Technical White Paper on Environmentally Friendly Intelligent Robot Automated Spraying System

With the continuous tightening of national environmental protection policies and the in-depth implementation of regulations such as the "Air Pollution Prevention and Control Law of the People's Republic of China" and the "Volatile Organic Compounds (VOCs) Pollution Prevention and Control Action Plan",environmental treatment in the industrial coating sector has become the core prerequisite for enterprise compliant production. Traditional manual spraying faces pain points such as severe coating waste,VOCs emission exceedance, low spraying efficiency, and uneven coating quality, making it difficult to meet the dual demands of modern industrial green production and efficient operations.

The Environmentally Friendly Intelligent Robot Automated Spraying System integrates industrial robot technology, intelligent control technology, and environmentally friendly coating processes.With "low VOC emissions, high coating utilization rate, no secondary pollution, high efficiency and precision" as its core advantages, it achieves automated, intelligent, and environmentally friendly spraying processes,completely solving environmental pain points and efficiency bottlenecks of traditional spraying. It has become the preferred solution for coating upgrades in environmental protection equipment,machinery manufacturing, hardware processing, construction machinery, and other industries.

This white paper systematically expounds on the technical principles, core structure, environmental advantages, core performance, selection logic,application scenarios, operation and maintenance specifications, and industry trends of the environmentally friendly intelligent robot automated spraying system. Combining GB/T26153.3-2015 "Offline Programming Robot FlexibleMachining Systems Part 3: Spraying Systems" and GB/T34701-2017 "Technical Specifications for Industrial Organic Waste Gas Treatment Engineering Using Catalytic Combustion" and other national and industry standards,it provides professional, accurate, and implementable technical references for enterprises in system selection, engineering support, environmental compliance, and cost optimization,helping enterprises achieve the

comprehensive goals of efficient coating, environmental compliance, cost reduction, and efficiency improvement.

I. Technical Principles and Core Environmental Value

1. Working Principles

The Environmentally Friendly Intelligent Robot Automated Spraying System uses industrial robots as the core execution unit, combined with intelligent control systems,environmentally friendly spraying equipment, and waste gas collection and treatment devices. Through preset programs or visual recognition technology, it achieves automated and precise spraying of workpiece surfaces.Its core workflow is: Workpiece positioning → Intelligent path planning → Environmentally friendly coating atomization → Precision spraying → Real-time waste gas collection → Purification and compliant exhaust,requiring no manual intervention throughout the process and achieving simultaneous spraying and environmental treatment.

The system optimizes spraying paths through intelligent algorithms, precisely controls spraying flow rate, spray gun distance, and spraying speed to reduce coating waste;with dedicated environmentally friendly coatings and efficient waste gas treatment devices, it collects and purifies VOCs, paint mist, and other pollutants generated during spraying in real time,ensuring emissions comply with national environmental standards and achieving green environmental protection at the source.

2. Core Environmental Value

Compared with traditional manual spraying, the core advantages of the environmentally friendly intelligent robot automated spraying system are concentrated in three dimensions: environmental protection,high efficiency, and energy saving, perfectly adapting to the green development needs of the environmental protection equipment industry. In terms of environmental treatment, the systemcan achieve VOCs emission concentration ≤30mg/m³, far below the national emission limits. Through precision spraying, coating waste is reduced, and coating utilization rate increases to above 85%,saving more than 40% of coating compared to traditional manual spraying, reducing pollutant generation at the source.

The system is equipped with fully enclosed negative pressure pipelines and efficient waste gas treatment devices. Paint mist and VOCs generated during spraying are collected in real time and treated through multi-stage treatment includingdry filtration, zeolite rotor enrichment, and catalytic combustion. Waste gas collection rate reaches above 98%, with no paint mist dispersion or waste gas leakage, completely solving the environmental pain point of "spray the paint,waste gas escapes" in traditional spraying. Additionally, the system operates with no noise pollution, with operating noise ≤65dB, adapting to various indoor and outdoor environmental coating scenarios and avoiding impacts on the surrounding environment and operators.

In terms of energy saving and cost reduction, the system achieves automated operations and can replace 5-8 workers, significantly reducing labor costs and environmental risks from manual operations;intelligent regulation of spraying parameters reduces energy consumption, saving more than 25% energy compared to traditional spraying equipment, and can significantly reduce enterprise operating costs over long-term operation.Furthermore, the system has high spraying precision with uniform coating quality, reducing defect rate from 5.2% for manual work to 0.8%, reducing coating and energy waste from rework,further improving environmental and economic benefits.

II. Core Structure and Key Component Analysis

1. Overall Structure

The Environmentally Friendly Intelligent Robot Automated Spraying System consists of five core parts: intelligent robot unit, environmentally friendly spraying unit,intelligent control unit, waste gas collection and treatment unit, and workpiece positioning and conveying unit. All units work collaboratively to achieve automated, intelligent, and environmentally friendly spraying processes.The system has a compact structure and reasonable layout, with flexible installation design schemes based on enterprise production sites and coating needs, adapting to coating requirements for different sizes and types of environmental protection equipment.

2. Key Component Analysis

The intelligent robot unit is the core execution component of the system, using a six-axis industrial robot with advantages of high flexibility, precise positioning, and stable operation.Repeat positioning accuracy ≤±0.05mm, achieving comprehensive, no-blind-spot spraying of complex curved surfaces and special-shaped structures of environmental protection equipment.The robot is equipped with explosion-proof design, complying with GB/T38361-2021 explosion-proof standards, with protection level reaching IP66/IP68,adapting to various types of environmentally friendly coating spraying scenarios such as solvent-based and water-based coatings, and avoiding safety hazards caused by coating volatile substances.Some high-end models use seven-degree-of-freedom rigid-flexible coupled robotic arms to further improve spraying coverage of complex workpieces and ensure uniform and consistent coatings.

The environmentally friendly spraying unit is key to achieving environmental coating, including environmentally friendly spray guns, coating supply systems, and atomization devices.Environmentally friendly spray guns use low-pressure electrostatic atomization technology to atomize coatings into fine particles, evenly adhering to workpiece surfaces, reducing paint mist generation and coating waste;the coating supply system uses closed-loop control, precisely controlling spraying flow rate and automatically adjusting based on workpiece size and spraying requirements.Spraying flow rate can be flexibly adjusted within the range of 30-500ml/min to avoid over-spraying and missed spraying. Atomization devices with air-assisted atomization technology further improve atomization effect,ensuring coating thickness error ≤±5μm while reducing VOCs volatilization.

The intelligent control unit is the "brain" of the system, consisting of controllers, touch screens, visual recognition systems, and offline programming software.Controllers use industrial-grade PLCs supporting multi-equipment coordinated control, with preset multiple spraying programs adapting to different specification workpiece spraying needs;visual recognition systems use 3D vision cameras and LiDAR to scan workpiece contours in real time, automatically generating optimal spraying paths.Collision detection coverage increases to above 96%, eliminating the need for manual teaching and greatly improving operation efficiency.

Offline programming software supports 3D model import and path simulation,allowing pre-view of spraying effects to avoid process blind spots and reduce debugging time.

The waste gas collection and treatment unit is the core guarantee of the system's environmental performance and the key component adapting to the environmental protection equipment industry,consisting of collection hoods, pipes, dry filter cotton, activated carbon adsorption devices, and catalytic combustion devices. Collection hoods use fully enclosed design to comprehensively collect paint mist and VOCs generated during spraying,avoiding leakage; dry filter cotton filters paint mist particles with filtration efficiency ≥99%; activated carbon adsorption devices adsorb VOCs with adsorption efficiency ≥95%;O, with no secondary pollution, VOCs removal rate ≥90%, ensuring compliant waste gas exhaust. Some systems are equipped with zeolite rotor enrichment devices to further improve VOCs treatment efficiency,$_2$ $_2$ achieving efficient treatment of low-concentration VOCs.

The workpiece positioning and conveying unit is responsible for automatic workpiece conveying and precise positioning, using belt conveyor lines or turntable conveying tables.Positioning accuracy ≤±0.1mm, achieving continuous spraying operations of workpieces and improving production efficiency. The conveying unit operates in coordination with robots and control systems,achieving full-process automation from workpiece positioning, spraying, to discharge, eliminating manual handling, reducing errors and environmental risks from manual intervention.

III. Core Performance Indicators

The performance indicators of the environmentally friendly intelligent robot automated spraying system directly determine its environmental effects, spraying quality, and operational efficiency.All indicators comply with national and industry-related standards, adapting to coating needs of the environmental protection equipment industry.In terms of environmental indicators, VOCs emission concentration ≤30mg/m³, complying with GB16297-1996 "Integrated Emission Standards for Air Pollutants";paint mist collection rate ≥98%, VOCs removal rate ≥90%, coating utilization rate ≥85%, saving more than 40% coating compared to traditional manual spraying reducing pollutant generation at the source.

In terms of spraying precision, robot repeat positioning accuracy ≤±0.05mm, spraying trajectory accuracy ≤±0.1mm, coating thickness uniformity ≤±5μm,coating adhesion reaches Grade 1 standard specified in GB/T9286-1998, with no defects such as sagging, missed spraying, or pinholes, meeting high-precision coating requirements for environmental protection equipment housings and components.In terms of spraying efficiency, a single robot can spray 50-200 workpieces per hour (adjusted according to workpiece size), improving efficiency 3-5 times compared to manual spraying,and can achieve continuous 24-hour operation, greatly improving production efficiency.

In terms of operating performance, system operating noise ≤65dB, complying with industrial enterprise noise emission standards;robot working radius can reach 1.2-2.5m, adapting to spraying of environmental protection equipment of different sizes; strong coating adaptability, compatible with various environmentally friendly coatings such as water-based coatings,powder coatings, and high-solid coatings, meeting coating scenarios with different environmental requirements. Overall system service life ≥8000 hours, core components (robots, controllers, waste gas treatment devices) service life ≥15000 hours,failure rate ≤1%, stable and reliable operation, reducing operation and maintenance costs.

In terms of safety and environmental protection, the system has multiple safety protection functions such as explosion-proof, leakage protection, overload, and emergency stop,complying with GB3836 series explosion-proof standards, grounding resistance ≤4Ω, avoiding safety hazards caused by static electricity; waste gas treatment devices comply with GB/T34701-2017 standards, with no secondary pollution;equipment surfaces use environmentally friendly materials with no harmful substance volatilization, complying with green production requirements.

IV. Product Classification and Applicable Scenarios

The environmentally friendly intelligent robot automated spraying system can be classified into three categories based on spraying method, robot model, and application scenarios,all adapting to coating needs of the environmental protection equipment industry and can be flexibly selected based on specific enterprise working conditions.

Electrostatic environmentally friendly spraying robot system, using low-pressure electrostatic spraying technology as its core, with high coating utilization rate and low VOCs emissions,suitable for large-area, regular-shaped workpiece spraying such as environmental protection equipment housings, boxes, and components, such as waste gas treatment equipment housings and sewage treatment equipment tanks.This system has good spraying uniformity and strong coating adhesion, effectively improving workpiece anti-corrosion and rust prevention performance while greatly reducing coating waste and VOCs emissions,making it the most commonly used model in the environmental protection equipment industry.

Flexible intelligent spraying robot system, using multi-axis robots and visual recognition technology, can adapt to complex curved surface and special-shaped structure workpiece spraying,such as environmental protection fan impellers, special-shaped environmental protection pipes, and precision environmental protection instrument components.This system has flexible path planning capability, can automatically identify workpiece contours, achieve comprehensive no-blind-spot spraying, with high spraying precision,meeting coating requirements for high-precision environmental protection equipment components while maintaining excellent environmental performance.

Integrated environmental spraying production line, consisting of multiple robots, conveyor lines, waste gas treatment systems, and drying systems,achieving full-process automation from workpiece loading, positioning, spraying, drying, to discharge. Suitable for large-scale, standardized batch coating of environmental protection equipment,such as batch-produced environmental protection filters and purification equipment housings. This production line can achieve simultaneous multi-workpiece spraying, with high efficiency and environmental compliance,greatly reducing labor costs and improving production standardization level, adapting to large-scale production needs of environmental protection equipment enterprises.

Additionally, the system can be widely applied in environmental protection equipment, machinery manufacturing, hardware processing, construction machinery,automobile components, and other industries, especially adapting to scenarios with strict environmental requirements such as dust-free workshops and

environmental protection equipment production workshops,achieving efficient, environmentally friendly, and precise coating operations and helping enterprises achieve environmental compliance and production upgrades.

V. Selection Logic and Adaptation Principles

Selection of the environmentally friendly intelligent robot automated spraying system requires comprehensive consideration of factors such as enterprise environmental requirements, production scale,workpiece specifications, and coating needs, following principles of "environmental compliance, precision adaptation, economic rationality, and high efficiency energy saving"to avoid environmental non-compliance, low efficiency, and cost waste problems caused by selection errors.

Selection by environmental requirements is the core prerequisite. For regions or industries with strict VOCs emission control, priority should be given to systems equipped with catalytic combustion + activated carbon adsorption dual waste gas treatment devices,ensuring VOCs emission concentration ≤30mg/m³ and meeting local environmental standards; for scenarios requiring no paint mist pollution, select enclosed spraying systems with efficient dry filtration devices,ensuring paint mist collection rate ≥98%. Simultaneously, select appropriate spraying systems based on coating types - water-based coatings should prioritize low-pressure atomization spraying systems,and powder coatings should select electrostatic powder spraying systems to further improve environmental effects.

Selection by workpiece specifications: for regular-shaped, large-area workpieces (such as environmental protection equipment housings and boxes), select electrostatic environmentally friendly spraying robot systems with high efficiency and uniform spraying;for complex curved surfaces and special-shaped workpieces (such as fan impellers and special-shaped pipes), select flexible intelligent spraying robot systems equipped with visual recognition and path planning functions to ensure no-blind-spot spraying;for small-batch, multi-specification workpieces, select flexible models that can quickly switch programs to improve adaptability; for large-batch, standardized workpieces,select integrated environmental spraying production lines to achieve full-process automation and improve production efficiency.

Selection by production scale: small enterprises with small-batch production, select single-robot spraying systems with lower cost and flexibility;medium-sized enterprises with medium-batch production, select 2-3 robot linkage systems balancing efficiency and cost; large enterprises with large-scale production,select integrated spraying production lines to achieve large-scale, standardized production and reduce long-term operating costs.

Additionally, system compatibility, operation and maintenance convenience, and after-sales service should also be considered during selection.

Prioritize systems that can be compatible with multiple coatings and support remote debugging and operation and maintenance to reduce later operation and maintenance costs;simultaneously select suppliers with professional after-sales service teams to ensure timely response and quick repairs when equipment failures occur, ensuring production continuity.

VII. Installation, Commissioning, and Operation and Maintenance Specifications

Correct installation, standardized commissioning, and scientific operation and maintenance are key to ensuring efficient, stable, and environmentally friendly operation of the environmentally friendly intelligent robot automated spraying system.Strictly follow relevant specifications to avoid equipment damage, environmental non-compliance, and safety accidents caused by improper operations.

During installation, select flat, firm, and well-ventilated sites, away from flammable and explosive materials, ensuring equipment is placed stably without tilting or shaking;before installation, check if all components are intact, connections are secure, electrical wiring is standardized, and pipe connections of waste gas treatment devices are sealed to avoid waste gas leakage;installation positions of robots, conveyor lines, and waste gas treatment devices should be reasonable to ensure unobstructed spraying paths and no blind spots in waste gas collection;after installation, clean site debris and check system sealing performance to ensure no paint mist or waste gas leakage.

During commissioning, first conduct no-load trial operation to check robot operation trajectories, spraying parameters, and waste gas treatment device operation status,ensuring all components operate normally with no abnormal noise or leakage; after no-load trial operation is normal, conduct trial spraying, use environmentally friendly coatings consistent with actual production,adjust spraying flow rate, spray gun distance, spraying speed, and other parameters, test coating thickness, uniformity, and adhesion to ensure compliance with standards;simultaneously test waste gas treatment effects and check VOCs emission concentration, ensuring compliance before entering formal operation.During commissioning, optimize spraying paths simultaneously to reduce coating waste and VOCs emissions.

For daily operation and maintenance, establish comprehensive operation and maintenance records documenting equipment operation status, maintenance content, and fault situations.Before daily operations, check robot joints, spray guns, and coating supply systems to ensure no blockage or leakage; check filter cotton and activated carbon in waste gas treatment devices,and replace promptly if blockage or adsorption saturation occurs; check electrical wiring and safety protection devices to ensure normal operation. After operations,clean residual coatings inside spray guns and pipes to avoid curing blockage; clean filter impurities in waste gas treatment devices to keep equipment unobstructed; turn off power and air sources and perform equipment cleaning.

For periodic maintenance, lubricate robot joints weekly and check conveyor line operation status, adjusting tightness; monthly check coating supply system sealing and calibrate spraying parameters and positioning accuracy;replace waste gas treatment device filter cotton and activated carbon every 3-6 months and check catalytic combustion device operation status; annually conduct comprehensive system inspection,test core component performance, and promptly replace aging components to ensure long-term stable system operation. For fault handling, when equipment cannot start, abnormal spraying, or waste gas emission exceedance occurs,stop the machine promptly for inspection and contact professional personnel for repair, strictly prohibiting unauthorized disassembly of equipment.

VIII. Typical Industry Application Solutions

Environmental protection equipment housing coating solution: for housing coating needs of waste gas treatment equipment, sewage treatment equipment, environmental protection fans, and other products,adopt electrostatic environmentally friendly intelligent robot spraying system, paired with water-based environmentally friendly coatings and activated carbon adsorption + catalytic combustion waste gas treatment devices.This solution achieves comprehensive uniform coating of housings with uniform coating thickness, strong adhesion, and excellent anti-corrosion and rust prevention performance; coating utilization rate ≥85%,VOCs emission concentration ≤25mg/m³, far below national emission standards; a single robot can spray 30-50 housings per hour, improving efficiency more than 3 times compared to manual spraying,greatly reducing labor costs and environmental risks, adapting to batch production needs of environmental protection equipment enterprises.

Environmental protection equipment precision component coating solution: for complex workpiece coating needs such as environmental protection instrument components, fan impellers, and special-shaped pipes,adopt flexible intelligent spraying robot system equipped with visual recognition and path planning functions, paired with high-solid environmentally friendly coatings.This solution can automatically identify workpiece contours, generate optimal spraying paths, achieve no-blind-spot spraying of complex curved surfaces, with high spraying precision and coating thickness error ≤±3μm,meeting coating requirements for precision components; waste gas collection rate ≥98%, VOCs removal rate ≥92%, ensuring environmental compliance while reducing coating waste and improving product quality.

Environmental protection equipment large-scale coating solution: for large-scale production needs of environmental protection equipment enterprises, adopt integrated environmental spraying production line consisting of 3-5 robots,automatic conveyor lines, drying systems, and waste gas treatment systems, achieving full-process automation from workpiece loading, positioning, spraying, drying, to discharge.This solution can achieve simultaneous multi-workpiece spraying, processing 100-200 workpieces per hour, greatly improving production efficiency; the system uses closed-loop control with unified spraying parameters and standardized coating quality;waste gas is collected and treated centrally, with VOCs emission concentration ≤20mg/m³,

complying with ultra-low emission requirements while greatly reducing labor costs and achieving large-scale, green production.

IX. Technical Development Trends

With the continuous tightening of environmental policies and the continuous upgrading of industrial intelligence, the environmentally friendly intelligent robot automated spraying system will develop towards being more environmentally friendly,more intelligent, more efficient, and more customized, further adapting to the green production needs of the environmental protection equipment industry.

Continuous upgrading of environmental performance is the core trend. Future systems will adopt more efficient waste gas treatment technologies, integrating advanced processes such as zeolite rotor enrichmentand low-temperature plasma to achieve near-zero VOCs emissions; simultaneously, promoting environmentally friendly coatings such as water-based coatings and powder coatings to further reduce pollutant generation;coating recovery technologies will be continuously optimized. Through high-voltage electrostatic fields to capture scattered paint mist and separate for reuse, coating utilization rate will increase to above 90%,achieving resource recycling.

Continuous improvement of intelligence level: AI visual recognition, big data analysis, and IoT technologies will be widely applied in systems to achieve functions such as automatic workpiece identification,autonomous spraying path optimization, real-time fault early warning, and remote operation and maintenance; robots will have more flexible motion capabilities to adapt to more complex workpiece spraying;offline programming and digital twin technologies will further proliferate, allowing pre-simulation of spraying processes to optimize parameters, reduce debugging time, and improve operation efficiency.

Obvious trends in high efficiency and energy saving: systems will adopt more efficient motors, atomization devices, and control systems to reduce energy consumption;robot motion trajectory optimization technology will continuously improve, shortening spraying paths and enhancing spraying efficiency; simultaneously, through intelligent regulation of spraying parameters,reducing

coating waste and energy consumption, achieving more efficient energy-saving effects and helping enterprises achieve "dual carbon" goals.

Growth in customization and integration needs: for different types and specifications of environmental protection equipment, personalized spraying system solutions will be provided to achieve"one machine, one working condition" precision adaptation; integrated spraying production lines will be further upgraded to achieve full-process integration of spraying, drying, waste gas treatment,and inspection, improving production automation level; simultaneously, systems will be linked with enterprise ERP and MES systems to achieve real-time monitoring and intelligent scheduling of production data,integrating into intelligent manufacturing systems.

X. Conclusion

The environmentally friendly intelligent robot automated spraying system is the core equipment for practicing green development concepts and achieving environmental compliance in the industrial coating field,and is also a key support for the upgrade and transformation of the environmental protection equipment industry. Integrating intelligent robot technology and environmental coating processes,it completely solves environmental pain points and efficiency bottlenecks of traditional spraying, achieving automated, intelligent, and environmentally friendly spraying processes,meeting enterprise demands for efficient production while ensuring environmental compliance, providing strong guarantees for enterprises to reduce costs, increase efficiency, and achieve green development.

This white paper systematically expounds on the technical principles, core structure, performance indicators, selection logic, operation and maintenance specifications, and industry applicationsof the environmentally friendly intelligent robot automated spraying system. Combining the latest national standards and industry trends, it provides enterprises with full-process technical references.