Development of Machine Vision System for Tracking Crane Mechanisms

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***Abstract*—In this paper, the issue of the technical possibility of a new method of the speed measuring of hoisting and transport equipment is revealed. The research is carried out for a bridge crane mechanical system. It is proposed to replace the system of absolute and incremental encoders with a system of computer vision. This technical solution makes it possible to replace several speed measurement devices with one camera. In addition, the computer vision system creates conditions for the development of a system for positioning of the bridge crane mechanisms. The main purpose of the research is to validate the possibility of technical implementation of the speed measurement system by the described method. This method of mechanism speed calculation is new for this application in the field of hoisting and transport equipment. As a result, the computer vision system was implemented to determine the speed and position of bridge crane mechanisms. The results of the speed measurement by two methods are compared: traditional methods are compared with the use of encoders and the proposed one with a computer vision system.**

Keywords—video analysis, digital photography, motion analysis, computer vision, tracking, overhead crane, OpenCV library.

I. Introduction

Nowadays various control systems for electric drive of bridge crane are used. The most advanced system is the AC drive control system with a frequency converter and programmable logic controller [1]. The obtaining of the required static and dynamic characteristics of the variable frequency drive can be carried out only in a closed-loop control system. The increasing of speed control range can be obtained by using speed feedback.

An incremental encoder as a speed sensor requires special hardware cards to process incoming pulses [2]. The incremental encoder pulse counting algorithm and determining the direction of rotation are complex technical tasks. The use of this type of encoder makes it impossible to determine an actual motor shaft position in case of power supply voltage loss.

An absolute encoder is more difficult to manufacture than an incremental encoder [3]. More communication lines are required to process absolute encoder signals. This problem is solved by converting the signals and transmitting them to the serial interface.

Machine vision is a branch of engineering related to computer science, optics, mechanical engineering and industrial automation [4, 5]. One of the most common applications of machine vision is the inspection of industrial goods such as semiconductor chips, cars, food and medicines. The topic of this work is machine vision in control systems of crane mechanisms [6, 7].

The purpose of this work is to obtain experimental data of a new tracking method based on the optical system [8], comparing the obtained velocity charts with the charts taken using standard sensors, exactly, incremental encoders.

II. Materials and Methods

The experiments were carried out in the laboratory using an overhead crane with a payload of 1000 kg with an electric drive system based on a frequency converter. Specified crane includes 2 motor type BF06-74/D06LA4-TF-S/E003B9HA and BF20-64R/D07LA4-TF-S/E003B9HA by Bauer Gear Motor GmbH. The electric drive system is based on Schneider Electric equipment. The Altivar Process 930 and The Altivar 71 variable drives are used. The measurement of the shaft angular speed is performed using an incremental encoder OsiSense XCC. The main crane characteristics are specified in Table 1.

TABLE I. THE CHARACTERISTICS OF THE LABORATORY INSTALLATION

Parameter	*Unit*	*Value*
Payload	kg	1000
Span length	m	5.5
Lifting height	m	2.5
Lifting speed	m/s	0.02
Crane speed	m/s	0.25
Trolley speed	m/s	0.25

The trolley reference speed has a trapezoidal shape. During the experiment, a video of the crane was recorded with a simultaneous oscilloscope procedure of the electric drive variables. The speed oscillogram is obtained with the help of SoMove software for parameterizing the frequency converter.

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The scheme of the laboratory installation for video recording is shown in Fig. 1. The tracking of the bridge crane trolley is performed in the Cartesian system of coordinates. The tracking of the trolley movement begins at the initial position XOY, the trolley moves along the x and y-axes. The camera is installed exactly in the middle of the crane at the height on the level of the crane trolley. The distance from the beginning of the crane railways to the installation site of the camera is selected so that the beginning of the crane railways lay into the area of view of the camera.

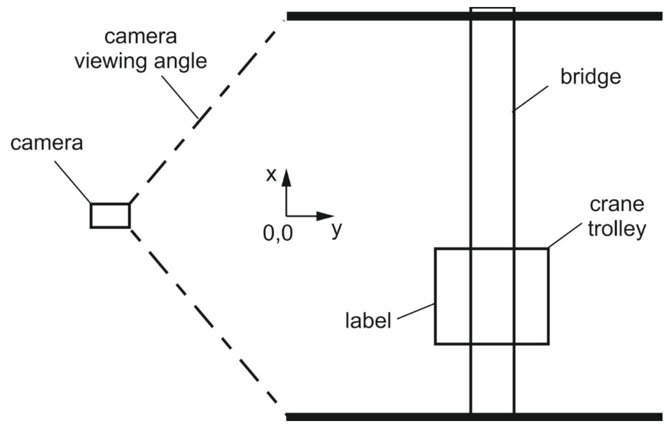

Fig. 1. A simplified scheme of laboratory installation

The experiment was conducted using the following equipment and software:

- Canon EOS 1200D digital camera;
- Personal computer based on Intel Core i3-4030U 1.90 GHz and 4 Gb RAM;
- The software for video processing is the Python programming environment with the OpenCV computer vision library. For processing the speed graphs, the software package MatLab was used.

The following camera settings were used to record video (Table 2).

TABLE II. THE CAMERA PARAMETERS AND SETTINGS

Parameter	*Unit*	*Value*
Resolution	px	1920x1080
Camera shutter speed	s	1/50
Focal length	mm	35
Frames per second (FPS)	-	23
Aperture	-	f/5
Sensitivity to light (ISO)	-	400

The experiment was carried out for the movement of the trolley along two horizontal axes. Every movement of the trolley was recorded using 2 systems: the electric drive system with an incremental encoder and a machine vision system. Tachograms from the encoder were taken using the Profibus industrial interface with the help of SoMove software by Schneider Electric.

The algorithm for determining the size and position of a special graphic label is used to determine the position of the crane trolley [9]. The algorithm is based on the program contour detection [10, 11]. The graphical label has a shape of rectangle mounted on the crane trolley. In order to exclude the influence of different lighting conditions in the room on the quality of the processed signal [12] from the camera, it is used own local lighting is used (Fig.2).

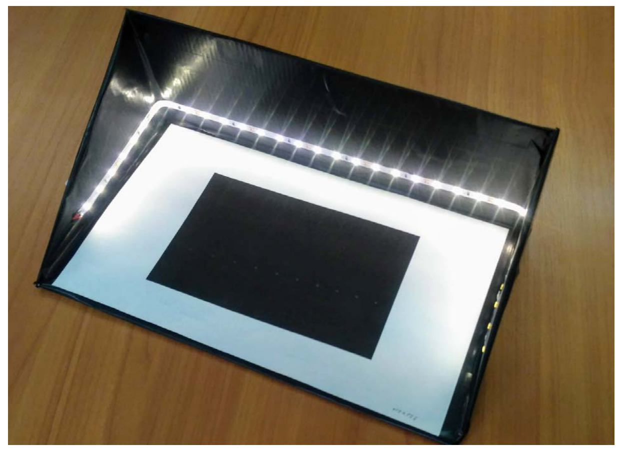

Fig. 2. Black rectangle label with a local lighting

The trolley coordinates in pixels are then converted to coordinates in meters. For each axis of motion, a different algorithm for calculating the position of the trolley is used.

Technical vision allows us to determine the size of objects with high accuracy [13]. Fig. 3 shows a diagram consisting of a camera matrix and a lens aperture.

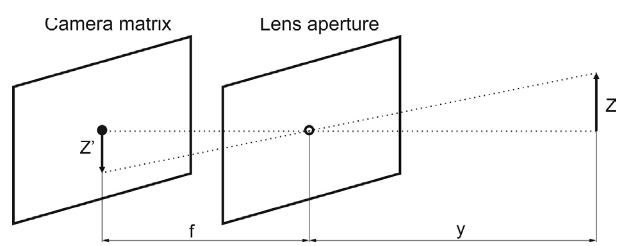

Fig. 3. Projecting an image to the camera matrix.

Knowing the physical dimension $\boldsymbol{Z}$ of an object and the $\boldsymbol{Z'}$ dimensions on a digital camera matrix it is possible to calculate the distance to object $\boldsymbol{y}$ by expression

$$y = Z{\cdot}f/ Z' \qquad (1)$$

where $\boldsymbol{f}$ indicates a camera focal length.

The $\boldsymbol{y}$ coordinate is determined by the similarity of triangles. The area of the label rectangle is used as the measured parameter **Z**.

Using the above feature of similarity of triangles and the obtained value ***y*** we can calculate the position of the crane on the ***x***-axis (Fig. 4).

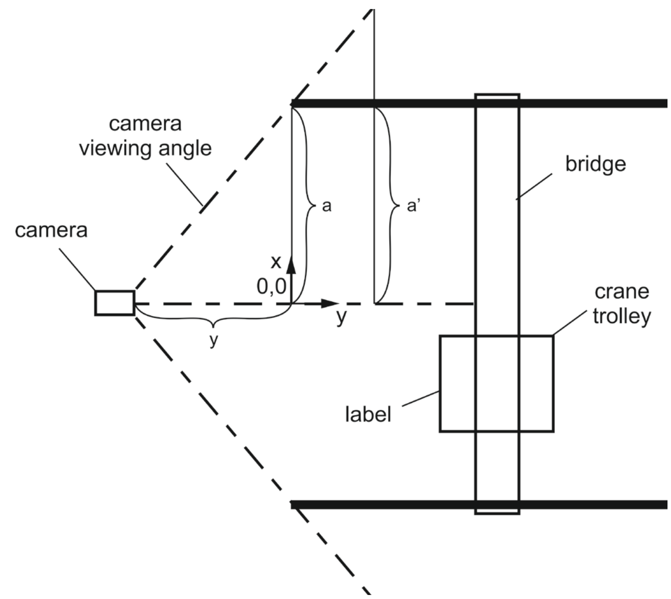

Fig. 4. Calculation of a crane trolley coordinate on the ***x***-axis

The position of the trolley must be calculated from the center of the coordinates since the distance from the camera increases the viewing area. The formula to calculate the x coordinate is following

$$X = Z_x{'} \cdot y/f \tag{2}$$

where ***x*** – distance from the camera axis to label center; ***Z_x'*** - distance from the camera axis to label center on matrix; ***y*** – trolley coordinate on ***y***-axis; ***f*** - focal length.

As a result, the movement transients of the bridge crane trolley position in two axes are obtained. To determine the speed, it is necessary to differentiate the resulting array of coordinates.

III. Results

With the help of MatLab software package the data obtained from the optical system was processed, charting and smoothing with the Kalman filter [14]. The processing results are shown in Fig. 5 and Fig.6.

Fig. 5 shows the movement of the trolley along the y-axis towards the camera. The movement of the trolley along the x-axis is performed in two directions of movement and is shown in Fig. 6. The speed graphs obtained by the vision system have distortions. These distortions are caused by uneven lighting during the experiment as well as the operation of differentiation of the digital signal. This problem is planned to be solved by improving the program code in the next stages of development and research of the system.

IV. Discussion

As a result of the data obtained it can be concluded that the accuracy of the developed tracking system based on technical vision is not inferior to the existing based on incremental encoders. In addition, the proposed technical solution can replace several speed sensors with one camera. The new tracking system is a cheaper solution than an encoders system. It will save the operator from the so-called dead zones. Also in the future, this system will fully automate the operation of the crane.

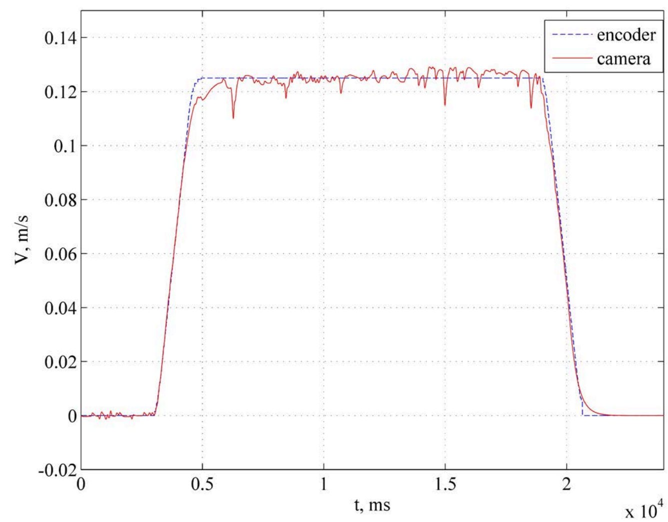

Fig. 5. Velocity charts of the movement of the bridge crane trolley along the y-axis (movement towards the camera)

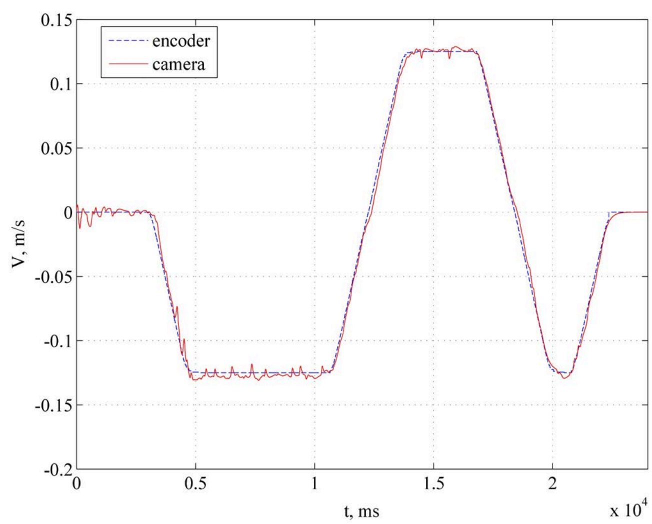

Fig. 6. Velocity charts of the movement of the bridge crane trolley along the x-axis (moving left-right-left)

The great advantage of the machine vision system is that it allows you to have information not only about the speed of the mechanism but also about its position. It will save the operator from the dead zones. Also in the future, this system can be integrated in fully automated operation of the crane.

To setup the proposed system on a specific object no preliminary measurements are required. All calculations are made on the basis of the camera parameters and the label the only thing that is necessary for installation is to install the camera in the center of the ***x***-axis for accurate tracking of the object. It should be noted that it is possible to increase the detection accuracy by calibrating the camera [15].

At the next stage of the study it is planned to realize speed feedback of the crane mechanism based on the data obtained by the machine vision system.

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