Development of Autonomous Bucket Wheel Reclaimer with Laser Vision

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Abstract: An autonomous system of the bucket wheel reclaimer is developed to improve capability of the reclaimer in dark or bad whether. It obtains the 3D shape of the pile by the laser scanners mounted the reclaimer, and extracts the landing position through computer vision techniques. All the operations of the reclaimer can be controlled automatically in the remote control room. The system can control simultaneously six reclaimers. And it has been successfully implanted to the reclaimer in the stockyards of Majishan of Bao Steel Co. and show satisfactory result.

Introduction

Bucket wheel reclaimers, as a kind of bulk material handling Machines, are widely used to dig raw materials from the stock pile and transfer the materials to other factories in modern industry [3]. In Figure 1, a picture of a bucket wheel reclaimer is shown. The traditional operation of the reclaimer is performed by the operator manually, which involves traveling, slewing, and pitching through an operation lever in the cab or the remote control room with the aid of some video cameras. However this operation is not an easy job because the operator’s eyes or the videos cannot recognize the real 3D shape of the stock pile precisely, especially in dark and bad weather. If the bucket wheel collided with the pile or other machines, it will be a serious accident. So we developed an autonomous bucket wheel reclaimer with the laser scanners mounted on both sides of bucket wheel. The laser scanner, as the eyes of the reclaimer, can “see” the 3D shape of the pile even in dark or bad weather, and the reclaimer can automatically dig the pile without the interruption of the workers.

Figure 1: A Picture of a Bucket Wheel Reclaimer
Imaging System of the Laser

To obtain the 3D shape of the pile, two laser scanners are installed separately at the two sides of the reclaimer, as shown in Figure 2(b), where only the scanner on the right side is shown, and the left one is behind the wheel. Two aspects are considered in this installation scheme. One is that the pile is always explored by the laser scanners without any occlusion when the reclaimer is moving. The other one is that the distance between the pile and the scanner is moderate because the material of the pile is not good for the reflection of the laser. In addition, for each of the laser scanners, a shield is added to protect the scanner from rain or dust in the outside work environment, as shown in Figure 2(a). And a blower is used to clean the lens of the scanners. To ensure stable measurement, the mounting brackets with good rigidity are needed.

![Figure 2: Installation of the Laser Scanners](image)

The type of the laser scanners we choose is the SICK LMS-221. The configuration of the laser scanner is reset for the environment. Its sensitivity is adjusted to dark material according to the bad reflection condition. The view of field and the angular resolution are set to 180° and 0.25°, respectively. We use mode 32m which is the maximum distance returning from the laser. The data link is the RS422 at 500kbps.

![Figure 3: The coordinates of a reclaimer](image)

A reclaimer can be treated as a robot arm. Using Danevit-Hartenberg notation[1], coordinate frames are assigned to the reclaimer as shown in Figure 3. Frame 4 and frame 6 are located the left and right laser scanners, respectively, and Frame 6 is for the wheel landing position. According to forward kinematics solutions, The general transformation matrices between Frame 0 and 4 can be derived as shown in formula (1) below.
Where \( d_4 \) is the distance from origin of Frame 3 coordinate to intersection of \( Z_3 \) & \( X_4 \) along \( Z_3 \); \( a_4 \) is the distance from intersection of \( Z_3 \) & \( X_4 \) to origin of Frame 4 coordinate along \( X_4 \).

The laser scanner is a polar coordinate system. For the left scanner, the coordinate of the point in Frame 4 is calculated from below formula.

\[
X_4 = (x_4, y_4, z_4)^T = (r \cdot \sin(\beta), r \cdot \cos(\beta), 0)^T
\]

Where \( r \) is the distance returning from the laser scanner, and \( \beta \) is the angle of this beam. So the coordinate \( X_0 \) of the same point in Frame 0 is calculated from below formula.

\[
X_0 = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = T_4^0 X_4
\]

For the right scanner, the operation is the same. So the 3D coordinates of the points of the pile surface in frame 0 are obtained with the movement of the reclaimer, and a height map is generated by mapping the range data to intensity value in the x-z image plane. In addition, Non-Local Means filter is explored to remove the noise of the image data [2]. The 3D shape of a pile is shown in Figure 4.

**Figure 4: the 3D Shape of a Pile**

**Extraction of the Landing Points**

In the operation of the reclaimer, the wheel bucket swings back and forth at the given landing height. Then it feeds to the next position and repeat the same swing movement, as shown in Figure 5(a). So it is essential to extract the landing pints of each swing. First, the contour lines at the landing height of the bucket are detected by the contour tracking techniques[4], as shown in Figure 5(b). Then, the curve of the candidates are extracted at the given feed under the constraint condition that the length(r) is constant, as shown in Figure 5(c). All points on the lines are assumed to be possible landing points and their feasibility are investigated. If a point brings about overload in the
slewing operation, it will be excluded from the set of candidates of landing points. All points on the contour line are examined if they belong to candidates for landing points by investigating the digging depth of the bucket wheel. In other word, each of the landing points must satisfy \( D < \text{DEPTH}_{\text{max}} \) to avoid overload. \( \text{DEPTH}_{\text{max}} \) is the maximum digging depth under the nonoverload condition.

If the Landing points are confirmed, the movement parameter of the reclaimer can be calculated using below formula by inverse kinematics solutions.

\[
\theta_4 = \arccos\left(\frac{y - L_2 - L_3}{a_6}\right)
\]

\[
\theta_3 = \arcsin\left(\frac{x}{\sqrt{a_6^2 \cos^2 \theta_3 + d_6^2}}\right) - \alpha
\]

\[d_1 = z + a_6 \cos \theta_3 - a_6 \cos \theta_4 \sin \theta_3\]

Where \( d_6 \) is the distance from origin of Frame 3 coordinate to intersection of \( Z_3 \) & \( X_6 \) along \( Z_3 \); \( a_6 \) is the distance from intersection of \( Z_3 \) & \( X_6 \) to origin of Frame 6 coordinate along \( X_6 \); \( \alpha = \arctan\left(\frac{a_6 \cos \theta_4}{d_6}\right) \). \( P(x, y, z) \) is one of the landing points.

**Implement of the System**

The whole architecture of the system is sketched in Figure 6(a), which shows the various formats of information exchanges between the computers and the sensors. The computers in the control room are connected to PLCs, cameras and Lasers in the reclaimers via Ethernet. The server manages all operation data in the yard and status of all reclaimers. It gets information for stockpiles from the image system and the database when they perform reclaiming. It also controls collision avoidance of all reclaimers in the yard. The image system manages the yard height map which calculated from the data of the lasers and the attitude of the reclaimers from the OPC server which communicates with the PLCs of the reclaimers. The client dispatches the operation commands of the PLCs over the OPC server, and monitor the status of the reclaimers from the information of the PLCs, the cameras and the 3D shapes of the piles via the HMI which is shown in Figure 6(b). The client can switch the work mode between the automatic mode and the manual mode. In the automatic mode, it simultaneously controls six reclaimers. In the manual mode, the workers can operate the reclaimer by the joystick in the control room. The PLC receives the command from the
client and performs the position control of the moving axis of the reclaimer which consists of translation on the rail, pitching and slewing.

Conclusions

The proposed System used two laser scanner to create the 3D shape of the pile, and extracted the landing points of the reclaimer by computer vision techniques. To avoid overload, each of the candidates are examined. In the control room, the worker can manage six reclaimers simultaneously in automatic mode. The system has been implanted to the reclaimer in the stockyards of Majishan of Bao Steel Co.. The error of position between trajectory of the bucket and the surface of the pile is within 15cm in the landing test, and this error can be accepted in the operation of the reclaimer.

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References

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