanning system is named as an opto-laser scanning system.

2 SYSTEM CONFIGURATION

2.1 *Laser scanner*

The main physical components of the opto-laser tunnel scanning system are as follows: laser scanners, image acquisition system, illumination, and Rail Guided Vehicle (RGV). A laser scanner set is composed of high speed Laser Range Finder (LRF) and line scanner (see Fig. 1).

The role of LRF is measurement of a distance from the sensor to a target. The range of the LRF used for the system is 16 m and sampling rate is 200 k/sec. An emitted laser ray is deflected while the laser rays pass through the line scanner, which includes a rotating mirror, a motor and an encoder. The stationary type laser scanner has a scanning profile in a single plane like in Figure 2.

Since the RGV moves the laser scanner moves along the axis of a tunnel. Consequence, the moving profile of laser rays is shown in Figure 3.

Three set of laser scanner units are installed on the opto-laser scanner. The system configuration is shown in Figure 4.

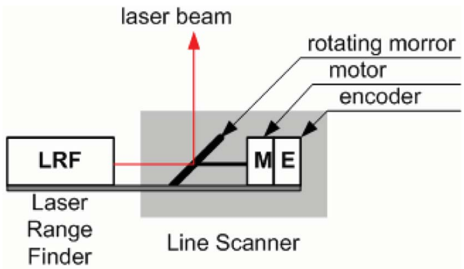

Figure 1. Constituent of a unit laser scanner.

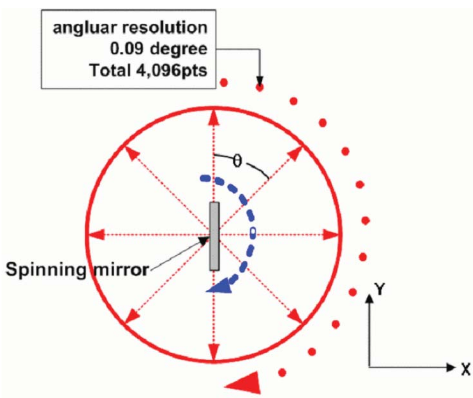

Figure 2. Laser rays profile of a single plane.

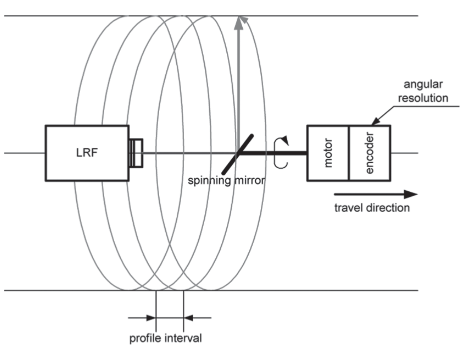

Figure 3. Helical profile of laser rays while traveling of RGV.

2.2 *Image acquisition system*

Like laser scanner, multiple channels of image acquisition system is installed for the opto-laser scanner. Three Charge Couple Device (CCD) and illumination are integrated. The effective picture element of the used CCD camera is 768(H) × 494(V).

A sufficient quantity and constant intensity of light is important for high quality image. The opto-laser scanner uses 250 W HID lamp. The CCD camera and ramp installed are shown in Figure 5.

2.3 *Rail Guided Vehicle (RGV)*

A locomotive type RGV was developed and the structure of RGV was designed to install the laser scanner, CCD camera and illumination. The RGV developed has 5 modules: laser scanner array, CCD camera array, control, battery, and power. Laser scanner and CCD camera array modules are main parts for data acquisition. In addition, the rest modules are quite important for accurate data acquisition. The control module executes overall control of RGV, and data management. The power module consists of RGV frame, DC motor, chain gear, bearing house, wheel shafts and wheel. The equally distributed data acquisition depends on traveling speed of RGV.

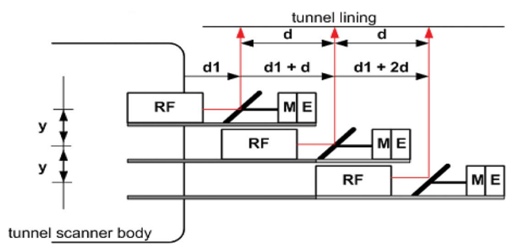

Figure 4. Multi laser scanner system configuration.

(a) (b)

Figure 5. CCD camera (a) and illumination (b) installed for opto-laser tunnel scanner.

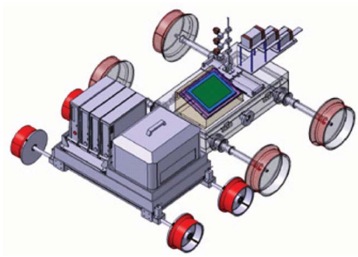

Figure 6. Three dimensional model of RGV.

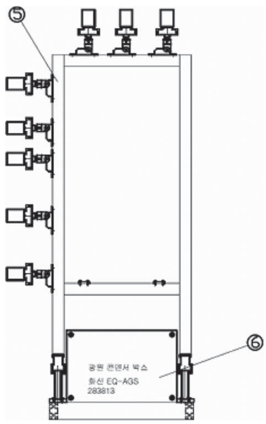

Figure 7. The main frame for cameras.

Hence assuring constant speed of RGV is quite crucial for the acquisition of high quality data set. A current generator was installed on the RGV to provide the required electric power for traveling of RGV and operating of the laser scanners and CCD cameras. The overall shape of RGV is shown in Figure 6.

The area covered by CCD camera depends on the distance between a camera and target. Due to the capacity of the camera, the covered area of a camera is limited and depends on the required resolution of an image. The opto-laser scanner can host 8 cameras and each camera can adjust their shooting angle toward the target. The main frame for the cameras was attached to the RGV and shown in Figure 7.

3 DATA ACQUISITION AND CORRECTION

3.1 *Development of digital filter for laser scanner*

An array of laser scanner acquires geometric and radiometric data which require correction process to increase the accuracy and resolution of the data. The sources producing low resolution data set of laser scanner are as follows: angular resolution of encoder in line scanner, laser spot size, edge effect, and interfering radiation. As the spot size of laser signal is smaller and the angular resolution is higher, higher resolution of laser data set can be achieved. The spot size and angular resolution depend on the capacity of laser sensor and line scanner.

The edge effect is another problem that deteriorates the resolution of laser scanning data. Once the laser ray hits the edge of a target, the reflected signal from the edge will be scattered and this process produces wrong point or artifact, which distorts realistic dimension of the target. Therefore, a digital filter is required to reduce the edge effect.

Finally, the radiation interfering is produced by the ambient light. The ambient light must be checked and laser signal must be modified to minimize the radiation interfering. A digital filter was developed to handle the edge effect and radiation interfering.

The digital filter developed to increase the resolution of laser data set uses a mixed criterion of range and ambient light intensity data. In a given range, the measure data should be in a limited range of light intensity. Therefore, with mixture of range and light intensity interval, a sufficient amount of noise points were eliminated. At the second stage, another digital filter was used. The filter used backscattered intensity values of laser rays. The outliers, the data points of unusual radiometric values, were eliminated from the normal distribution of intensity value. Figure 8 shows a raw data set and the digital filter processed data set.

3.2 *Panoramic image generation*

The arrays of CCD camera with macro lens capture surface images of tunnel liner. The opto-laser tunnel scanning system employs relatively small size main frame and small numbers of cameras and illumination compared to an ordinary vision based tunnel scanning system. The ordinary vision based tunnel scanning system uses almost the same size and shape of frame with a tunnel to install the CCD camera or camcorder and illumination. Under this configuration of camera, the Field Of View (FOV) of each camera is short and this condition requires large number of cameras. Hence at least one or two hours are required for setup. However, the permitted time for a railway tunnel inspection at most is three or four hours at night in Korea. Therefore, a rapid installation of components is important function which is required in the field.

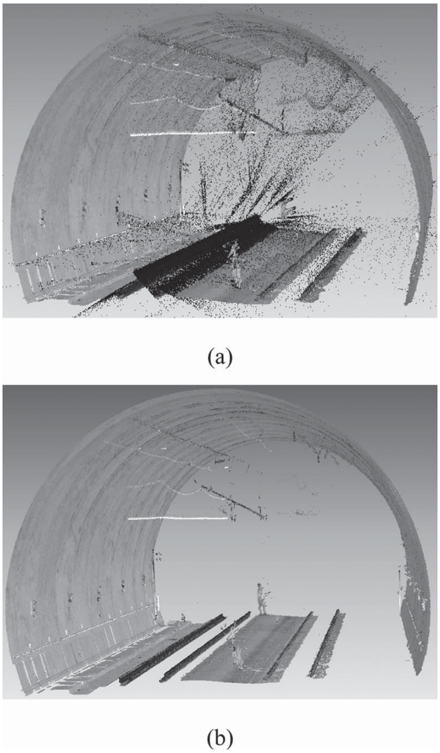

Figure 8. Laser scanning data set. A raw data set (a) digital filter processed data set (b).

The capture image undergoes panoramic image generation and image processing to obtain high quality images Since the concrete liner surface is not flat, the pixels will distort, near the edge. Therefore the zone of non-distorted image segment needs to be defined. From the continuously capture images, an edge or singular point is determined and the point is used as a reference point to calculate the amount of shift or travel for each images. Based upon the calculated pixel, an effective image segment is determined for each image. A panoramic image is generated from the merge of the effective image segments which was collected from the continuously capture images (see Fig. 9).

Figure 10 shows a merged image representing the surface features of concrete liners. In order to obtain high resolution images, several steps of digital image process were conducted. Initially, bright compensation process was conducted. Bright compensation process eliminates the bright difference generated by the various target distance from the sensor. Bright compensation process uses image histogram. The range, distribution and centroid of image histogram were adjusted to display images with relatively similar brightness.

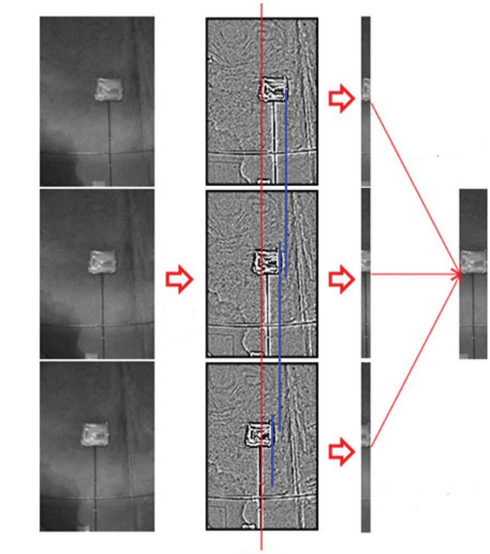

Figure 9. Merge process of image segment.

Figure 10. Panoramic image merged from image segments.

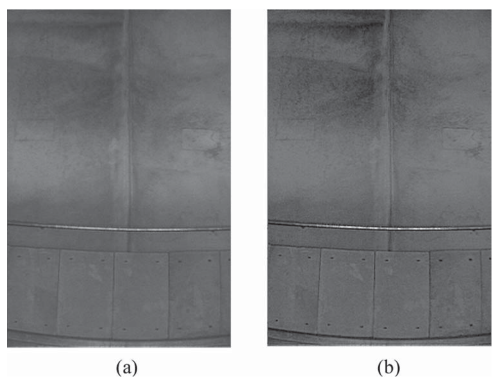

Figure 11. A comparison between original (a) and processed (b) images.

The contrast compensation process employs various filters such as layer blending, gradient map, Gaussian blur. Figure 11 shows original and processed images.

The merge and generation of panoramic image were conducted after enhancement of image quality.

4 MAPPING OF IMAGE AND LASER DATA

The merit of the use of laser and image data is that the two data sets can be used for different purposes. Image data can be used of identification of surface texture and condition and laser data can be applicable for geometric investigation of structures. In addition, an integration of these two different features of data produces another way of application. Mapping of laser and image data produces three dimensional image which reproduces realist condition of tunnel. This kind of mapped data has more versatile application for tunnel inspection and maintenance. Figures 12 and 13 show merged panoramic image and mapped image.

The mapped image detail displays surface characteristics of concrete liner. The process of mapping follows i) edge detection ii) thining iii) key point extraction and iv) key point matching.

Figure 12. Panoramic image.

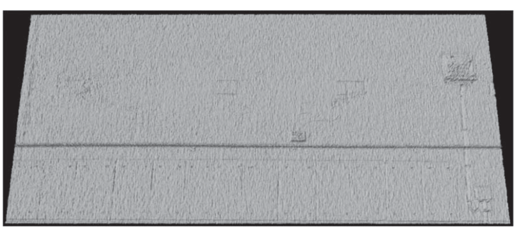

Figure 13. Mapped image.

5 CONCLUSIONS

The developed IT and computer technologies are getting applied to the labor intensive tunnel inspection. Hence an automation of the inspection process will reduce the cost and time in near future. In this paper, a system configuration and data processing for tunnel scanner employing image and laser scanners was discussed. The integrated system captures surface image of tunnel liners and geometric features of the structure. The optimized vision system developed was intended to reduce the install time and number of CCD cameras and illumination. The capture image undergoes digital image process such as bright and contrast compensation. In addition, the effective image segment is collected to generate the merged image. These processes produce high resolution image that can be used to define surface characteristics of concrete liner. The digital filter was developed to eliminate outliers of laser data set. The filter employs the use of ambient light intensity, range, and backscattered intensity. The mixed used of three parameters shows successful elimination of outliers.

The developed laser and image scanning systems were mounted on a RGV. While RGV travels, laser and image scanners continuously scan the internal features of a tunnel. The scanned data successfully represents surface characteristics of concrete liner and dimension of the tunnel. In addition, the mapped data displays realistic three dimensional features of a tunnel. The merged data represent extended application of the opto-laser tunnel scanner.

Further study needs to automatically identify the cracks and classified surface characteristics such as leakage and spalls.

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