Investigation on Key Techniques of Measurement Device of Position and Attitude Applied in Large-Scale Pushing Bridge Construction Machinery

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Abstract—**The problem about measurement of position and attitude of the existing pushing railway bridge construction engineering machinery needs to be solved. The paper designs two kinds of measurement devices adopting phototransistors array and CCD aimed at the demands of pushing railway bridge construction. Multiple serial port communication technique is used to connect devices with industrial PC. Effectiveness of these two kinds of devices has been validated in practice, and the results review that they can not only meet the needs of construction, but also can be used under sunlight circumstances. The measurement system and devices improve the efficiency of pushing railway bridge construction greatly and provide valuable reference for other large-scale engineering machinery's measurement of position and attitude.**

Keywords—**Position measurement, phototransistors array, CCD.**

I. Introduction

With the development of economy and Olympics game's promotion, many cities desire to build a large number of traffic facilities, such as overpasses and toll circuits. However, new highways have to go through original railway because of city's expansion, the problem that stopping traffic for construction comes out. In order to deduce the economic losses during bridge construction, the method of pushing railway bridge construction which will not interrupt communication is adopted and become the most popular construction technique. This method's main steps include pouring bridge and pushing bridge to specified location, and so on.

How to measure bridge's position and attitude is a difficulty problem which needs to be solved as soon as possible. Firstly, the existing measurement method obtains bridge's position and attitude by using gradienter and theodolite. This kind of manual operation relies on operator's experience greatly, so it is not real-time and not accurate, which will influence construction's precision. Secondly, although such devices as laser total station and differential GPS system can measure bridge's position and attitude, the high price of the entire measurement system made up of multiple devices, plus the cost of educating operator how to develop and extend product's functions, make total stations difficult to be used widely. In a word, it's necessary to develop low-cost measurement system and device of position and attitude fitting field requirements.

Such large-scale engineering machinery as pushing railway bridge construction machinery can be treated as generalized engineering robot. In the field of engineering robot, advanced techniques including machine vision, bus technique and net control have been used widely, and the level of automation has been improved to a great extend. As for large-scale engineering machinery, the accuracy of steering and moving influences the accuracy of construction job. Therefore, investigating the measurement device of position and attitude applied in large-scale engineering construction machinery is valuable for improving the technique level and construction efficiency.

Experts and specialists study the problem and apply achievement in practice. At the present time, laser guide and CCD technique have been used successfully in tunnel borer[1], tube push bench[2], AGV[3-7], and so on.

Though the measurement technique of position and attitude for large-scale engineering machinery has made great progress, there're several problems to be solved:

(1) Lack of versatility: A kind of device is designed for a kind of specified construction field;

(2) Can't be used under sunlight: Most of measurement devices can only be used in dark circumstances;

(3) High price: High cost of device prevents its application.

Accordingly, developing low-cost measurement device of position and attitude characterized by good versatility which can be used under sunlight will do great good to improve large-scale engineering machinery' s construction efficiency.

The paper is organized as follows. Measurement system of position and attitude for pushing railway bridge is presented in section II. The specification of phototransistors array method and CCD method is discussed detailed in section III followed by the description of the multiple serial ports communication in section IV. Related conclusions are presented in section V.

II. Measurement System of Position and Attitude for Pushing Railway Bridge

Considering the requirement of pushing railway bridge construction, the measurement system of position and attitude is shown in Fig. 1. Two laser transmitters and two receiving

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targets work together and high accuracy angular transducer is adopted to obtain bridge's pitch angle and roll angle. Two beams of laser from laser transmitter are projected onto individual receiving target and the coordinates of laser point on receiving target will be sent to IPC through serial communication. Combined with mathematical model of coordinate conversion, the bridge's position and attitude can be calculated accurately and conveniently on real-time, which provide digital information for deviation correction operation. The most important issue it to design a kind of measurement device which can be used under sunlight conveniently.

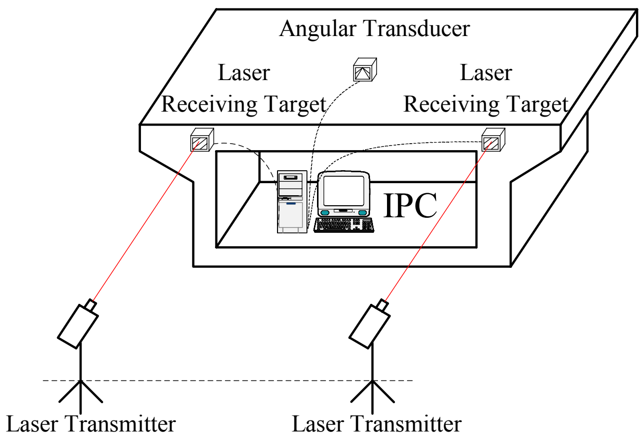

Figure 1. Measurement system of pusing bridge construction

III. PHOTOTRANSISTORS ARRAY METHOD AND CCD METHOD

A. Summarization of two methods

Phototransistors array and CCD can be used as photoelectricity sensor in receiving target. The following contents list out two methods' individual characteristics and compare these two methods with each other according to measurement accuracy, speed, reliability, and the adaptability to outer circumstances.

1) Phototransistors array method

- The quantity of data needs to be processed is less than CCD, and the processing algorithm is more simple, so the measurement speed is high. However, the above merits decrease the measurement accuracy.
- Laser spot's position captured by sensitive elements isn't the same as CCD method that the position will be influenced by lens's distortion.
- Phototransistors array includes many discrete components, such as sample circuit and power switch, which increases the scale of circuit and decreases device's reliability. Besides, the most serious problem is that the coherence of all components can't be guaranteed, which causes many problems including difficulty of process data, low accuracy, etc.

2) CCD method

- CCD has a large number of photosensitive portion, which provides higher resolution and requires the controller has higher operating frequency.
- Optical distortion brought by CCD causes three problems: decreases measurement accuracy, increases the amount of data processing, larger capacity for reducing the influence of optical distortion.
- Related image acquisition components and devices, such as high-speed AD chipset, image acquisition card, and so on, can be obtained conveniently. So this method's cost and reliability can be guaranteed.

B. Relization of target based on photosensitive diode array

Through collecting analog quantity from photosensitive diode array, the device can work under sunlight circumstances properly.

1) Design of circuit

- Schematic plan of photosensitive diode array is shown as Fig. 2. The number of IO can be decreased greatly by matrix scanning mode: controller output column scanning signal, which break over the power change switch of column j. Every line connected with column j becomes closed circuit and photosensitive diode's voltage signal enters corresponding AD port after filtration. Schematic plan of phototransistor array's external appearance is shown as Fig. 3.

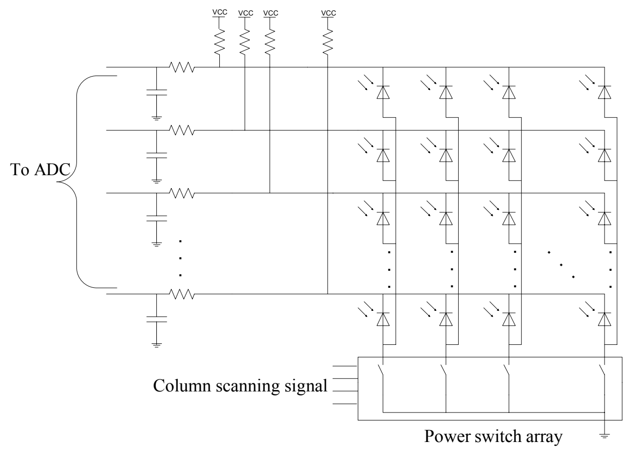

Figure 2. Schematic plan of photosensitive diode array

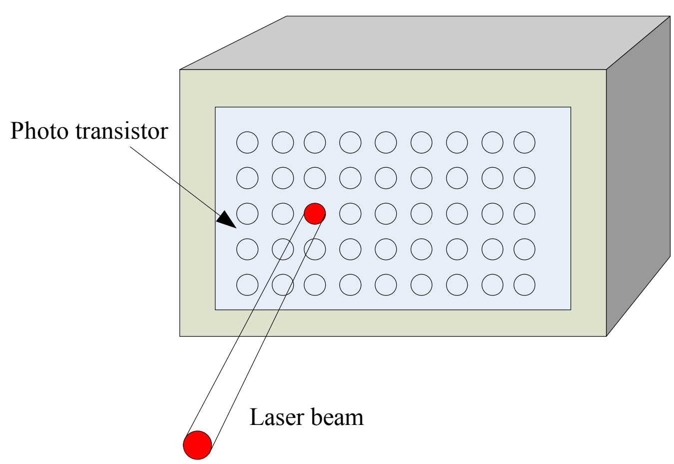

Figure 3. Schematic plan of phototransitor arry's aexternal apperance

2) Data processing algorithm

- Calibration of photosensitive diode array: The purpose of this step is to reduce the influence of inconsistency of diode's photoelectricity character. Firstly, every AD channel should be calibrated. Secondly, under ambient light, every diode should be calibrated to obtain a reference table that records the extent of ambient light's influence on every diode.
- Preprocessing phototransistor's signal: Considering sampling error and noise, median filtration is adopted to preprocess analog signals. The periodic time depends on laser point's moving speed.
- Eliminating the influence of ambient light is as follows: Firstly, get the reference photo-transistor signal value Vr and take it to find the background reference table TB . Secondly, get the signal value of the photo-transistor at position V0(i,j) and find the background value VTB(i,j) in TB . Thirdly, The difference between V0(i,j) and VTB(i,j) is the net value V(i,j) ,which is the real criterion of the photo-transistor at position (i,j) .
- Locating the center of laser spot: Generally, one laser beam's point can cover from 4 to 9 diodes. So, the following way is adopted to calculate the center of laser point in the process of scanning target. Firstly, 9 diodes' position and value should be recorded which value is greater than other diodes. After finishing scanning, gravity model approach is used to obtain the center of laser point.
- The phototransistor array receiving target's workflow is shown as Fig. 4.

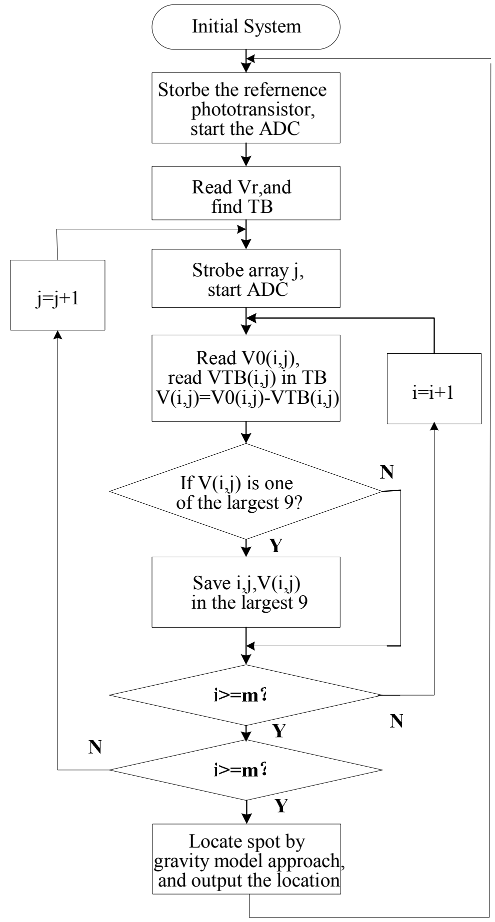

Figure 4. Phototransistor array receiveing target's workflow

C. Relization of target based on CCD

1) Hardware System Design

Laser receiving target based on CCD is an image acquisition and processing system, shown as Fig. 5. The signal the CCD outputs is standard VGA signal, which not only contains the image signal, but also the line synchronization signal and the field synchronization signal. The image signal, in analog form, will be converted into digital form by the high speed ADC. Additionally, for obtaining the correct image, the CPU must start AD conversion and save data at the right time according to the synchronization signal. The transient process of the VGA signal is at the level of microsecond. So it is not reasonable to assign the CPU as a monitor of the VGA signal, and independent circuit of synchronization signal separation is needed.

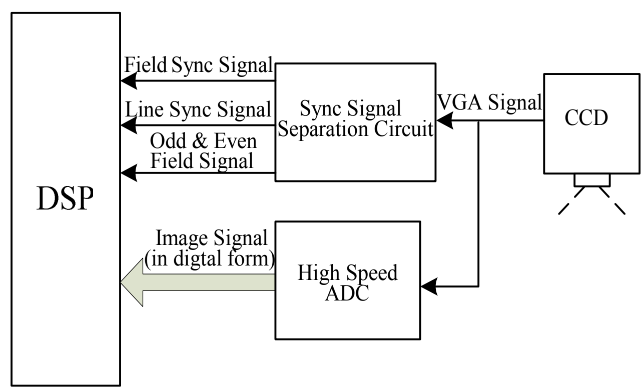

Figure 5. Image acquisition and processing system based on CCD

2) Image Processing Algorithm

The CPU in this system is just the normal DSP or MCU, whose operation frequency range is from several MHz to tens of MHz, the storage capacity is at the level of tens of Kbytes。 But the data quantity of a frame of image is more than 100Kbytes. So it can not process an whole frame at one time. In the designment of algorithms, full consideration needs to be paid in the use of storage capacity and the complexity of the algorithm.

a) Image Preprocessing

Due to the noise of the CCD imaging, the image preprocessing of denoising is necessary before the image processing. Median filter is a common method of denoising, which could maintain the edge of the image, so in this paper median filter is used in the image preprocessing.

b) Image Segmentation

Before being located, the laser spot needs to be separated from the background; the following is an iterative algorithm for the threshold value of the segmentation.

Step 1: Search the maximum value $Z_{\max}$ and the minimum value $Z_{\min}$ of a frame . The initial value of threshold value is $T^0 = \left(Z_{\min} + Z_{\max}\right)/2$.

Step 2: Use T^k to separate the object part from the background part, calculate the average values of the two parts, Z_O 和 Z_B .

$$Z_O = \frac{\sum_{Z(i,j)<T^k} Z(i,j)N(i,j)}{\sum_{Z(i,j)<T^k} N(i,j)}, \quad Z_B = \frac{\sum_{Z(i,j)>T^k} Z(i,j)N(i,j)}{\sum_{Z(i,j)>T^k} N(i,j)} \quad (1)$$

In (1), $Z(i,j)$ means the gray value of point (i,j) . $N(i,j)$ is the weight of point (i,j) ,the normal value of which is 1.

Step 3: The new threshold value is $T^{k+1} = \left(Z_O + Z_B\right)/2$. Search the pixels of the object part and the background part.

Step 4: If $\left|T^k - T^{k-1}\right| < \varepsilon$, the iterative process ends, otherwise turn to Step2.

c) Location of the Centre of the Spot

Consider $Z(i,j)$ as the mass value of the pixel (i,j), so the location of the mass centre of the object part $(\bar{i}, \bar{j})$ is calculated as (2).

$$\bar{i} = \frac{\sum_{(i,j)\in O} iZ(i,j)}{\sum_{(i,j)\in O} Z(i,j)}, \quad \bar{j} = \frac{\sum_{(i,j)\in O} jZ(i,j)}{\sum_{(i,j)\in O} Z(i,j)} \quad (2)$$

IV. MULTIPLE SERIAL PORTS COMMUNICATION

Because measurement system includes several serial port devices, while the industrial PC needs to collect data from all of these serial port devices, how to coordinate the communications between these serial ports is a key problem.

As for serial port communication, many communication programs are realized by MSCOMM control and serial communication software develop kit provided by the manufactory of hardware board[8]. This method can meet simple communication programming need, but not well enough for developing the program which support user-defined communication protocol. Furthermore, such factors as timeout and examining data's integrality should be considered also. Especially, the Overlapped IO mode under WINNT OS increases the difficulty of programming.

Compared with NonOverlapped IO mode, the most important difference is to allow multiple threads to operate IO communication simultaneously or some thread does some job in background while this thread processes IO communication in foreground. Although Overlapped IO mode provides user better response characteristic and programming agility, the difficulty of programming is increased also. Overlapped IO mainly includes two parts: (1) Create Overlapped struct and call IO functions; (2) Detect the IO operation's status.

Generally, the main thread creates sub-threads for every serial port and such synchronization tools as CEvent, CSemaphore, CCriticalSection and CMutex to control the logical relationships between main thread and sub-threads. Multiple serial ports data acquisition's workflow is shown as Fig. 6. The main thread creates sub-threads which synchronize each other through CEvent, and then the main thread uses WaitForMultipleObjects function to judge the job status of sub-threads for following data processing.

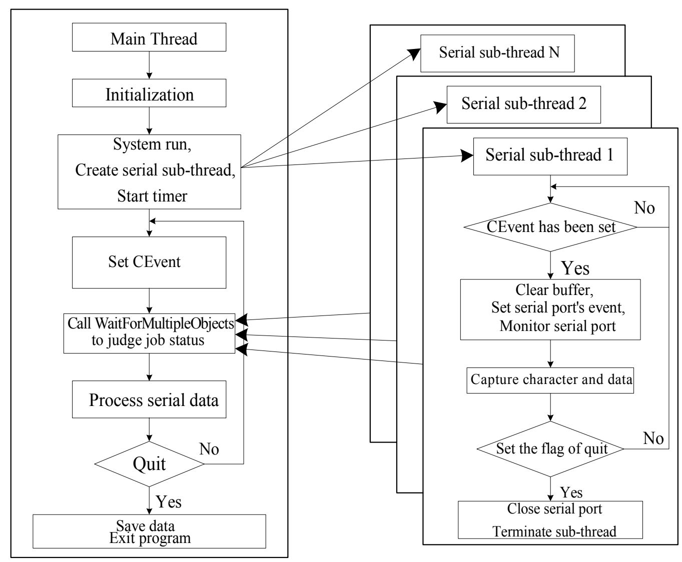

Figure 6. Multiple serial ports data acquisition's workflow

V. CONCLUSION

The main purpose of this paper is to design the measurement device of position and attitude according to the requirements of pushing railway bridge construction adopting two kinds of methods: light-sensitive diode array and CCD. The former method's controller can be designed easily and response speed is higher, but its accuracy is lower with complicated circuit layout. On the contrary, the later method's controller is more complex and response is lower, but its accuracy is higher with well flexibility for other different engineering applications through modifying inner program. Multiple serial ports communication technique is brought into measurement system to connect devices with industrial PC. At present time, these two kinds of measurement devices are applied in actual construction. The effects review that these devices meet the actual measurement requirements. Furthermore, the techniques of these devices provide valuable reference for research about other large-scale engineering machinery's measurement device of position and attitude.

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