# A Practical Visual Positioning Method for Industrial Overhead Crane Systems

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**Abstract.** To solve the problem of information acquisition of an industrial overhead crane, this paper uses an industrial camera to get the information. The information includes the height and the swing angle of the hook and the distance between the hook and the cargo. To obtain the real-time data of the hook's height and swing angle, firstly the whole image captured by the industrial camera is processed and the hook's initial position is obtained by shape matching. As the trolley tracks the hook according to the local information of the image, the height is calculated by the interpolation method according to the number of local pixels. The swing angle is measured by the height of the hook and the distance between the initial and current positions of the upper edge. In addition to the measurement of the height and swing angle, this platform calculates the distance between the hook and the cargo based on a visual method, the cargo is observed by such features as length, width and height input by operators. This method gets the static information of the industrial scene, drives the trolley to the cargo, detects whether the hook's swing is within the proper range, and hoists the hook to the desired position. Experimental results on a 32-ton industrial crane system implies that this algorithm solves the problem of information collection and transfers the hook to a desired position.

**Keywords:** Industrial crane · Information acquisition · Real-time positioning

## 1 Introduction

An overhead crane is a transportation equipment widely used in many industrial production situations. Most of the cranes are manually operated, which causes many injury accidents. For this reason, it is important to design an automatic control system for overhead cranes. For this reason, many algorithms are proposed to restrain the swing of the hook or position the cargos precisely. As a

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basic need to synthesize the algorithms, acquiring the states of the crane system is crucial.

As a frequently used equipment in industry, a lot of works have been done to solve the control problem of overhead cranes, and the proposed algorithms are tested on small scale laboratory cranes [1–11]. Because of the simple mechanical structure and the usage of high accuracy sensors [12], the state variables of the entire system can be obtained for laboratory cranes. In practice, because of the complex industrial situations and the consideration of the costs, we seldom get all the state variables of an industrial crane system, including the height and the swing angle of the hook, the velocity of the trolley, and the distance between the crane and the cargo, which are very important for automatic control of cranes. To be specific, the height of the hook provides the vertical position of the hook, and this information is useful in many control algorithms. The frequently used method to measure the height of the hook is using an absolute encoder, and the rope length can be calculated by the reduction ratio and the data of the absolute encoder. The measurement of the swing angle is necessary in most feedback control methods, which can be measured by some special mechanical structures on small scale laboratory crane platforms. In industrial situations, the swing of the hook is usually observed by workers near the cranes, but the accuracy cannot be guaranteed. The velocity of the trolley is measured by encoders, which is adopted in many practical situations. Positioning is a very important aspect of an automatic crane, the common method to calculate the displacement of the trolley is to accumulate the encoder's data. Another method for position measurement is to divide the ground into different areas, and transport the cargo to the specified grid, but this method highly depends upon on the operating environment.

The collection of system states mentioned above is achieved by contact sensors, but the drawback of most contact sensors is that one sensor can only measure one specific kind of signal. Collecting the information based on the visual method is more flexible and economic, and different system states can be obtained by only one camera. The visual method is applied in many areas in manufacturing [13,14]. Many researchers use cameras as signal collectors on crane platforms. In [15], a ball is installed under the hook to detect the swing angle. Singhose et al. use a stick as a guidance, and make the crane track the trajectory of the stick through a camera installed on the trolley [16], which uses input shaping to optimize the operating process. In [17] , two cameras are installed on the mechanized platform to position the payload and measure the swing angle. Binocular vision is also adopted in [18], and after getting the states of the crane system by two cameras, the sliding-mode control is used in the transportation process.

Compared with the laboratory cranes, the industrial cranes are usually operated in more complex situations, which makes it difficult to collect all states. It is important to pick up the information we really need and easy to get in practice.

For the information collection problem for practical cranes, this paper provides an information collection method based on an industrial camera, the information to be collected includes the rope length, the swing angle and the distance between the hook and the cargo. To be specific, before the movement of the trolley, we first obtain the position of the hook and the distance between the hook and the cargo through static images using feature matching. Then, the trolley transports the hook to the set point right above the cargo. In the transportation process, we use local characteristics to track the hook and measure the swing angle by the images captured by an industrial camera. After the horizontal movement, it is detected whether the positioning error caused by swing is in a reasonable range. Finally, the hook is lowered to the target place according to the height information captured by the camera, which uses the partial information of the image to track the hook and calculate the height by interpolation method.

## 2 Scenario Analysis

We define one corner of the plant as the origin of the world coordinate. The camera is fixed on the trolley, which is convenient to calculate the extrinsic parameter matrixes $M_1$.

To get the intrinsic matrix, we lower the hook to a specific position, measure the distance between the camera and the hook, and then obtain the pixel number of the upper edge. The intrinsic matrix $M_2$ can be calculated by the pixel number and actual distance. The relationship between a point $X_w$ in the world coordinate and the imaging point $M$ can be expressed as:

$$M = M_1 M_2 X_W \tag{1}$$

When transporting the cargo to the target place, we should consider the acceptable offset of the hook and make the error converge to an appropriate range. The error is induced by three factors, which includes the accuracy of the camera, the error caused by hook's swing, and the vibration transmitted from the trolley.

The accuracy of the camera depends on the resolution. It is assumed that the resolution of the camera is $m \times n$. After installing the camera to the fixed place, the corresponding observation size near the ground is $x \times y$, then one pixel can represent the actual distance $\Delta l$, satisfying the following equation:

$$\Delta l = l/m \tag{2}$$

In practice, we are interested in the error near the hook instead of the error near the ground. We assume the distance between the hook and the camera is $l_0$, and the height of the camera is $l_1$. The distance represented by each pixel near the hook is

$$\Delta l_{hook} = l_0 \Delta l / l_1 \tag{3}$$

In the transportation process, the trolley will vibrate due to the hook's sway or the uneven pathway. We should investigate the vibration during the movement process as a feedback in some algorithms. After the trolley is transported to the target place, we should also observe the hook's sway because it will affect the locating control performance. To obtain the error caused by vibration, the trolley starts to move with its maximal speed, and then we measure the deviation of the camera by observing the change of the image's edge. Assume that the largest deviation of the image near the ground is $\Delta l_{vibration}$.

The sway of the hook will also affect the positioning of the cargo. The maximal error induced by swing is $\Delta l_{sway}$, and the total deviation of the measurement $\Delta l_{total}$ can be expressed as:

$$\Delta l_{total} \leq \Delta l_{sway} + \Delta l + \Delta l_{vibration}. \tag{4}$$

The total deviation, which can be detected by the camera, converges to an appropriate bound as the vibration and sway become more and more slight. Then we can lower the cargo to the ground with an acceptable error. But $\Delta l_{total}$ calculated by (4) is the deviation near the ground, and we should convert it to the acceptable deviation $\Delta l_1$ near the hook through the following equation:

$$\Delta l_1 \leq l_0 \Delta l_{total} / l_1. \tag{5}$$

In this equation, $l_0$ is the distance between the hook and the camera, and $l_1$ represents the height of the camera. After the horizontal moving, if the deviation is larger than $\Delta l_1$, we should wait until the deviation converges to the proper bound, and then proceed to the next operation.

## 3 Measurement of the Height and Sway Angle

To obtain the real-time information of the hook, we adopt the partial feature matching method to track the hook and measure the height and the sway angle. The flow chart of the whole process is shown in Fig. 1. First, the states of the trolley should be confirmed. If the trolley is not moving, we detect whether the vibration exists. Otherwise, the camera collects the image of the workplace.

Commonly, the hooks of the heavy-load cranes are extremely large, and the camera's installation place should be kept away from the rope, so it cannot be installed right above the hook. Because of this, the image captured by the camera involves the side information of the hook, which enables the camera to adopt shape matching to find it. The camera is fixed on the trolley, so the hook is operated in the specific area of the camera's field of view. Based on this, we detect the outline of the hook in a specific area, which increases the efficiency of the shape matching process.

The features of the hook will change as the hook is at different heights. The camera should consider all the situations to exactly detect the hook.

After finding the hook, one can get the upper edge through the change of the coordinate values, and then extract the number of pixels of the upper edge. The interpolation method is adopted to calculate the length of the rope according to the length-pixel number relationship measured off-line. The position of the hook at this moment is considered as the initial position.

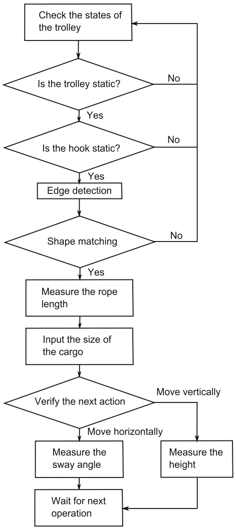


**Fig. 1.** The total flowchart.

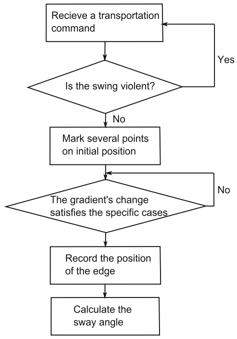


**Fig. 2.** The flowchart of the measurement of sway angle.

According to the industrial standard, the trolley and the hook cannot move at the same time, so when the trolley moves horizontally or stops moving, and we only pay attention to the sway angle. When the sway angle converges to an acceptable range and the hook starts moving vertically, the height of the hook is the only problem we should concern.

The sway angle of the hook is measured by an industrial camera, and the flowchart of the process is shown in Fig. 2. The upper edge of the hook is tracked as the trolley moves horizontally. Then we calculate the distance between the initial position and the last position, which is represented by $d_2$, The sway angle $\theta_0$ can be calculated by the following equation:

$$\theta_0 = \arctan(d_2/l_2), \tag{6}$$

where $l_2$ is the length of the rope at this time.

To measure the rope length, when the hook is at the initial position, we mark several spots on the upper edge of the hook, and the number of spots satisfy the Gaussian distribution because the spots close to the centre of the hook are more effective. Then we should know the next action is hoisting or lowering to decide whether the measurement range should expand or compress. For each spot, we get $n_0$ pixels along the sway direction of the hook, and detect the gradient variation to get the position of the upper edge. Then the number of pixels of the upper edge can be obtained by edge detection, which will reflect the length of the rope through interpolation. The sway angle is so small that we can assume the number of pixels are the same when the hook is at the lower point and the higher point. Based on this, we can ignore the change of the number caused by sway. So the interpolation method is available whether the hook is swaying or not swaying. To adopt the interpolation method, the relationship between the number of pixels of upper edge and the length of the rope should be built off-line. There are several sets of data:

$$(h_1, x_1), (h_2, x_2), \ldots, (h_n, x_n). \tag{7}$$

In this equation, $x_n$ is the number of pixels when the height of the hook is $h_n$. Assume that the number of pixels at current time is $x_m$, we can judge the range of the number is $x_k < x_m < x_{k+1}$, the height of the hook can be expressed as:

$$h_m = h_k \frac{x_m - x_k}{x_{k+1} - x_k}. \tag{8}$$

## 4 Measurement of the Distance Between the Hook and the Cargo

The distance of the hook and the cargo is measured by the industrial camera to facilitate the design of the online trajectory tracking algorithm. Before capturing the static image, it is confirmed that the trolley and the hook are stable. The worker inputs the length, the width and the height of the cargo, and guarantees that the cargo is on the ground. Then we calculate the range of the length and width on the platform of the height, which satisfies the following inequality:

$$l_{low} < l_{cargo} < l_{high} \tag{9}$$

$$d_{low} < d_{cargo} < d_{high}. \tag{10}$$

Then we can get the range of the total pixel numbers $n_{cargo}$, which is expressed as:

$$2l_{low} + 2d_{low} < n_{cargo} < 2l_{high} + 2d_{high}. \tag{11}$$

The Canny edge detection algorithm is adopted to count the number of pixels of the edge. If the number satisfies (11), then it is detected whether the shape is a quadrilateral and the range of the included angles satisfies the following condition:

$$\alpha_{min} < \alpha < \alpha_{max}, \tag{12}$$

where $\alpha_{min}$, $\alpha_{max}$ are calculated by the camera's parameters calibrated before. The rope and the hook may interference the views of the camera. To improve the efficient of the process, this area will not be detected. If the cargo is infected by this, the trolley will change its position automatically to find the cargo.

After finding the edge of the cargo, the coordinate of the corner will be selected to calculate the center of the cargo. Assume that the corner with the minimum $x$-coordinate and $y$-coordinate is $(x_1, y_1)$; other corners $(x_2, y_2), (x_3, y_3), (x_4, y_4)$ are acquired clockwise. The coordinates of the cargo's center $x_{cargo}, y_{cargo}$ can be expressed as:

$$x_{cargo} = \frac{(x_2 - x_1) + (x_3 - x_4)}{2} \tag{13}$$

$$y_{cargo} = \frac{(y_3 - y_1) + (y_2 - y_4)}{2}. \tag{14}$$

The coordinate of the midpoint $(x_0, y_0)$ of the hook's upper edge is easy to acquire, and the coordinate of the center of the hook $x_{hook}, y_{hook}$ satisfies:

$$d_x = x_{cargo} - x_{hook} \tag{15}$$

$$d_y = y_{cargo} - y_{hook}. \tag{16}$$

To improve the accuracy and efficiency of the transformation, an online trajectory planning method [19] is adopted to accomplish this process. The distance to the target position, which is estimated by operators in [19], is detected by the camera and substituting into the equations of this algorithm to calculate the proper parameters of the trajectory.

## 5 Experiment Results

The experimental platform is a standard 32 ton double-girder crane. Considering the space to place the tools and the passway, the main operation area of this crane is 47.5 m × 25 m. In this platform we use a Blackfly camera made by Point Grey company, whose the model in [20] is used to calculate the visual angle, the horizontal and vertical viewing angle as $\theta_h = 68.31°, \theta_v = 56.98°$. The height of the camera is 10 m. We can calculate that the distance of one pixel near the ground is 0.0106 m. Because the view of the camera cannot cover the whole area, the operators should move the overhead crane to the area where the cargo is in view of the camera.

Considering the feature of the hook in this platform, the right side of the hook is used for shape matching, the position of the upper edge is detected according to the variation trend of the pixel. The relationship between the rope's length and the pixel's number is measured outline. The rope's length can be calculated by (8).

To verify the accuracy of the height detection, we fix the laser on the trolley and an reflector on the hook. Table 1 lists the comparison of these two kinds of data, where the error of the laser is 0.002 m. We assume the data measured by the laser is precise. The table implies that when the distance increases, the accuracy decreases. The maximum error of the method proposed in this paper is 0.02 m.

**Table 1.** The accuracy of height measurement.

| Camera | Laser |
|---|---|
| 0.03016 | 0.03025 |
| 0.05083 | 0.05071 |
| 0.07049 | 0.07067 |
| 0.09102 | 0.09131 |
| 0.11064 | 0.11037 |

The process of the measurement of the sway angle is shown in Fig. 3. The initial position of the upper edge is the white line, and the position of the upper edge is the blue line during the transit process. The distance of the blue and the white line is 0.3 m, and by using Eq. (6), we can calculate the sway angle as 3.37°.

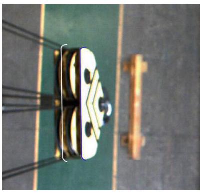

**Fig. 3.** Measurement of the sway angle.

Figures 4 and 5 express the deviation caused by sway and tremble, where the trolley is operated at the maximum speed to guarantee that the sway is severe enough. The result is shown in Figs. 4 and 5.

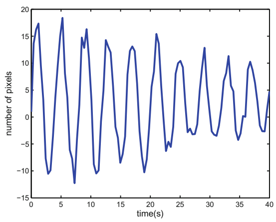


**Fig. 4.** The deviation induced by vibration. (Color figure online)

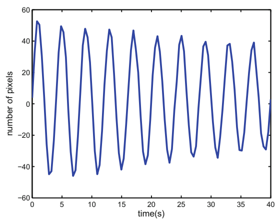


**Fig. 5.** The deviation induced by sway. (Color figure online)

The maximum deviation induced by sway is 50 pixels, one pixel represents 0.0106 m near the ground, so the maximum deviation is $\Delta l_{sway} = 0.53\,\text{m}$. Similarly, the maximum deviation caused by vibration is $\Delta l_{vibration} = 0.22\,\text{m}$, and the maximum total deviation is $\Delta l_{total} = 0.75$ m. Normally, the hook is not operated close to the ground. The deviation of the hook can be calculated by Eq. (5). In this experiment, the rope's length is 6 m, the height of the camera is 10.5 m, the maximum deviation at that height is 0.43 m. The camera detect the deviation incessantly until it satisfies the acceptable deviation.

After some basic tests, we apply this method on the 32 ton overhead crane produced by Tianjin Hoisting Equipment Company. This technique collects the information exactly and the hook is transported to the target place precisely. Compared with the manual operation, the efficiency is enhanced and the safety is guaranteed.

## 6 Conclusion

To meet the practical demand of industrial cranes, this paper proposes a method of using an industrial camera to measure the height and the sway angle of the hook. The distance between the hook and the cargo is also acquired by the camera. Firstly, the camera collects the image if the trolley and the hook are static, acquiring the initial position of the hook by the graph matching method. In the process of transporting the hook or the cargo, the camera can realize the real-time object tracking through persistently detecting the upper edge. The height is calculated by the interpolation method according to the number of pixels of the edge. The sway angle of the hook is obtained by comparing the present position and the initial position. After the horizontal transportation, the camera detects whether the hook's deviation induced by sway and vibration is at a proper range to guarantee the accuracy is acceptable before the cargo start lowering. This method is applied on the overhead crane system in a practical industrial situation, where the information of the system is collected by the camera. The hook is located at the target position by cooperating with the motion control system. The next step to improve this system is adapting the information collected by the camera in a more intelligent algorithm. In this paper, the operators should move the trolley to the position close to the cargo, and more cameras will be placed in the workspace to acquire the position of the cargo in a global coordination.

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