Research on Key Technologies of Intelligent Industrial Robot System for Bulk Material Transportation

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Abstract. With the application of Intelligent Manufacturing in the mining industry, the demand for intelligent and unmanned delivery of Stacking material is more and more urgent. The particle size of iron mineral powder is very small, the surface shape is very irregular, and Acquisition effect affected by absorbing wave, diffuse reflection, signal interference and other factors. The intelligent Industrial robot system has a great challenge in the accurate selection of grab point, which is easy to cause the lower chute and upper rope climbing of grab, and cause the delivery business interruption. Because of the above characteristics of iron mineral powder, it is very difficult to develop an intelligent shipping system with precise collection, intelligent scheduling and automatic shipping technology. At present, there is no systematic, practical and intelligent industrial robot system. After three years of research, the project team has conquered the key technologies of the project, developed the key technologies such as the iron concentrate height acquisition radar, three-dimensional distribution algorithm, and developed the intelligent industrial robot shipping system, which can be applied to the full-automatic delivery of bulk materials in the stacking warehouse. Field test shows that the intelligent system have good effect.

Keywords: Industrial robot; 3D modeling; Intelligent shipping; Microwave radar.

1. Introduction
With the application of intelligent manufacturing, automation, AI and other technologies in the industry, the demand of Stacking material intelligent automatic shipping is more and more urgent. More than 20 years ago, western developed countries began to study industrial robots, ABB robotics in Sweden, FANUC in Japan, KUKA Roboter in Germany and Adept Technology, American Robot in American etc, Industrial robot business has become theirs main industries in its region [1]. In the research and development of dry bulk delivery robot, ABB introduced a more advanced automatic operating system at that time, "bridge grab ship unloader automatic operating system (grab swing and performance optimizer GPO)". After years of development, foreign dry bulk equipment technology has entered a relatively mature stage, and the technical level is in a leading position. In China, Baosteel used the automatic train operation system in 2007 and launched the first unmanned intelligent train operation workshop in 2018 [2-3]. However, the current unmanned bridge crane system can not meet the shipping requirements of various bulk materials. Because of the variable distribution of bulk materials, it is difficult to select the appropriate grab point. In recent years, the development and application of 3D scanning and modeling technology provide a way to solve the difficulties of the project [4-7]. The lidar is not accurate for the collection of absorbing materials, so it has developed a general collection radar. In addition, the three-dimensional distribution and scheduling algorithm is the key technology to solve the system. The above two points are the key factor to the success of the system.
2. System Architecture

The system includes field information, equipment, communication, business, algorithm, alarm and other aspects. The real-time situation changes frequently and is very complex. According to the overall business requirements, the system can be divided into three modules: acquisition module, motion control module, intelligent scheduling module, which are equivalent to the "eye", "hand" and "brain" functions, each module includes related sub modules, realizing three major functional modules of the whole scene information "input", processing and command, and motion control.

The first part of the system needs to collect field information, positioning information, equipment information, business information, security information, etc. in real time. It needs to have real-time, stability, and efficient coordination of various information. The most important is high-level collection, which is the key factor related to the grasping effect. The second part of the system is Intelligent scheduling. when the system state is normal, the task type is determined according to the planned and waiting vehicle status. before, during and after the execution of each task, the system status is detected to determine whether to enter the next task or execute the abnormal execution process. The relationship and flow of main modules of the system are shown in figure 2. The third part of the system is motion control, it is the action actuator of the system. It includes intrinsic safety, fault alarm, task signaling reception, cart movement, grab lifting, opening and closing action, grab online weighing, attitude detection, automatic manual switching, etc. It’s task is to receive the control command, complete the grabbing and shipping work, and determine whether to interrupt the work according to its own fault alarm. The workflow is shown in Figure 3.

3. Development of Anti-jamming Altitude Acquisition Radar

The system has a high demand for real-time and stability, so the collection ability of the system should be efficient and anti-interference. after three years of research, a radar with anti-jamming and effective collection of absorbing materials has been developed. The situation at the delivery site is complex, so the radar of high acquisition should consider the weather of rain and fog or the absorbing characteristics of materials. Through the experiment of laser, infrared and other height acquisition equipment, it is found that the measurement error for absorbing and scattering materials of small particles is large, and it is strongly interfered by rain and fog weather. Through research, the above problems can be well solved by microwave. Millimeter wave radar head has strong ability to penetrate fog, smoke and dust, and has small volume, light weight and high spatial resolution. The radar transmits the millimeter wave modulated by the frequency to the fine particles through the antenna. The millimeter wave is reflected by the surface of the ore pile. The difference frequency signal generated by mixing the reflected signal and the transmitted signal is converted into a digital signal after AD sampling. The digital signal is processed by the high-precision ranging signal processing
algorithm, and the height of the pile surface can be obtained. According to the above principle, the radar acquisition module is designed, including the following parts: millimeter wave radar, wireless communication transmission module, wireless communication receiving module, upper computer, as shown in Figure 4(a). The millimeter wave radar carries on the uninterrupted continuous measurement, after the measurement ends, it transmits the distance information back to the upper computer through the wireless transmission way. The structure of microwave radar is shown in Fig. 4(b), including antenna, RF front end and signal processing board. FMCW system is adopted for radar, FMCW RF module is used for front-end, and FPGA is used for core chip of signal processing board. When the radar is working, the height information in the radar signal is extracted by running a high-precision ranging algorithm in FPGA.

![Figure 4. Height acquisition system and radar structure.](image1)

![Figure 5. Spectrum amplitude of FFT direct conversion.](image2)

![Figure 6. Spectrum amplitude after spectrum refinement.](image3)

The radar uses the continuous wave system to change the frequency of the transmitted signal in time and measure the frequency difference between the echo signal and the transmitted signal, so as to determine the distance of the target. In a modulation period, the transmitted signal is expressed as:

$$V(t) = V_0 \cos[2\pi(f_\text{c} + \frac{f_B}{T}t + \frac{B}{2}t^2) + \phi_0], 0 \leq t < T$$

(1)

$V_0$ is the amplitude of the transmitted signal, $T$ is the modulation period, $f_\text{c}$ is the center frequency of the transmitted signal, $B$ is the sweep bandwidth of the transmitted signal, and $\phi_0$ is the initial phase of the transmitted signal. The echo signal $f_e = 2R/c$ is received by the radar after two-way delay, and the frequency difference signal mixed with the transmitted signal is simplified and the amplitude normalization results are as follows:

$$v_e(t) = \cos[2\pi(f_\text{c} + \frac{B}{2}t^2) + \frac{B}{2}tR/c], 0 \leq t < T$$

(2)

The frequency of the difference frequency signal obtained by mixing the transmitted signal and the echo signal is:

$$f_d(t) = f_e(t) - f(t) = \frac{2B}{cT}R$$

(3)

$f_d(t)$ indicates the frequency of the transmitted signal, $f_e(t)$ represents the frequency of the received signal, and the frequency of the difference frequency signal is proportional to the ore pile distance. It is assumed that in the case of continuous measurement, after Fourier transform of the difference frequency signal, the peak value of the spectrum amplitude of the difference frequency signal can be accurately found, so the measurement accuracy is mainly determined by the signal-to-noise ratio. The
analysis shows that increasing the number of FFT spectral lines and spectral resolution can reduce the effect of fence effect, increase the sampling length, but increase the time cost. Therefore, the method of spectrum refinement and energy center of gravity correction is used in the project to achieve high-precision ranging. Figure 6 shows the spectrum amplitude after FFT transformation, and Figure 7 shows the spectrum amplitude after spectrum refinement. The expected ranging accuracy of MMW radar is about 10cm. Through field test, the acquisition height and physical measurement value of microwave radar are shown in Table 1. The error between the collected value and the measured value is about 0.10m, which can be eliminated by software algorithm to meet the accuracy requirements of stacking and delivery.

| collection value | Measured value | Error value |
|------------------|----------------|-------------|
| 0.62             | 0.53           | 0.09        |
| 0.93             | 0.83           | 0.10        |
| 1.01             | 0.99           | 0.02        |
| 1.57             | 1.47           | 0.10        |
| 2.09             | 2              | 0.09        |
| 2.15             | 2.07           | 0.08        |
| 2.65             | 2.56           | 0.09        |
| 2.77             | 2.7            | 0.07        |

4. 3D Modeling and Grab Scheduling Algorithm

When carrying out the delivery business, it is necessary to conduct 3D modeling for the stacking in real time to identify the stacking distribution. During the first delivery, the whole delivery area needs to be scanned and 3D modeled, as shown in Figure 7. K-means algorithm is applied to divide the site stacking distribution, as shown in Figure 8. Then, the size of sliding window is determined according to the size of grabbing. According to the grabbing efficiency and the requirements of the nearest distance, intelligent generation of a round of scheduling task queue, and the effect after a round of grabbing is shown in Figure 9. Fig. 9 is a three-dimensional figure after a round of grabbing by applying the window sliding algorithm. After one round of grabbing, according to the dynamic 3D data, K-means algorithm and window sliding algorithm are applied again to divide the next round of region, as shown in Figure 10.

**Figure 7.** 3D model of bulk material.

**Figure 8.** Distribution of dry bulk material based on k-means algorithm.
5. System Application and Effect
In October 2018, the system was applied in Meishan Mining Company and the system was stable. Radar acquisition meets the accuracy requirements of 10cm, can timely model according to real-time three-dimensional coordinates, recognize the distribution of stacking materials, realize the unmanned management of the whole process of distribution, warehousing and shipment of finished iron concentrate stock yard according to the site and system conditions, and provide key technologies, equipment and application cases for unattended delivery of domestic dry bulk industry, which has broad application and promotion Prospects.

6. Conclusion
The delivery system of unattended robot for dry bulk materials is a very complex and difficult system. It’s key technologies include high precision detection technology of microwave radar, 3D modeling algorithm and task scheduling algorithm. This paper introduces the principle and optimization method of microwave radar detection, as well as the three-dimensional generation algorithm and task height algorithm. It describes the cooperation relationship and the working process of the system, and introduces the application effect of the system, which provides technical reference for people to study and apply the intelligent shipping of bulk materials.

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