An Advanced Method of Acquiring Distorted Images Information with Height Compensation

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Abstract. The innovation work is to acquire distorted images information with height compensation. Computer vision allows observation of the surroundings. Generally, images collected from cameras in automated production lines are front views. But there is a certain angel between the camera and the working platform in limited space which will result in perspective distortion and make following works such as feature extraction and object recognition much more difficulty. Even more, it will reduce precision for grasping objects and production efficiency. For efficient considerations, correction of the distorted image has potential economic and social needs. Thus, we propose the combined method of Hough transformation and perspective transformation, which can convert the distorted image into a front view. In addition, we remove the effect of objects’ height to improve positioning accuracy. Then we apply it to the Delta robot to correct the distorted image and recognize objects. It is important to note that the camera can be mounted in any position. Verification of the effectiveness of method is required for a final practical test of the experiment. The experimental results have proved the accuracy of this method well. Moreover, positioning accuracy can be easily improved by an average of more than 10 percent with the method of height compensation.

Introduction

As a numerical control tool, robots with the characteristics of machine vision occupy a large proportion of life and industry. The transportation robot was used in the field of logistics automation initially, plays an important role in industrial manufacturing automation. Most of the transfer robots are designed and preprogrammed for Teaching-Platform. The starting and ending positions of this type of robot must be first immobilized. The motion trajectory of robot has been predetermined. The objects are not recognized practically. With the implementation of computer vision (Ibaraki and Tanizawa, 2011; Li et al., 2015; Saegusa et al., 2010), we can solve this problem.

In order to accomplish more complex tasks, it is necessary to recognize the location of objects. Typical robot can select unordered objects on the conveyor before, then place on the next belt regularly. Tho and Thinh (Tho and Thinh, 2015) and Zhang et al. (Zhang et al., 2012) have proposed an algorithm for detecting circles with cameras that are perpendicular to the working platform. Liu et al. (Liu et al., 2016) acquire the information of the road centerline accurately from a distorted image. The proposed algorithm based on inverse perspective transformation. Koufogiannis et al. (Koufogiannis et al., 2011) present an image rectification framework using perspective transformation to require accurate knowledge of the internal image structure. The framework is used for the automatic rectification, metric correction, and rotation of distorted integral images. Malkov et
al. (Malkov et al., 2009) restore distorted images by the perspective transformation. Zhao et al. (Zhao et al., 2017) proposed a new method for non-linear distortion correction of Chinese vehicle plate. They reconstruct the non-linear distortion of the license plate image by the perspective projection model, then realizing the license plate image correction. But they all ignore the effects of objects’ height.

In this paper, we propose an algorithm to obtain perspective distorted image information in limited space and apply it to the transfer robot to realize the automatic control system on the production line. First, we will improve the Hough transformation to find the line that holds the four points required of perspective transformation. Second, the perspective transformation is used to correct the perspective distorted image. Finally, the position and color of objects can be identified.

The remainder of this paper is structured as follows: Section 2 describes our methodology and applies it to the sorting system. Section 3 describes robotic and experimental platforms to demonstrate the benefits of our method. Section 4 concludes this paper.

Methodology

The methodology consists of four stages: image acquisition, perspective transformation, object recognition, calculation of objects’ rotation angle. The specific calculation flow diagrams of the proposed algorithm are shown in Figure 1. In this section, there is a certain angle between the camera and the working platform in limited space which will result in perspective distortion. By proposing an advanced perspective transformation with height compensation, we can correct the image.

Image Acquisition

Image acquisition is the premise of recognition. It uses a hardware system that includes a CCD camera, a computer, multiple accessories, and some representative objects for imaging.

For the same object, the obtained images are different due to the different angles and position of the camera. In general, we need to get a front view to extract features and recognize objects. But the picture is distorted since the camera is not perpendicular to the working platform.

Figure 1. Flow chart of an advanced method of acquiring distorted images information with height compensation.
**Perspective Transformation**

There is a certain angel between the camera and the working platform. The exact locations of objects are difficult to be obtained since the shapes of the objects are distorted. Thus, the corrected shapes must be obtained first. The shape is corrected from the distorted shape by perspective transform in Figure 2, as the following equation:

\[ I_a = T I_b. \]  

Where \( I_a \) and \( I_b \) are corrected image and distorted image while \( T \) is the transformation matrix from \( I_b \) to \( I_a \).

![Figure 2. The principle of perspective transformation. (a) An incomplete quadrangle, (b) The quadrangle is repaired by calculating the intersection with its two neighbor edges, (c) A corrected quadrangle can be corrected to a square with Eq. (1), (d) The original image, (e) The top-view of (d), C represents a Circle, T represents a Triangle, P represents a Pentagram.](image)

In order to calculate \( T \), four corresponding points between the corrected image and the distorted image are required.

A square black ribbon is attached around the working platform. The transformation matrix \( T \) between the adjusted image and the distorted image is the same as that between the corrected shape of the ribbon and the distorted shape of the ribbon. Thus, \( T \) can be calculated by two sets of dots, as follows:

\[
[x'_i, y'_i, 1]^T = T^*[x_i, y_i, 1]^T \quad (i = 0, 1, 2, 3) \]  

Where \((x'_i, y'_i)\) are the four points of a square with the corrected image and \((x_i, y_i)\) are the four corresponding points in the distorted image, as shown in Figure 1 (b) and (c). With Eq. (1) and (2), the distorted image can be rectified with a corrected image.

In order to save the robot workspace, this vision system is near the robot body as far as possible. So, some or even all the angles are lost in the original image. An example is shown in Figure2 (d), where only three corners can be found. The points, which include the hidden and the visible, are counted with intersecting lines. These lines include image contours and can be detected by Hough line transformations (Duda and Hart, 1972).

Generally, a line that passes a point \((x_0, y_0)\) can be defined as follows:

\[ r_0 = x_0 \cos \theta + y_0 \sin \theta \]  

where \( r_0 \) is a radial from the origin to that point which is perpendicular to the line passed through the point \((x_0, y_0)\), and \( \theta \) is the angle between the radial and X-axis.
Figure 3. A point \((x_0, y_0)\) implies many lines each parameterized by a different \(r\) and \(\theta\). These lines each imply points in the \((r_0, \theta)\) plane, which taken together form a curve of characteristic shape.

Different lines passed the point \((x_0, y_0)\) have different \(r_0\) and \(\theta\), which form characteristic shape curves together in the plane \(r_0\theta\) in Figure 3. If the curves of two different points cross each other at one point, means that both points are on the same line. The more curves intersect in one point, means that the line represented by this intersection is made up of more points. In total, we can define the minimum junction threshold to detect a line. Probabilistic Hough Line Transform is more efficient than Standard Hough Transform and gives the end points of the line segment \((x_0, y_0, x_1, y_1)\). The result of line detection is shown in Figure (4)(a).

![Figure 4](image)

Figure 4. Acquiring the four vertices of the square. (a) Lines detection with Hough line transform. (b) \(l_1, l_2, l_3, l_4\) and \(v_0, v_1, v_2, v_3\) can be calculated.

When extracting lines from images, there are many lines that are useless. Thus, we propose a better algorithm that extracts 4 edges. Then we can get the intersection of all the lines and \(l_5\). The distance from this intersection can be calculated. If the intersection is to the left of \(l_6\) and the distance is minimum, the line is \(l_1\). If the junction is on the right of \(l_6\) and the distance is minimum, the line is \(l_1\) in Figure 4 (b). Likewise, \(l_2\) and \(l_4\) can be found. Then, the transformed image will be obtained by Eq. (1). With the preceding equation, the original graph can be adjusted to the top view, as shown in Figure 2 (c).

**Objects Recognition**

With the Probabilistic Hough Line Transform method, circles and pentagrams are released by setting a threshold which is the minimum number of intersections to detect a line, defined previously as 60. Some lines can be detected from contours with Probabilistic Hough Line Transform. If three lines of the shape are detected, then the shape is a triangle.

It is impossible to distinguish circles and pentagrams accurately with Probabilistic Hough Line Transform because the lines are highly detectable on the contours of circles and pentagrams. Pentagrams and circles can be distinguished by comparing the area. The pentagram area is smaller than a circle. The center of the circle, the triangle and the pentagram can be obtained by calculating the boundary centers. Be careful that all shapes are distorted due to the height in Figure 6.

The real center can be found by eliminating inaccuracies. After a perspective transformation, the cylinder will become a rounded rectangle. The center of the shape we are counting is the rounded rectangle center \(O(x, y)\) as shown in Figure 5. There is an inaccuracy due to the height of the cylinder.
The center of the circle $O'(x_1, y_1)$ is the true center. Since the angle of the rounded rectangle’s rotation is small, the major axis should be vertical. Thus, the center of the circle $O'$ can be found as:

$$
\begin{align*}
  x_1 &= x \\
  y_1 &= y + (a - d/2)
\end{align*}
$$

(4)

Figure 5. Calculating the deviation $d_1$ from the real center. $O$ is the center of the oval, $O'$ is the center of the circle, $h$ is the height of objects, $h'$ is the inaccuracy deviation because of the height of objects.

In order to transform the central point of the pixel coordinates to the absolute coordinates, the center $O_1 (c_1, c_2)$ of circle in the middle must be determined in Figure 6 (a). The hough gradient method is proposed to solve the problem. The principle of the Hough gradient method requires a center to be the normal vector of these points on the circle. First, the center of the candidate can be found with a gradient of any zero in the edge image. Second, all nonzero pixels are sorted by the distance from the center. A single radius is best supported by selected nonzero pixels. If the center has sufficient support from nonzero pixels on the edge image and the distance is quite far from the previously selected center, the center will be stored.

Figure 6. Coordinate transformation. (a) Converting from pixel coordinate system $u$-$v$ to image coordinate system $x$-$y$, (b) Converting from image coordinate system $x$-$y$ to world coordinate system $x_w$-$y_w$, (c) $x_w$-$y_w$-$z_w$ is world coordinate system.

Only the plane coordinates need to be calculated because $z$ is a constant. The coordinates of the central points are converted into absolute coordinates in Figure 6 as follows:

$$
\begin{align*}
  x_i &= s[(x - c_1)\cos \theta + (y - c_2)\sin \theta] \\
  y_i &= s[(x - c_1)\sin \theta - (y - c_2)\cos \theta]
\end{align*}
$$

(5)

where $(x_1, y_1)$ is the point with absolute coordinates; $(x, y)$ is the point with pixel coordinates; $\theta$ is the angle between the two coordinate systems and $s$ is the scaling of the pixel coordinates into the absolute coordinates.
Calculation of Objects’ Rotation Angle

In order to place these objects in a predetermined position, the rotation angle of the object needs to be calculated. Among 3 kinds of shapes, we do not need to calculate the angle of the circle. Be careful that all shapes of target positions are distorted due to the height of target positions’ shapes.

First, the lines in triangular form are extracted with Probabilistic Hough Line Transform. Second, this slope will be determined by these points in the first step. Of course, it is necessary to sort the slopes of objects and the target positions. Lastly, the angle includes 2 lines can be confirmed. We will get 3 corners with this method. The last rotation angle is an average of 3 angles.

For pentagrams, the slope of the line from the farthest point to the center of the rectangle should be calculated. Then the angle of pentagrams can be obtained by calculating the angle between 2 lines.

Experiments and Results

Robot Platform

The Delta robot is a parallel 3-DOF (Degree of Freedom) Mechanism with high speed and high precision. The precision execution of the Delta robot is smaller than 0.01mm. In addition, it can also perform pick-and-place operations more than 120 times/minute (Tsarouchi et al., 2016).

As shown in Figure 7, three servo motors are mounted and fastened on the base, three actuators mounted under the motor are separated at an angle of 120 degrees; three follower arms are connected to three actuators. The robot work area is decided by the actuator and follower's arm. Stepping motors can provide an alternative DOF that is the rotation. Although the structure of the Delta robot is simple, it can be a complex task in the large space. Furthermore, the Delta robot is connected to the robot control system.

In order to adapt to the complex environment, some Delta robots are equipped with machine vision systems, including image acquisition cards and CCD cameras. If the target objects are interrupted by some things, for example, Delta robot arm followers, their location, and position will not be obtained. Thus, the camera cannot be set perpendicular to the work platform, if the platform is under the Delta robot.

Figure 7. The structure of the Delta robot system. (a) The system consist of a robot controller, a Delta robot, a working platform, and a vision system which is aslant set, (b) The structure diagram. $x_Y^c z_c$ is camera coordinate system, $x_1 y_1 z_1$ is platform coordinate system, $\alpha$ is the angle between the camera and the ground.

The core of our main system includes the robot control system, the Delta robot, the working platform under the Delta robot, and the inclined camera, as shown in Figure 7.

Experiments

We have evaluated our method with real data. In our experiments, a CCD camera was mounted on the side of the working platform. When central points and the rotation angles of objects are obtained, this data is sent to the robot by the socket. In this situation, the object will be placed in the right position. In addition, the robot will move the motor at the end of the robot manipulator to control the angle of the
object. Then, the observed object will be placed in the target position.

We have conducted several experiments in which the cameras are positioned differently by 25, 30, 35 and 40 degrees relative to the horizontal line. The results are shown in Table 1. The accuracy that the robot places objects to its corresponding target positions is 100% when all objects are placed below \( L_1 \). While some objects are placed above of \( L_1 \) without height compensation, the accuracy is only 88.9% in the case of 25 degrees, and the number of objects placed in the correct target positions are 8. While all objects are placed above of \( L_1 \) without height compensation, the accuracy is 77.8% in the case of 25 degrees. The results showed that the method we proposed was feasible and the resistance was strong. Height compensation has improved positioning accuracy of 10%. At the same time, this shows that our method also has room optimization and improvement.

### Table 1. Results of experiments.

<table>
<thead>
<tr>
<th>Camera Angle ( \alpha ) (°)</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>All objects are placed below of ( L_1 ) Without Height Compensation</td>
<td>Number of Objects</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Deviation slightly</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Precision</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>With Height Compensation</td>
<td>Number of Objects</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Deviation slightly</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Precision</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Some objects are placed above of ( L_1 ) Without Height Compensation</td>
<td>Number of Objects</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Deviation slightly</td>
<td>88.9%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Precision</td>
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<td>100%</td>
<td>100%</td>
</tr>
<tr>
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<td>9</td>
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<td>With Height Compensation</td>
<td>Number of Objects</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
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<td>0</td>
</tr>
<tr>
<td></td>
<td>Precision</td>
<td>100%</td>
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</tr>
</tbody>
</table>

### Conclusions

In this paper, we have proposed a better algorithm for returning distorted images and applying them to the Delta robot to recognize different objects in different shapes and colors in limited space. The Graphs is taken from a sloping angle. First, the Hough Line Transform is used to search for multiple lines. There are only four lines required. The distorted image can be transformed to the front view by perspective transformation. Then, the recognition of objects is manifested by its shape and color. At the same time, height compensation has improved positioning accuracy of 10%. Finally, the rotation angle of objects is obtained to place them in the correct position. The experimental results show that our method is effective. There are some interesting issues about acquiring more distorted image formations that we want to research in the future. The surrounding light will be needed to overcome, the shape is slightly distorted because of the camera lens, and therefore, they need to be calibrated to get the right angles and positions.

### References


