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DESIGN AND IMPLEMENTATION OF AN INTELLLIGENT COAL BUNKER CLEANING ROBOT

SRIKANTH SIRIMALLE[1], SAKSHI[2], R. JOSHNA[3], INDHU[4]

ASSISTANT PROFESSOR 1, UG SCHOLAR 2,3,4

DEPARTMENT OF ECE, MALLA REDDY ENGINEERIGNG COLLEGE FOR WOMEN (UGC-AUTONOMOUS), MAISAMMGUDA, HYDERABAD, TELANGANA-500100

ABSTRACT— This article addresses the challenges posed by the complex environment of coal mines and underground coal bunkers, focusing on the design of a stable and flexible mechanism that meets the movement and operational needs of a coal bunker cleaning robot in confined spaces. The robot is equipped with a power system specifically adapted to the harsh coal bunker environment, ensuring an adequate supply of energy. The power source is based on a streamer power supply, while hydraulic systems provide support and stability. Additionally, the robot is outfitted with high-precision sensors to perceive its surroundings and make real-time decisions and adjustments as needed. The integration of autonomous navigation and path planning algorithms allows the robot to complete cleaning tasks independently, adjusting its actions based on environmental changes. To ensure the safety of both the robot and workers, safety features such as collision sensors and emergency stop buttons are included. The design and development of coal bunker cleaning robots are aimed at enhancing their functions and performance, ultimately offering a scientific foundation for the advancement of future robotic cleaning systems. This research lays the groundwork for improving efficiency, safety, and operational capabilities in the coal mining industry. By continuously refining the system, future robots can achieve higher levels of automation and adaptability, contributing to a safer and more productive working environment.

Index Terms— cleaning robot; coal bunker; sensor; autonomous navigation; path planning algorithms.

I. INTRODUCTION

Coal bunkers play a vital role in coal production and transportation by serving as storage, regulation, and measurement units. However, coal bunker blockages have become a significant issue for coal mining companies, affecting the timely completion of production schedules and leading to increased production costs. Consequently, addressing and resolving the problem of coal bunker blockages is of great importance. One effective solution to this problem is the use of robots for cleaning coal bunkers, which can replace manual labor and tackle common challenges such as wall sticking and arching. Robot cleaning offers several key advantages. First, it ensures safe production by eliminating the risks associated with manual cleaning, such as exposure to hazardous conditions. Second, it reduces labor costs and increases the overall efficiency of coal mine operations. Third, robot cleaning provides a stable and continuous improvement in production efficiency, ensuring that coal mining operations are not hindered by coal bunker blockages. By automating the cleaning process, coal mines can achieve greater consistency in their production capacity, making it less susceptible to disruptions caused by blockage issues. The flexibility and adaptability of robots make them an ideal solution for cleaning coal bunkers. These robots can operate in confined spaces and efficiently clean coal bunker walls and clear blockages that may obstruct the flow of coal. Unlike manual labor, robot cleaning is not restricted by time, allowing it to perform tasks continuously and at any given moment, greatly enhancing overall work efficiency. Additionally, robot cleaning systems can monitor coal bunker conditions in real-time, providing timely data on blockages and enabling rapid responses to emerging issues. Another significant benefit of robot cleaning is its ability to provide precise monitoring of coal bunkers. With built-in sensors, robots can detect blockages or other issues within the bunker, identifying problems early on and taking corrective actions before they escalate into more serious challenges. This capability ensures the smooth operation of coal mining enterprises, preventing delays and disruptions in production. As a result, the use of robots for cleaning coal bunkers can contribute to maintaining a steady flow of coal, which is essential for meeting production targets. The research and application of robotic cleaning systems for coal bunkers carry substantial practical and economic benefits. By eliminating manual labor and reducing the risks associated with traditional cleaning methods, robots provide a safer and more efficient alternative. Moreover, the integration of automated cleaning systems can lead to significant cost savings for coal mining companies, while simultaneously enhancing productivity. With these advantages in mind, the continued development and implementation of robotic cleaning solutions in coal bunkers will likely play a crucial role in advancing the coal mining industry, ensuring smoother operations and greater long-term profitability. Furthermore, as technology advances, robotic cleaning systems

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for coal bunkers are expected to evolve, incorporating more sophisticated features such as AI-driven maintenance alerts and automated problem-solving capabilities. The future of coal mine operations could see even greater levels of automation, where robots not only clean but also perform diagnostic tasks and predict potential issues before they cause disruptions. This progression would contribute to a more resilient and efficient coal mining sector, paving the way for safer, more sustainable production methods. In conclusion, the use of robots for coal bunker cleaning presents a groundbreaking solution to the persistent issue of blockages, which can otherwise disrupt production schedules and increase operational costs. Through the continued research and development of these robotic systems, coal mining enterprises can experience significant improvements in safety, efficiency, and cost-effectiveness. This innovation marks an important step towards more advanced, automated coal mining practices, and it is clear that the future of the industry will be shaped by the growing role of robotics in maintaining smooth and uninterrupted production. The implementation of robotic systems in coal bunker cleaning not only ensures greater safety and efficiency but also reduces the environmental impact of coal mining operations. Traditional methods of cleaning coal bunkers often involve the use of harsh chemicals and manual labor, which can be both hazardous and environmentally damaging. By employing robots, coal mining companies can reduce the need for such chemicals and minimize the risks associated with human exposure to dangerous environments. Additionally, robots can be designed to operate with energy-efficient technologies, further contributing to the sustainability of the mining process. The adaptability of robotic cleaning systems also extends to their ability to handle a wide range of coal bunker types and sizes. Coal bunkers vary significantly in design, and the flexibility of robots allows them to clean both small, confined spaces and larger, more complex bunker configurations. This versatility makes robotic cleaning an ideal solution for diverse mining environments, ensuring that all coal bunkers, regardless of size or layout, can be efficiently cleaned. This adaptability also means that robotic systems can be scaled or modified to fit the specific needs of any coal mine, making them a long-term solution for improving production efficiency. Looking ahead, the role of robotics in the coal mining industry is set to expand further with the development of more advanced autonomous systems. These robots will be capable of performing not only cleaning tasks but also monitoring and inspecting the structural integrity of coal bunkers, identifying potential safety hazards, and conducting preventative maintenance. Such capabilities would enable coal mines to take a proactive approach to maintenance, minimizing downtime and maximizing productivity. The integration of robotics with AI and machine learning will also allow these systems to continuously improve their performance, adapt to changing conditions, and further reduce the reliance on human intervention, ultimately transforming the coal mining industry for the better. As the technology behind robotic systems continues to evolve, the potential for their integration with other advanced technologies, such as the Internet of Things (IoT) and data analytics, becomes increasingly promising. By equipping coal bunker cleaning robots with IoT sensors, real-time data can be gathered and transmitted to centralized control systems, providing continuous monitoring of the coal bunker's condition and the robot's performance. This data can be analyzed to predict potential issues before they arise, allowing for preemptive maintenance and further reducing operational downtime. The combination of robotics, IoT, and data analytics represents the next frontier in coal mining automation, offering unprecedented levels of efficiency, safety, and cost-effectiveness for the industry.

II. LITERATURE SURVEY

A) Design of Inspection Robot System for Mining Belt Conveyor - The mine belt conveyor patrol robot system provides a complete unattended patrol solution for the material transportation system. It has the core functions of unmanned patrol inspection of material transportation system, heating detection alarm of material transportation system components, noise identification, belt deviation identification, belt damage identification alarm, etc. The supporting centralized control software of the material transportation system can control the entire conveyor belt patrol robot group. In addition, it can collect and analyze a large amount of data on the conveyor belt system, and realize intelligent operation and maintenance of the material transportation system through artificial intelligence algorithms, including patrol inspection, parts detection and system alarm. The mining industry relies heavily on belt conveyor systems to transport materials efficiently across vast distances. These systems play a critical role in ensuring that the mining operations run smoothly, minimizing downtime, and optimizing productivity. However, due to the scale and complexity of these systems, traditional inspection and maintenance methods are often labor-intensive, time-consuming, and prone to human error. This can result in delayed identification of system faults, which may lead to increased downtime, safety hazards, and costly repairs. To address these challenges, the development of automated solutions like the patrol robot system for mining belt conveyors is becoming increasingly important. The patrol robot system for mining belt conveyors is designed to enhance the efficiency and reliability of conveyor belt operations by providing an unmanned, fully automated inspection process. The core functionality of this system includes the detection of

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heating in critical components of the conveyor, noise identification, belt deviation detection, and belt damage identification. By performing these tasks autonomously, the robot system can operate continuously, without the need for human presence in potentially hazardous environments. This reduces the risk to workers and ensures that inspections are carried out more frequently and thoroughly than traditional methods allow. The system is powered by advanced sensors and detection technologies that enable it to monitor the conveyor belt for any signs of wear and tear, misalignment, or other operational issues. By integrating noise and heating detection sensors, the robot is able to identify early warning signs of malfunction, which are often difficult to detect through visual inspections alone. Furthermore, the robot can detect belt deviation, which can lead to inefficient operation and even damage to the conveyor system if not addressed promptly. These capabilities ensure that potential issues are identified before they can escalate into serious problems, helping to prevent costly repairs and downtime. Centralized control software plays a key role in managing the robot system and ensuring that the conveyor belt system is efficiently monitored. The software not only enables operators to control the entire fleet of inspection robots, but it also collects and analyzes data from the robots to gain deeper insights into the overall health of the conveyor system. This data can be used to perform predictive maintenance, allowing for the identification of potential failures before they occur, and ensuring that the necessary repairs or replacements are made in a timely manner. The integration of artificial intelligence algorithms further enhances the system's capability to learn from the collected data, making the operation and maintenance of the conveyor system more intelligent and automated. In conclusion, the patrol robot system for mining belt conveyors represents a significant step forward in the automation of conveyor belt maintenance. By offering unmanned inspections, continuous monitoring, and real-time alerts, the system helps to improve safety, reduce operational costs, and enhance the overall performance of the material transportation system. The adoption of such technologies is crucial for the future of mining operations, where efficiency, safety, and sustainability are becoming increasingly important. The integration of AI and centralized control software further amplifies the impact of this technology, bringing us closer to fully automated and intelligent mining operations.

B) Design and Application of Control System for Underground Inspection Robot - Coal resources play an important role in China's energy structure. Using coal mine inspection robot to replace the traditional manual inspection operation has important application value for realizing coal mine intelligent production. Most of the existing control systems of coal mine inspection robot are bare metal program control, and few real-time operating systems with better real-time and stability are applied. In order to improve the performance of the inspection robot control system, a coal mine inspection robot control system based on QT and RT-Thread and the host computer of human-computer interaction interface are designed, which improves the real-time performance of the inspection robot and the ability to deal with concurrent tasks. The experimental results show that the control system is stable and reliable, and has good cross platform characteristics. The coal mining industry plays a pivotal role in China's energy structure, providing a significant portion of the nation's energy needs. However, coal mine inspections, which are crucial for ensuring safety and operational efficiency, have traditionally been performed manually. These inspections are often hazardous for workers and are prone to human error, which can lead to accidents or delayed identification of critical issues within the mine. The development of coal mine inspection robots is a transformative step toward increasing safety, improving operational efficiency, and reducing the risks associated with manual inspections in hazardous environments. In recent years, the use of robots for coal mine inspections has gained significant attention, as they can perform tasks that are both physically demanding and potentially dangerous for human workers. These robots are equipped with various sensors and tools to detect environmental conditions such as gas leaks, temperature changes, structural integrity issues, and other potential hazards. While traditional control systems for these robots have utilized bare-metal program controls, these systems often lack the necessary real-time performance and stability required for the complex and dynamic environment of an underground mine. This gap has limited the effectiveness and efficiency of coal mine inspection robots. To address these limitations, a more advanced control system is necessary—one that can improve the real-time responsiveness, stability, and multitasking abilities of the robot. This paper introduces a control system based on QT and RT-Thread, which are designed to enhance the robot's real-time capabilities and its ability to handle concurrent tasks efficiently. QT provides a powerful framework for developing human-computer interaction interfaces, enabling operators to easily monitor and control the robot remotely. RT-Thread, a real-time operating system, is used to handle the critical tasks of the robot, ensuring that operations such as sensor data collection, movement control, and hazard detection are performed with minimal delay and maximum reliability. The proposed system is designed to be both stable and versatile, ensuring that the inspection robot can operate in the challenging and often unpredictable conditions of an underground coal mine. The combination of QT for the human-computer interface and RT-

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Thread for task management allows for seamless communication between the robot and the operator, while also providing the robot with the computational power needed to perform complex inspections autonomously. The real-time capabilities of the system enable it to respond promptly to environmental changes, such as sudden fluctuations in temperature or gas concentration, which are critical for ensuring the safety of the mine. Experimental results have shown that the control system is both stable and reliable, with good cross-platform compatibility. The system's ability to manage concurrent tasks and respond in real time to the dynamic conditions of an underground environment has proven to be effective in improving the efficiency and safety of coal mine inspections. By replacing manual inspection processes with autonomous robots, the industry stands to gain from enhanced safety protocols, reduced human error, and the ability to conduct more frequent and comprehensive inspections. The integration of advanced control systems into coal mine inspection robots represents a significant step toward achieving smarter, safer, and more efficient coal mining operations.

C) Application of Roadway Deformation Detection Method Based on Machine Vision for Underground Patrol Robot - A set of track patrol robot system is designed for the problems of inadequate monitoring of underground coal mine equipment, the high labour intensity of patrol personnel, and roadway deformation. In addition to the automatic cruise mode, the system can collect and store the environmental data in the roadway in real-time, and can intelligently identify abnormal situations, especially through machine vision to monitor the deformation of the roadway in the coal mine, which ensures the safety of underground production and personnel. Underground coal mining operations are complex and inherently dangerous environments where ensuring the safety of workers and the structural integrity of the mine is of paramount importance. A significant challenge faced by coal mines is the deformation of roadways, which can lead to catastrophic accidents such as collapses or blockages. Traditionally, the monitoring of mine roadways and equipment has been carried out by human patrols, which are labor-intensive, time-consuming, and subject to human error. These limitations increase the risks for workers and hinder the ability to efficiently detect potential hazards in real time. To address these challenges, there is a growing interest in integrating automated technologies such as robotic systems into the monitoring and inspection process. Patrol robots equipped with advanced sensors and machine vision technologies offer a promising solution for reducing human labor, increasing the frequency and accuracy of inspections, and enhancing safety in underground mines. These robots can autonomously patrol the mine's roadways, collect environmental data, and identify abnormal situations, including the early signs of roadway deformation. Machine vision, in particular, enables robots to visually detect and monitor roadway deformations, providing a more precise and reliable method of inspection compared to traditional techniques. This paper introduces a roadway deformation detection method that utilizes machine vision to monitor the condition of underground mine roadways. The proposed system incorporates a track patrol robot designed specifically for underground coal mine environments. Equipped with an array of sensors and cameras, the robot continuously captures real-time data about the state of the roadways, including potential hazards like cracks, shifts, and other deformations. By employing machine vision algorithms, the robot can intelligently analyze the captured images, identify deformation patterns, and issue alerts when necessary, ensuring that abnormal conditions are detected promptly. In addition to its deformation detection capabilities, the robot operates in an automatic cruise mode, which allows it to navigate the mine independently. This feature minimizes the need for manual intervention, making the system more efficient and cost-effective. The robot can also store the environmental data it collects, creating a detailed log that can be analyzed later to monitor long-term trends in roadway health. This data collection process not only aids in identifying immediate hazards but also supports predictive maintenance strategies, helping to prevent future issues before they escalate. By leveraging advanced technologies such as machine vision and robotics, this patrol robot system offers a more effective and reliable approach to monitoring roadway conditions in underground coal mines. The ability to detect and address roadway deformations early can significantly reduce the risk of accidents and enhance the safety of mining operations. This paper outlines the design and functionality of the system, highlighting its potential to revolutionize underground patrol operations and contribute to the development of safer and more efficient coal mining practices. Through automation and intelligent monitoring, this system sets the stage for the future of coal mine safety and operational optimization.

BLOCK DIAGRAM

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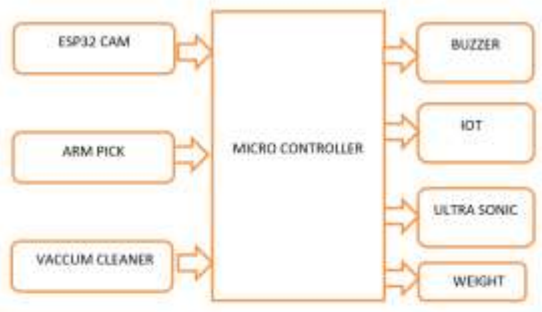

DESCRIPTION

POWER SUPPLY

A **regulated power supply** transforms unregulated AC (Alternating Current) into a stable DC (Direct Current). It guarantees consistent output despite variations in input. A regulated DC power supply is also known as a linear power supply, it is an embedded circuit and consists of various blocks

- **Regulated Power Supply Definition**: A regulated power supply ensures a consistent DC output by converting fluctuating AC input.
- **Component Overview**: The primary components of a regulated power supply include a transformer, rectifier, filter, and regulator, each crucial for maintaining steady DC output.
- **Rectification Explained**: The process involves diodes converting AC to DC, typically using full wave rectification to enhance efficiency.
- **Filter Function**: Filters, such as capacitor and LC types, smooth the DC output to reduce ripple and provide a stable voltage.
- **Regulation Mechanism**: Regulators adjust and stabilize output voltage to protect against input changes or load variations, essential for reliable power supply

SENSORS

Sensors are used for sensing things and devices etc. A device that provides a usable output in response to a specified measurement. The sensor attains a physical parameter and converts it into a signal suitable for processing (e.g. electrical, mechanical, optical) the characteristics of any device or material to detect the presence of a particular physical quantity. The output of the sensor is a signal which is converted to a human-readable form like changes in characteristics, changes in resistance, capacitance, impedance, etc

What is HC-SR04 Ultrasonic Sensor:

The HC-SR04 ultrasonic sensor includes a transmitter & a receiver. This sensor is used to find out the distance from the objective. Here the amount of time taken to transmit and receive the waves will decide the distance between the sensor and an object. This sensor uses sound waves by using non-contact technology. By using this sensor the distance which is required for the target can be measured without damage and provides accurate details. The range of this sensor available between 2cms to 400cms.

What is the HC-SR04 Ultrasonic Sensor?

The HC-SR04 is a type of ultrasonic sensor which uses sonar to find out the distance of the object from the sensor. It provides an outstanding range of non-contact detection with high accuracy & stable readings. It includes two modules like ultrasonic transmitter & receiver. This sensor is used in a variety of applications like measurement of direction and speed, burglar alarms, medical, sonar, humidifiers, wireless charging, non-destructive testing, and ultrasonography.

Fig: HCSR04-ultrasonic-sensor

Weight Sensor

Definition: A load cell or weight sensor is one kind of sensor otherwise a transducer. The **working principle of the weight sensor** depends on the conversion of a load into an electronic signal. The signal can be a change in voltage; current otherwise frequency based on the load as well as used circuit.

Theoretically, this sensor detects changes within a physical stimulus like force, pressure or weight and produces an output that is comparative to the physical stimulus. So, for a specific

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stable load otherwise weight size, this sensor provides an output value and that is comparative to the weight's magnitude. The best example of this sensor module is SEN0160.

Module – SEN0160

The SEN0160 weight sensor module is based on HX711 ADC; it is an accurate 24-bit ADC which is designed for industrial control as well as weighs scale applications to connect straight with a bridge sensor. Evaluated with other integrated circuits, this HX711 includes basic functions and also some features like a quick response, high integration, immunity, etc. This chip reduces the cost of electronic scale as well as improves the reliability and performance.

Fig: SEN0160-wireless-sensor-module

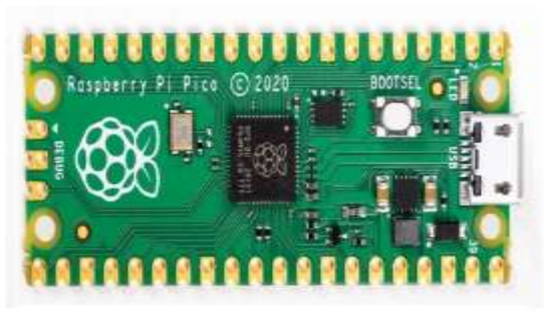
RPI –PICO

A Raspberry Pi Pico is a low-cost microcontroller device. Microcontrollers are tiny computers, but they tend to lack large volume storage and peripheral devices that you can plug in (for example, keyboards or monitors).

A Raspberry Pi Pico has GPIO pins, much like a Raspberry Pi computer, which means it can be used to control and receive input from a variety of electronic devices

Raspberry Pi Foundation is well known for its series of single-board computers (Raspberry Pi series). But in **January 2021 they launched their first micro-controller board known as Raspberry Pi Pico**.

It is built around **the RP2040 Soc, a very fast yet cost-effective microcontroller chip packed with a dual-core ARM Cortex-M0+ processor.** M0+ is one of the most power-efficient ARM processorRaspberry Pi PICO board



Raspberry Pi PICO board

Fig: Raspberry Pi Pico Board

Raspberry **Pi Pico is a small, fast, and versatile board that at its heart consists of RP2040**, a brand-new product launched by Raspberry Foundation in the UK. It can be programmed using MicroPython or C language.

DESCRIPTION

The challenge of coal bunker blockages is a persistent issue in coal mining operations, significantly affecting production schedules and increasing operational costs. These blockages, often caused by wall sticking or arching within the bunkers, hinder the smooth flow of coal, which is essential for maintaining steady production. Coal mining enterprises are constantly seeking solutions to address this problem efficiently and safely. One of the most promising solutions is the implementation of robotic cleaning systems, which offer a more effective and safe way to address coal bunker blockages compared to traditional manual cleaning methods. The design of coal bunker cleaning robots focuses on overcoming the unique challenges presented by narrow and confined spaces within coal bunkers. These robots are equipped with flexible and adaptive mechanisms that allow them to maneuver easily within tight spaces, cleaning the bunker walls and removing blockages that would otherwise be difficult to access. The robots' ability to operate autonomously makes them an ideal solution, as they can work continuously without the need for human intervention, thereby improving operational efficiency and reducing labor costs associated with manual cleaning. One of the key benefits of using robots for coal bunker cleaning is the enhanced safety they provide. Traditional cleaning methods often expose workers to hazardous environments, with risks such as falling debris, confined space exposure, and equipment malfunctions. By utilizing robots, these risks can be mitigated, ensuring that workers are not put in harm's way while still maintaining the necessary level of cleaning within the bunkers. Furthermore, robots can be designed with built-in safety features such as collision sensors and emergency stop mechanisms, further

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minimizing the risk of accidents. In addition to safety and efficiency, robotic cleaning systems also contribute to cost savings for coal mining companies. Robot-operated cleaning systems can be deployed at any time, ensuring that coal bunkers remain free from blockages without interrupting the mining process. This continuous operation leads to a more stable production environment, with fewer disruptions caused by coal bunker blockages. The reduction in labor costs and the avoidance of costly downtime further enhances the financial viability of robotic cleaning systems in coal mining operations. Another advantage of robotic cleaning is the ability to provide real-time monitoring and data collection. Equipped with high-precision sensors, coal bunker cleaning robots can detect the level of blockage and monitor the condition of the bunkers continuously. This data can be used to track performance, predict future issues, and make necessary adjustments to the cleaning process. The ability to monitor the condition of the bunkers also ensures that cleaning tasks are done efficiently, preventing over-cleaning or missed spots, which could lead to future blockages. Looking forward, the development and deployment of coal bunker cleaning robots have significant potential for the coal mining industry. These robots not only address the immediate challenges of coal bunker blockages but also pave the way for further advancements in automation and maintenance within mining operations. The integration of AI, machine learning, and IoT technologies will enhance the robots' capabilities, enabling them to perform predictive maintenance, detect structural issues within the bunkers, and adapt to changing conditions. With continued research and development, robotic cleaning systems will play an increasingly vital role in improving the safety, efficiency, and sustainability of the coal mining industry.

CONCLUSION

From the perspective of robotics technology, coal bunker cleaning robots are still in the early stages of development within the industrial robot field. These robots currently operate with semi-artificial intelligence, and their mobility remains fixed. However, from the standpoint of coal bunker cleaning itself, the integration of robotic technology has introduced innovative solutions for the coal industry. Given the high-risk nature of mining, where accidents occur frequently, the urgent need to adopt robotic technology in coal mines is clear. This approach not only addresses safety concerns but also acts as a crucial step towards high-end technological advancement in the industry. As technology continues to evolve, coal bunker cleaning robots are expected to progress from basic operational robots to more advanced programmed robots, eventually transitioning into fully intelligent systems. This transition will require ongoing improvements in the design, functionality, and integration of these robots to meet the ever-growing demands of coal mine operations. To achieve the ultimate goal of creating intelligent and unmanned coal mines, it is essential to continually enhance the institutional frameworks and methods for implementing coal bunker cleaning machines. By doing so, the development of more advanced, efficient, and autonomous robots will be realized, driving significant improvements in safety, productivity, and cost-effectiveness within the coal mining sector. Furthermore, the future of the coal industry will be shaped by these technological advancements, with the potential to transform traditional mining operations into highly automated, safer, and more sustainable processes.

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