Automated Dimension Measurement System

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Abstract: In this fast-paced world, it is inevitable that the manual labor employed in industries will be replaced by their automated counterparts. There are a number of existing solutions which deal with object dimensions estimation but only a few of them are suitable for deployment in the industry. The reason being the trade-off between the cost, time for processing, accuracy and system complexity. The proposed system aims to automate the mentioned tasks with the help of a single camera and a line laser module for each conveyor belt setup using laser triangulation method to measure the height and edge detection algorithm for measuring the length and breadth of the object. The minimal use of equipment makes the system simple, power and time efficient. The proposed system has an average error of around 3% in the dimension estimation.

Keywords: Laser, Warehouses, Dimension Measurement, Automation.

I. INTRODUCTION

Efficient warehouse management is critical for an effective supply chain in the world where e-shopping is getting popular [1], [2]. A lot of warehouses even systems today employ manual labor for monotonous jobs like measuring dimensions of objects, scanning codes, etc. These systems are not only slow, but also not as cost effective as their automated counterparts [3], [4]. Also, in a post-Covid world, contact-less delivery will play a major role in warehouse systems, ensuring the safety of the customers. Many E-Commerce and E-Grocer Companies have their sales increased by 100% due to Covid19 [5]. There has been a drastic increase in the sales of packed foods, sanitizers and other household things. According to a report an E-Grocer company received 30,000 orders per day due to high requirement. Thus, as the demand rises, compromise in the services takes place. This may include wrong delivery of a product, delay in the shipment. Thus, a system is required that is faster, is contact less and involves fewer manual efforts. 3D reconstruction of objects using 2D images have been a great advancement in the field of computer vision. This can be done to analyze the object without any physical intervention in the process which makes it suitable for fragile objects. 3D reconstruction of objects also makes it easier for computational analysis and extracting the attributes of the object [6]–[8]. There are several solutions to solve the mentioned problem of estimating the dimensions of boxes. Each method employs a different set of hardware and different algorithmic process to achieve the same. Some focus extensively on the accuracy of the measurement while some focus on the operational speed and computational time. The power consumption varies based on the hardware employed. Height of a 3-D object can be measured with the help of a line laser and a camera. This is done with the help of laser triangulation method. The deflection in the line laser is checked by an algorithm to determine the shape of the surface of the object. Thus, this model works correctly for objects of any shape since the top surface is considered. Since, there is no estimation of the length and breadth of the objects, this model is not well suited for industrial applications where all the three dimensions of the object are required. The system that we are designing will consist of a single line laser and a camera module. This system focuses on utilizing as low power as possible because of a smaller number of components and high speed of operation which would be favorable for most of the industrial applications. The trade-off between the accuracy and the speed of operation is well suited for industrial needs. From algorithmic perspective, the only major operations would be masking the unwanted sections of the image and detecting the red laser line. This makes the process faster than the other observed methods which involve multiple lasers and cameras.

II. METHODOLOGY

In order to compute the three dimensions (length, breadth and the height) of an object, the initial step has to be calibrating the camera to map the pixel values to the real-world dimensions (in centimeters). This can be done by placing a line (of known length) of a distinct color on the ground level and detecting the number of pixels it takes in the image, this can be seen in the figure 5. To identify the line on the surface we use edge detection algorithm [9]–[11]. The length and breadth that the camera will see depends upon the height of the box under the camera (closer objects appear larger). Hence, we first need to compute the height of the box. The displacement in the line laser projected on the box is directly proportional to the height of the box as shown in figure 4.

Once the displacement is obtained, the height of the box can be calculated. The camera being a point camera, there will be error introduced in the height of the box as shown in figure 2.
This error can be eliminated by knowing how far the displaced laser line is from the center of the laser. Thus, the actual height of the box is obtained. The box is assumed to be in a certain color range. Hence, the unwanted colors in the image are masked so that only the box is visible. From the figure 9 the box length and breadth can be obtained in pixels using contour detection algorithms [12], [13]. If this pixel value is multiplied by the calibration factor, the projection of the dimension on the ground will be obtained as seen from figure 6. The actual length and breadth of the box can be obtained by applying the principle of similarity of triangles.

To get the desired length we need to calculate this error. To find the length ‘X’ in figure 3, we extract coordinates of the center of the image and the laser line on top of the box and subtract them. For a given camera height and the length recorded in the camera, the desired length can be calculated as follows.

\[
\tan(\theta) = \frac{e \cdot \tan(\phi)}{d} = \frac{X}{H} \\
d \cdot (1 + \frac{X}{H \cdot \tan(\phi)}) = D \\
d = \frac{D}{1 + \frac{X}{H \cdot \tan(\phi)}} \\
X = D - d = D - d \cdot \frac{X}{H \cdot \tan(\phi)}
\]
B. Height Calculation

As explained earlier, the height of the object will be proportional to the displacement in the laser. Also, from figure 4, it can be said that the height of the object is equal to the displacement in the laser light if the angle of projection of laser inclination is set to 45°. Implementing this system would give us the displacement of the laser line in number of pixels. The required result should be in units of distance like millimeters or centimeters.

The number of pixels which represent the displacement of the laser line will be linearly proportional to the actual height of the object. This means that to find the actual displacement, the pixel value has to be multiplied by a constant (K). To find the value of K, the camera is made to point to a surface from a height equal to the height of the camera in the system that is desired. Then, a line of known length is drawn on the surface and recorded by the camera as shown in figure 5. After the length of the line is measured in pixels, the proportionality constant 'K' can be calculated using the formula,

\[ K = \frac{\text{dist in cm}}{\text{dist in pixels}} \]  

(5)

In figure 4, the top view explains what the setup will look like from top. The line laser is directed towards the box. Some part of the laser falls on the top surface of the box while some of it falls on the bottom surface. The side view explains the same setup seen from the side where the laser will be the top left of the triangle. The laser is fired such that it makes an angle of \( \phi \) with the vertical line in anti-clockwise direction.

This proportionality constant basically converts pixels to centimeters on the ground level. From the figure 4 it can be seen that the camera is able to capture the distance between the two lines of the laser. Let this length be "d" and let the height of the box be "h". Now using trigonometry, we can calculate the height, given the angle of inclination of laser light from the normal and the distance d.

\[ h = \frac{d}{\tan(\phi)} \]  

(6)

Figure 5 explains the calibration of pixel values of camera reading to physical dimensions (in cm).

The red line drawn on the white paper in figure 5 is of 20 cm. The camera is held at a fixed height above the paper and the image is taken. This configuration will have a fixed k. Note that every configuration depends on the distance of the camera from the ground and the angle at which the laser light plane is projected. In this case after applying some image processing techniques which will be discussed further, it is found that the length of the line is 232 pixels in figure 5. This gives us a reference and the proportionality constant in this case is,

\[ K = \frac{232}{232} = 1 \]

(7)

Now after finding the constant of proportionality, we can now find the height of any object under this configuration.

In equation 4 the quantity 'D' (displacement observed by camera) and 'X' (Distance between the center of the camera and the laser line on the top of the box) are recorded in pixels. These quantities need to be multiplied by the constant K to convert in cm.

C. Length and Breadth Calculation

For calculating the length and breadth we can directly use edge detection algorithms which will be discussed further. But again, the length and breadth of the box are in pixels and it needs to be converted into centimeters.

The calibration factor used to calculate the height of the box cannot be used in this case. The reason being that at different heights with respect to the base of the system the calibration factor changes. The calibration factor for the base can be calculated by drawing a line of known length and measuring it, but it is not possible to calculate it at every height. So to dynamically calculate the calibration factor at different heights we use the property of similarity of triangles in figure 6.
Figure 6: Length and Breadth calculation of the box

Figure 6 explains the concept of false length (projected length) and a method to calculate the desired length.

Now for a given configuration the height of the camera is fixed. Consider this height to be \( H \) refer 9 and the height of the box to be \( h \), for simplicity lets calculate the length first. To calculate the length of the box in centimeters from the pixel values consider the height of the box to be approximately zero (\( h \)). So, the top face of the box will lie in the same plane as the 20 cm line used for calibration. Therefore, we can make use of the calibration factor \( K \) used to calculate the height and find the pseudo length. This is the length of the box at the height \( H \), then the length of the box at height \( H-h \) will be given as,

\[
TL = FL * \frac{H - h}{H} \tag{11}
\]

where,

- \( h \) : Height of the box.
- \( H \) : Height of the camera from ground.
- \( FL \) : False length recorded by the camera.
- \( TL \) : Desired length.

Similarly, we can calculate the breadth of the box.

IV. ALGORITHMIC FLOW FOR ESTIMATION OF DIMENSIONS

Under the given configuration we tried to measure the height of a box. The original image of the box can be seen in figure 7. Figure 7 is the image of the box as taken from the camera without any processing.

Figure 8: Distance between the laser line
\[ h = 0.0862 \times \frac{105}{\tan(45) \times (1 + \frac{50+0.0862}{53})} \]

\[ h = 8.37 \text{cm} \]

**B. Calculation of Length And Breadth**

Calculation of length and breadth consists of four major steps:

1) **Masking and Blurring:** Masking simply means removing the part of the image that is not required. In the case of finding length and breadth of the box in the image, we will mask the box in the image. The resulting image will have background of 0 pixel value (black) and original box image will be retained. After masking, we perform blurring. The image is convoluted with a Gaussian filter. Gaussian Filter is a low pass filter that removes high frequency components.

2) **Edge Detection:** The output of the masking algorithm will produce an image where only the portion where box is present will be intact, while the other part of the image will be masked with black color. In order to find the edges of the box in the image, we need to apply an edge detection algorithm. The edge detection algorithm will detect the portion of the image as edges where there is an abrupt change in the pixel values. For the edge detection algorithm to work properly, initial blurring is required so that certain noise elements from the image get nullified and are not detected as edges. When the edges are detected, a bounding-rectangle algorithm will be run on the image where the detected edges are marked with a certain distinct colour (green in this case) so as to verify the correctness of the edge detection algorithm. The lengths of the edges can be obtained in pixels which then can be converted to real length and breadths in cm.

3) **Threshold:** In threshold function the first argument is the source image, which should be a grayscale image. The second argument is the threshold value which is used to classify the pixel values. The third argument is the maximum value which is assigned to pixel values exceeding the threshold. Fourth argument is the type of thresholding we apply (here we use THRESH_BINARY).

4) **Bounding-Box:** A bounding box is created around the box considering the threshold generated. Here bounding box will be rectangle in shape. (cv2.rectangle is used). Length and breadth detected is shown in pixels above the box.

The output of all these operations can be seen in fig. 9

![Figure 9: Length and Breadth of the box](image)

Figure 9 shows the output of the box detection algorithm where all the colors outside the range of possible box colors are masked with black color, thus keeping the box visible.

This will ease the process of calculating the length and breadth of the box in pixels.

5) **Calculation:** After the boundary is defined, the edges are measured in pixels and then converted to centimeters using the methodology discussed previously. In this case the length and breadth in pixels are 347px and 299px respectively. To convert it into centimeters we use the given formula, 11

Table I is the tabulated form of the results that was produced after running the above algorithm on boxes of various sizes.

### Table 1 : Results Produced Using the Proposed Methodology

| Box No. | Real dimensions | Calculated dimensions | Error |
|---------|-----------------|-----------------------|-------|
|         | Length(cm)      | Breadth(cm)           | Height(cm) | Length(cm) | Breadth(cm) | Height(cm) |
| 1       | 35.8            | 24                    | 15.6      | 36.104     | 24.121      | 15.664     | 0.849     | 0.504     | 0.269     | 0.540     |
| 2       | 35.8            | 15.6                  | 24        | 37.043     | 16.567      | 23.402     | 3.472     | 6.198     | 2.491     | 4.054     |
| 3       | 24              | 21.2                  | 9.1       | 24.171     | 20.744      | 9.978      | 0.712     | 2.150     | 9.648     | 4.170     |
| 4       | 21              | 9.5                   | 24.5      | 22.151     | 9.661       | 23.648     | 5.480     | 1.694     | 3.477     | 3.551     |
| 5       | 19.1            | 15.8                  | 16        | 20.993     | 16.545      | 15.774     | 9.910     | 4.715     | 1.412     | 5.346     |
| 6       | 20.3            | 16                    | 16.5      | 20.178     | 15.942      | 16.263     | 0.600     | 0.362     | 1.436     | 0.799     |
| Total   |                 |                       |           |            |             |            | 3.504     | 2.604     | 3.122     | 3.077     |
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Table 2: Comparative Analysis of Existing Methodologies.

| Parameter | [14] | [15] | [16] | [17] | [18] | Proposed methodology |
|-----------|------|------|------|------|------|----------------------|
| Length(%) | 1.1  | 5    | 8.5  | 0.742| 1.032| 3.504               |
| Breadth(%)| 1.182| NA   | NA   | 0.05 | 4.1  | 2.604               |
| Height(%) | 1.502| NA   | NA   | NA   | 3.6  | 3.122               |
| Error(%)  | 1.261| 5    | 8.5  | 0.396| 2.91 | 3.077               |

As it can be seen from the above results, the error is close to 3%. The error that can be seen in the cases is majorly due to the inaccurate laser angle and camera image quality.

B. Comparison With Existing Methodologies

Some of the existing methodologies are compared with ours to analyze the pros and cons of each one. There are some methodologies that employ multiple lasers and cameras or cameras with depth sensors, etc. Some measure the length of the objects based on how fast they are moving. Some of them only calculate single dimension of the objects.

Comments on existing methodology,
1) This methodology uses laser triangulation and deep learning methods for dimensions estimation. Two cameras and four lasers are required for the process. It produces very accurate results but the processing is very costly, leading to slower operations [14].
2) This methodology measures only the height of the object. The shape of deflected laser is considered so it can be used for curved surfaces as well. The camera error is not accounted for. This methodology uses only one camera and laser [15].
3) This method uses laser triangulation principle for height estimation. Only height of the object is calculated using this method. Camera error is not accounted for which leads to higher error. This methodology uses only one camera and laser [16].
4) The proposed methodology uses Computer Controlled Laser mounted Camera combo (CCLC) to measure the distance of the object from the camera and the laser triangulation method to measure the length and breadth of the object. The methodology uses two lasers and one camera, and the mean error is quite low [17].
5) To measure the height of the object, a camera with depth sensor is used. As the objects move over a conveyor belt (with known speed), the time that an object takes to cross the depth sensor is used to measure the length of the object. The error in the measurements is low. The error will depend upon the speed of the conveyor belt and the speed of the camera [18].

VI. CONCLUSION

The proposed system can be used to estimate the dimensions of the objects very quickly and with minimal components as compared to other methods. The precision and speed of this methodology are well suited for industrial needs. Since only a single camera and laser are used, power consumption will be minimal. An error in measuring the Laser Angle $\phi$ can greatly affect the accuracy of the system. To minimize the errors that happen due to lighting conditions, the system can be enclosed in a casing with internal lighting. This system can also be integrated with an IoT based system to create a real time object tracking system. It can be easily integrated with any other automation system that makes use of object dimensions for efficient stacking of objects. Since the process of calculating the dimensions is contact-less it can be used to calculate the dimensions of fragile objects. This system will have high importance even in the post-covid world where contact-less operations are the key.

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