Research on measuring system of bulk cargo

Dengenchang[1, a *], Zhaoxiangqian[2,b] and Yuanzhengpeng[3,c]

[1] Shenhua Tianjing coal port, Tijian,China

[2]Shanghai Eastern source automation Co., Shanghai, China

[3]Shanghai Findtruth laser technique Co., Shanghai, China

[a]dengec1981@sina.com, [b]zhaoxq@theidi.com, [c]zpyuan@findtruth.com.cn

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Abstract. The paper proposed an algorithm about volume-calculation and weight estimation of coal stack based on image-processing. In this application system, the laser was assembled on the stacker, so that the scanning data can be collected from the laser with the movement parameter of the machine. 3D point cloud of coal stack and yard will be rebuild in the absolute coordinate system, then the point cloud of coal stack will be segmented by image processing method.

Introduction

Today, there has a common issue faced by all major bulk port, which include how to effectively reduce labor costs, improve the working environment, keep stable productivity and reduce manual intervention production. The key of this problem lies in the development of automated stacking and reclaiming systems. The measuring system of bulk cargo is an important part of automated product system. The current solution[1, 2, 3] is still relatively backward, measure it manually with a tape measure or off-line laser scan system. This paper presents a fast and reliable way to measure the volume of the coal stacks which can be used in most automated stacking and reclaiming system.

3D point cloud

Definition of coordinate system

The coordinate definition in the coal field as show in Fig.1, in which a presents the top view of the field, and b presents the three dimensional diagram.
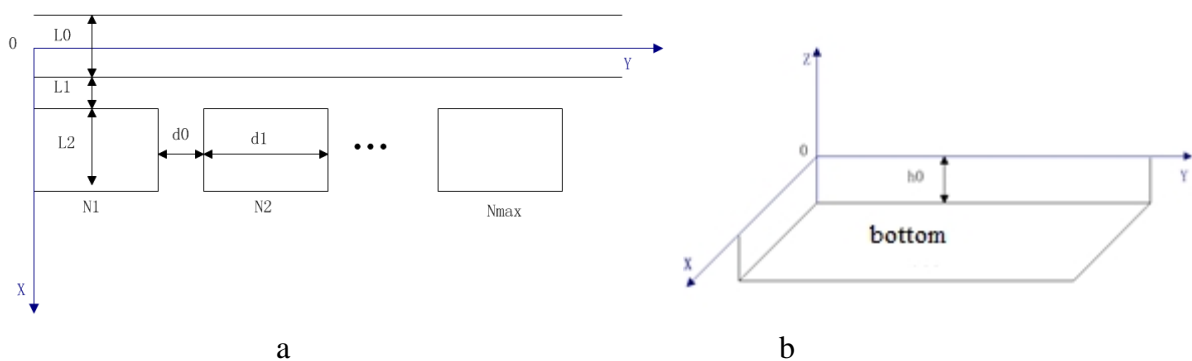

Fig.1 coordinates definition of the field

Where L_0 is the width of the orbits, L_1 is the distance between the orbit and the field, L_2 is the width of the field, d_0 is the distance between two fields, d_1 is the length of the field, h_0 is the orbit height, N_1 , N_2 , … , N_max are the number of all the fields.

Conversion of laser scanner 's data

The lase was assembled on the arm of the machine (Fig.2), and the relationship can be got in the Fig. 3. In the scanning process, and all the surface of the target stack will be covered by the laser's scanning planes when the laser following the movement of the machine.
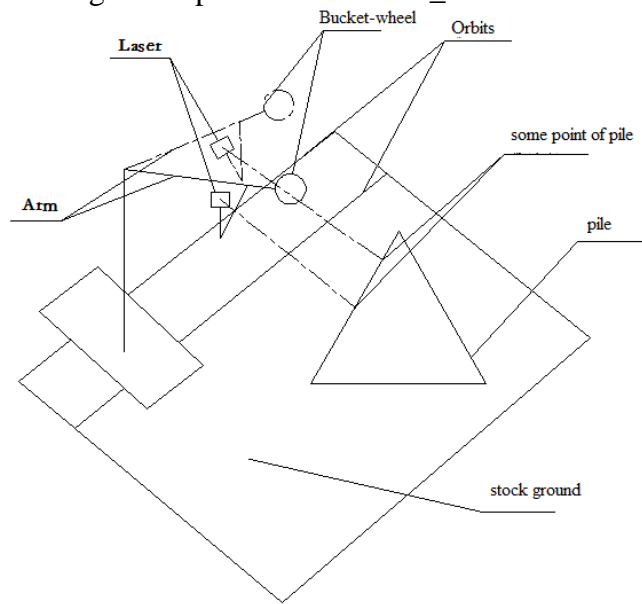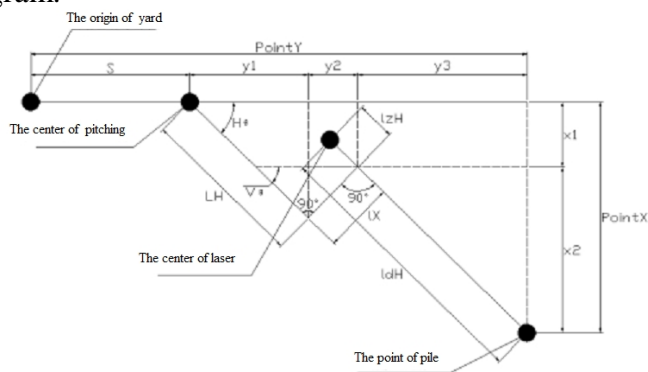
Fig.2 The position sick LDR_LRS3100

Fig.3 The schematic diagram of the actual object model

In order to facilitate the analysis and calculations, the actual object model can be abstracted as a schematic diagram. The Fig. 4-a is the top view of the schematic diagram, and the Fig. 4-b is sectional view of the schematic diagram.
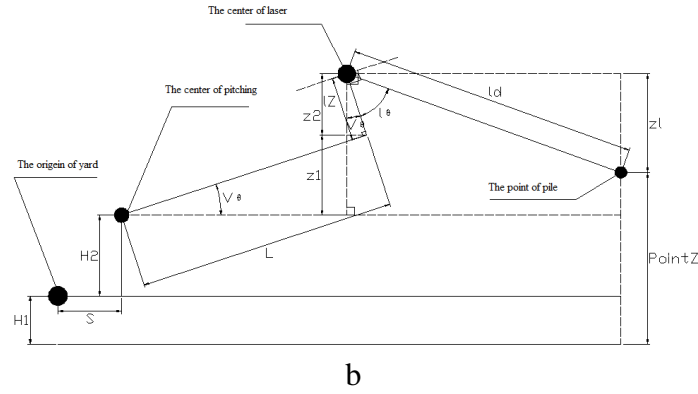

a

b

Fig.4 the schematic diagram of actual object model

The following relationship can be obtained from in Fig. 4-a:

$$L_H = L \times \cos V_\theta \tag{1}$$
$$L_{ZH} = l_z \times \sin(V_\theta + l_\theta) \tag{2}$$
$$ld_H = ld \times \sin(V_\theta + l_\theta) \tag{3}$$
$$x_1 = L_H \times \sin H_\theta - l_x \times \cos H_\theta \tag{4}$$
$$x_2 = (ld_H - L_{ZH}) \times \sin H_\theta \tag{5}$$
$$y_1 = L_H \times \sin H_\theta \tag{6}$$
$$y_1 = L_X \times \sin H_\theta \tag{7}$$
$$y_1 = (ld_H - L_{ZH}) \times \cos H_\theta \tag{8}$$

Where S is the distance between the zero and the machine in the y direction, H_θ is the Horizontal swing angle, L_H is the straight line from the laser to the rotary axis in the horizontal plane of projection, ld_H is the distance between the target point and the laser scanner in the horizontal plane, l_{ZH} is the distance between the laser scanner and the machine's arm, H_1 is the height of the track surface height, H_2 is the height of the pitch axletree , V_θ is the pitch angle, The formula (9) follows the formula (4) and formula (5):

$$Point_x = (ld \times \sin(V_\theta + l_\theta) - l_z \times \sin V_\theta) \times \sin H_\theta + L \times \cos V_\theta \times \sin H_\theta - l_X \times \cos H_\theta \tag{9}$$

The formula (10) follows the formula(6) , (7) , (8):

$$Point_y = L \times \cos V_\theta \times \sin H_\theta + l_x \times \sin H_\theta + (ld \times \sin(V_\theta \times l_\theta) - l_{ZH} \times \sin V_\theta) \times \cos H_\theta + S \tag{10}$$

The formula (11), (12), (13) follow Fig.4-b that can derive the formula (14).

$$z_1 = L \times \sin V_\theta \tag{11}$$
$$z_2 = l_z \times \cos V_\theta \tag{12}$$
$$z_1 = ld \times \cos(l_\theta + V_\theta) \tag{13}$$
$$Point_z = H_1 + H_2 + z_1 + z_2 - z_1 = H_1 + H_2 + L \times \sin V_\theta + l_z \times \cos V_\theta - ld \times \cos(l_\theta + V_\theta) \tag{14}$$

Image Processing

Mapping to Grey-scale Image

Because it is hard to process data of three-dimensional point cloud, the three-dimensional point cloud data can be mapped to gray-scale image firstly, then do some image-processing on it. Hypothesis p_n is a point in the field, where p_n is a point in the Nth field and $p_n \in (x, y, z)$, $x \in [L_1 + \frac{L_2}{2},\ L_1 + \frac{L_2}{2} + L_2]$, $y \in [(n-1) \times (d_0 + d_1),\ (n-1) \times (d_0 + d_1) + d_1]$, $z \in [-h_0,\ h_{max}]$. p_n can be mapped to g, a pixel in gray-scale image, where $g \in (x, y, z)$, x is the horizontal coordinate value and $x \in [0, w]$, y is the vertical coordinate value and $y \in [0, h]$, z is the gray value and $z \in [0, 255]$. Because the maximum height of the coal stockpile is18m and the maximum height of a pixel's value is 255. So the mapping formula is as followed.

$$g_y = \left| \frac{p_y - (n-1) \times (d_0 + d_1)}{s_y} \right| \tag{15}$$

Fig.5 The gray-scale image of the field

The outline of the stockpile

There are two ways to process the original grayscale image: The first is image-filtering, remove noise, and then extracting the outline; the second is extracting the outline, and then do image-filtering. In this paper, I chose the latter, because the original image filtering directly damages the image of the original boundaries of the stockpile, which may expand or shrink the effective range of the pile in the filtering process.

When using the linear mapping, transform the point-cloud data to image data, there has a following rule:

$$p_g = \begin{cases} 0 \\ x \end{cases} \quad x \in (0, \ 255] \tag{16}$$

Where p_g is the grey value of the P in the grayscale. So the coal stockpile can be obtained by filtering all the pixels, whose value is under the specific value. The value of pixel in the binary-image only could be 0 or 255 , and the transform formula is as followed.

$$p_{bin} = \begin{cases} 0, & p_g < T \\ 255, & p_g \geq T \end{cases} \tag{17}$$

Where T is the threshold of binaryzation. The entire pixel, whose grey-value is below T, will be removed. In order to keep the integrity of the data, the value of T will be set as 2% of p_g. I.e. $T=\lfloor 255 \times 2\% \rfloor = \lfloor 5.1 \rfloor = 5$, and the result is in Fig. 6.

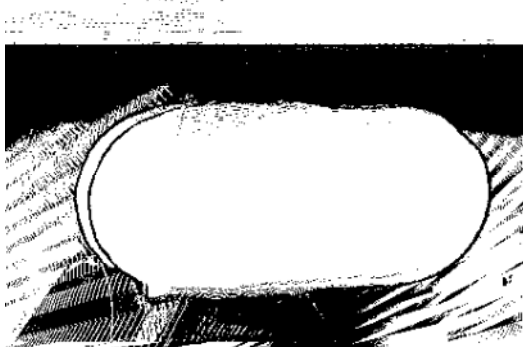Fig6. The binary-image of the field

Image Filtering on Binary Image

Hypothesis $p(p \in A_t)$ is a point in the Binary-image of the field, where A_t is the Nth connected domain, there has a discipline: the coal stockpile must in the biggest connected domain. So the biggest connected domain can be found by calculate the area of the entire connected domain, then remove the last connected domain. After get the binary-image of coal stockpile, it is easily to fill it with crisscross filter, shown in Fig.7.
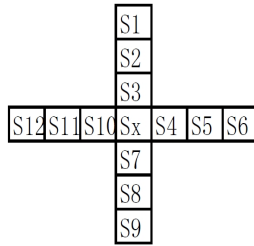
Fig.7 Crisscross filter

Where S_x the target pixel, $S_1 \sim S_n$ are the pixels close to S_x. And the process of filtering is that the value of S_x will be set to 255 when the number of pixels, whose value are equal to 255, is larger than the number of pixels, whose value are equal to 0, in $S_1 \sim S_n$. Also the value of S_n will be set to 0 when the number of pixels, whose value are equal to 255,is less than the number of pixels, whose value are equal to 0, in $S_1 \sim S_n$. And the result is as shown in Fig.8.
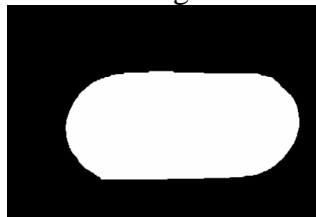

Fig.8 The binary-image of coal stockpile

Stockpile Image

Hypothesis p_b presents a pixel in binary-image, there has a rule:

$$p_b = \begin{cases} 0, & p_b \text{ out of the range} \\ 1, & p_b \text{ in the range} \end{cases} \tag{18}$$

Hypothesis p_s is a pixel in original gray-scale image, and p_n is a pixel in the stockpile image, so the following formula can be got easily and the stockpile image shows as Fig.9.
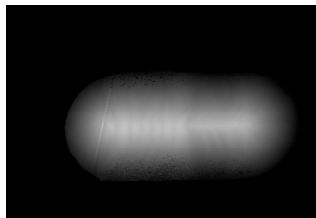
$$p_n = p_s \wedge p_b \tag{19}$$

Fig.9 stockpile image

There is much noise in gray-scale image. In order to ensure the material pile edge not destroyed and filter the image, this paper uses bilateral filtering [4]: restrain the pixel difference with the center pixel, and the value of output pixel depends on the weighted-sum of neighborhood pixel value the. Fig.10 shows the result of bilateral filtering.
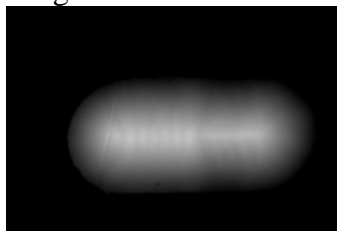

Fig.10 stockpile image after filtering

Volume Calculation

Every point's height in the stockpile can be got from stockpile image. So it is easily to calculate the stockpile's volume by cumulating the entire pixels' value in gray-scale. Also the entire pixels' value in gray-scale should be mapped to the actual height value in the stockpile, refer formula (18).

$$p_z = f(g_z)^{-1} = \frac{g_z \times 180}{255} \tag{20}$$

The calculation formula of volume is (21).

$$V = \sum_0^{y_{max}} \sum_0^{x_{max}} \left(\frac{18 g_z \cdot s_x \cdot s_y}{255} \right) \tag{21}$$

Summary

This paper proposes an auto-estimation system of coal stockpile: firstly, the three-dimensional point cloud data of coal stockpile can be got by using laser scanner; secondly, map the three-dimensional point cloud data to gray-scale image, and the point cloud of coal stack will be segmented by image processing method ; thirdly, the volume value of stockpile can be got by processing the gray-scales image.

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