Research on Anti-collision Method of Trackless Equipment in Underground Mine

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Abstract. In trackless transport of underground mines, accidents are much more frequent and serious due to the lack of effective safety warning measures. In this paper, a method of anti-collision for trackless equipment based on lidar was described. The background of the technology was recommended and the characteristics of roadway and data processing method were introduced. The method of processing radar data was proposed and a distance model was built, so the distance judgment method was provided. Finally, the method was applied on a Load-Haul-Dump (LHD) and it was proved that this method had obvious effectiveness and wide application for unmanned LHD in deep mining.

Keywords: Anti-collision; Trackless equipment; Early warning classification; Lidar; Underground mine.

1. Background
Trackless transport is one of the main ways of ore transportation in underground mines. The geological conditions are getting worse with the increase of the mining depth. Under this circumstance, the traditional trackless transport system faces the challenges of poor operation environment, heavy transportation tasks, backward management means, high security risk, to name a few[1-2]. Accidents are often caused by trackless equipment due to the lack of effective safety warning measures, especially in large-scale transportation system[3-4]. Therefore, researching the anti-collision method of underground trackless equipment can effectively improve the safety and efficiency of underground trackless transport system, which is of urgent requirement and important significance.

The research on anti-collision of trackless equipment started very early overseas, and the digital mining is particularly represented by the Automine system and Optimine mine information management system of Sandvik Group[5-6]. BGRIMM Technology Group and University of Science and Technology Beijing have developed a positioning and navigation system for trackless equipment, based on the UWB-Laser, realizing the collision prevention of trackless equipment in China[7-9]. The existing anti-collision methods of trackless equipment mainly based on the lidar warning system, to judge the distance between the equipment and the roadway. If the setted threshold is too high, there will be frequent alarm during driving, leading to low driving efficiency; if the setted threshold is too low, early warning cannot be given in case of emergency, and the safety cannot be guaranteed.

In this paper, a three-level early warning method of anti-collision for trackless equipment is proposed, which can avoid collision accidents of trackless equipment in fast driving and reduce the risk of underground trackless equipment operation.
2. Dynamic Collision Warning Method of Perimeter

In order to realize anti-collision of trackless equipment, it is necessary to install the roadway profile sensing system on trackless equipment. By collecting the two-dimensional information of the lane, with laser radar, the distance can be confirmed and judged, so the early warming for collision prevention can be provided.

2.1. Distance Judgment Model

In order to realize the anti-collision warning of trackless equipment in driving process, the distance judgment model was established to judge the information of vehicle and surrounding environment real time and provide data support for the next driving. According to the characteristics of roadway environment, the distance judgment model includes the information of transverse distance and longitudinal distance. The model is shown in Figure 1.

![Figure 1. The distance judgment model](image)

It is assumed that the width of trackless equipment is \( R \); the length of trackless equipment is \( B \); the scanning range of lidar is \( 0 \sim 190 ^\circ \); the distance between the scanning point \( P \) and the lidar is \( S \); the transverse safety distance is \( M \); the angle between the point \( P \) and the x-axis is \( \alpha \); the distance between the point \( P_1 \) and the lidar is \( S_1 \); the angle between the point \( P_1 \) and the x-axis is \( \alpha_1 \); the distance between the point \( P_2 \) and the lidar is \( S_2 \); the angle between the point \( P_2 \) and the x-axis is \( \alpha_2 \); the effective distance is \( L \). There must be enough effective distance in the vehicle driving direction to ensure that the vehicle has enough time to autonomously braking in case of emergency.

Separate the distance into transverse distance and longitudinal distance for each scanning points. Taking lidar as the center point, left and right \((R / 2 + M)\) distance of the front area is the longitudinal sensitive area, and the area outside the longitudinal sensitive area is the transverse sensitive area. If the points fall in the transverse sensitive area, the longitudinal distance is taken as the reference value, then screen out the points that may affect the straight-line driving or steering driving. If they fall in the longitudinal sensitive area, the horizontal distance is taken as the reference value similarly, and the lane contour and the position of obstacles can be determined.

2.2. Hazard Judgment Conditions

On the basis of longitudinal and transverse sensitive area, the effective detection distance \( L \) is setted. To confirm the effective detection distance, braking distance, judgment distance and vehicle dynamics characteristics should be considered. The calculation formula is as follows.

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L = c + d + v \cdot t
\]  

where \( c \) is the braking distance; \( d \) is the judgment distance; \( v \) is the vehicle speed; \( t \) is the floating time parameter.
By comparing the transverse distance of scanning point with the minimum safe distance \(R/2+M\), and taking the effective detection distance into consideration, the dangerous state is divided into three levels: green safety level, yellow alarming level and red warning level.

1) Green safety level. If \( |S \cdot \cos \alpha | \geq (R/2 + M) \), it indicates that all scanning points of the effective detection area are outside the sensitive area, which means the vehicle can keep the front frame direction and drive in a fast and straight line under this tunnel environment.

2) Yellow warning level. If \( |S \cdot \cos \alpha | < (R/2 + M) \), it indicates that there are some scanning points in the straight-line driving sensitive area, indicating that the direction of roadway has changed or there are obstacles. In order to accurately judge the current roadway environment, it is necessary to further analyze the scanning points in the sensitive area. If the scanning point meets the auxiliary judgment condition \( |a_1 - a_2| \leq 5^\circ \), it is determined that the direction of the roadway in front of trackless equipment has changed, and the dangerous state level is raised to the yellow alarming level to remind the roadway circumstance in the front. If the auxiliary judgment condition \( |a_1 - a_2| \leq 5^\circ \) is not met, but the auxiliary judgment condition \( \|S \cdot \sin a_1| - |S \cdot \sin a_2| \geq \frac{b}{2} \) is met, it means that the roadway environment in front of the vehicle has changed into the curve direction or there are obstacles on two sides of the roadway. The longitudinal distance between scanning points can allow the vehicle to pass through by changing the driving angle. Now the dangerous state level is increased to the yellow alarming level, and attentions should be paid to the roadway situation in front.

3) Red warning level. If the scanning points in the sensitive area cannot be clearly judged by the judging conditions of the yellow warning level, the dangerous state level should be raised to the red warning level. The main judgment formula in the red warning level is the same as that in the yellow warning level, that is \( |S \cdot \cos \alpha | < (R/2 + M) \). The purpose is to screen out the scanning points in the sensitive area, and then judge through three auxiliary judgment conditions. If the scanning point satisfies the auxiliary judgment condition \( |a_1 - a_2| > S' \), it indicates that the scanning point is not continuous in the straight-line driving sensitive area. If the scanning point meets the auxiliary judgment condition \( \|S \cdot \sin a_1| - |S \cdot \sin a_2| < \frac{b}{2} \) and the auxiliary judgment condition \( \|S \cdot \cos a_1| - |S \cdot \cos a_2| < R + 2M \), it means that the longitudinal distance and transverse distance between these scanning points cannot allow trackless equipment to pass safely, so as the dangerous status level should be raised to the red warning level.

3. Test Results Analysis and Application

The anti-collision method proposed in this paper was tested and applied to the driving of the scraper in the underground tunnel of Fankou mine, as shown in Figure 2.

**Figure 2.** Driving test of underground scraper

In the autonomous driving test of the scraper in underground tunnel, the anti-collision method proposed earlier in this paper was adopted. The final driving route contains straight lines and curves, and the test tracking results is shown in Figure 3.
The test results show that the anti-collision method can provide accurate data support for the safe driving of trackless equipment. It is proved that the method has effectiveness and wide application prospects for unmanned LHD.

4. Conclusions
The method of anti-collision for trackless equipment is proposed in this paper, which can effectively restrain the driving path of the equipment and avoid the collision between trackless equipment and people in the driving process through multi-level early warning. The study has been verified by experiments that his method can reduce the accident risk of trackless equipment operation and improve the intelligent degree of trackless transportation system effectively, which is of great significance to reduce the probability of collision accidents and improve the safety level of mine production.

Acknowledgement
This work was supported by the National Key R&D Program of China (No. 2017YFC0804600).

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