Manipulator and Robotic Arm

Product Overview

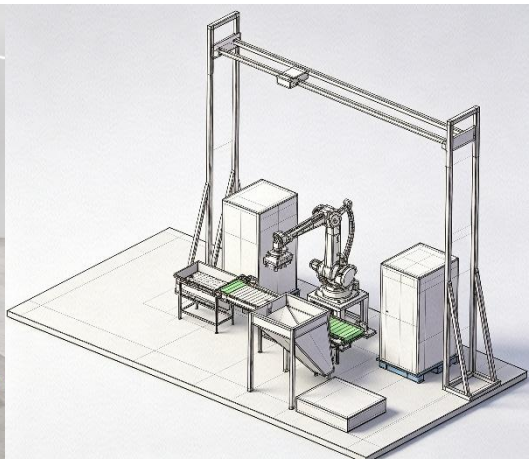
Palletizing robots are industrial automation devices designed to replace manual labor in the handling and palletizing of bagged, boxed, bottled, and drummed materials. The robots utilize a robotic control system to achieve point-to-point linear interpolation, ensuring smooth and fluid motion; the teach pendant features key-controlled display, and palletizing patterns can be preset, flexibly added, or modified. The equipment is widely applicable to the palletizing needs of finished products—including cartons, bags, cans, boxes, and bottles—in industries such as feed, chemicals, food, beverages, beer, plastics, and refractory materials. It helps enterprises shed the label of “labor-intensive” and liberate workers through automation.











QINGDAO QUANHANG MACHINERY CO., LTD

Technical Specifications

Palletizing Robot

Palletizing Capacity	600 – 1,200 bags/hour
Number of Pallet Layers	Floors 1 – 10
Repeatability	High Precision (Closed-Loop Dynamic Control)
Air Supply	0.4 – 0.6 MPa
Power Supply	380 VAC, 50 Hz ±10%
Power Consumption	Up to 12 KVA
Pallet Diameter	4.8 – 6.4 m

Small Robotic Arm

Degrees of freedom	4-axis
Payload	50 / 100 kg
Maximum Operating Radius	2,400 mm
Repeatability	±0.1 mm
Power	8.75 kW
S-axis Travel Range	±330°
L-axis Travel Range	110°, +30°
U-axis Travel Range	-30°, +110°
T-axis Travel Range	±360°

Collaborative Robots

Safety	Industrial-grade force sensors; 10-level collision detection; 16 safety I/O ports
Deployment	Integrated design, lightweight and flexible, compact footprint; quick and easy setup for new tasks
Programming	Visual programming, no specialized programming language required; get started in 0.5 hours, complete simple programming in 1 hour
Flexibility	Supports human-robot, two-robot, and multi-robot collaboration; quick switching between multiple scenarios
Cost-Effectiveness	Average return on investment within 6 – 12 months
Applicable Industries	Food, pharmaceuticals, 3C, personal care, e-commerce

Key Benefits and Features of the Product

High precision, high efficiency

High-precision robot arm + gear reducer + optimized closed-loop dynamic control; low weight reduces cycle time.

Easy Integration

This Windows-based control technology is easy to install, program, and commission, and can be integrated into any production line.

Compact size, high reliability

Compact design; picks up and stacks items at any location within the working range; completes both packaging and palletizing in a single operation.

Tailor-made, 24-hour operation

With proper planning, operations can proceed continuously without interruption, and there will be no work slowdowns.

Working closely with the assembly line

Works in coordination with forklifts, conveyors, and balers to meet cycle time and interval requirements.

青岛铨航机械设备有限公司
Qingdao Quanhang Machinery Co., Ltd

Applications

Feed / Fertilizer / Recycled Pellet Plants: High-speed palletizing of bagged materials to address labor shortages and harsh working conditions.

Food / Beverage / Brewery: Automated case packing and palletizing of finished products in cartons, bottles, and cans.

Chemicals / Building Materials / Refractory Materials: Ensuring personal safety in hazardous or physically demanding environments.

Compatible Packaging Types: Cartons, plastic crates, bottles, bags, drums, boxes, and other packaging formats.

Palletizing and handling of lightweight bagged or boxed materials

Machine tool loading/unloading, assembly, and sorting

Clean or compact production lines in the food, personal care, and electronics industries

Food / Pharmaceuticals: Sorting, packaging, and loading/unloading, meeting cleanliness and compliance requirements.

3C Electronics: Precision assembly, testing, and flexible production lines.

Consumer Goods / E-commerce: Picking, palletizing, and packing, handling order fluctuations.





Qingdao Quanhang Machinery Co., Ltd

Why Choose Us?

Expert Technical Team: Over 10 years of experience in R&D of mixing equipment, providing customized solutions

Quality Assurance: Rigorous quality control system; ISO 9001-certified company

After-Sales Service: Global service network, 24-hour response, and lifetime technical support

Success Stories: Serving over 500 companies across more than 20 countries and regions

Customer Testimonial

1.

★★★★★ Purchasing Manager, a cement plant (Saudi Arabia)

We are very satisfied with this big bag packaging machine. Not only does it meet our production needs, but it has also significantly improved our work efficiency. In addition, we were deeply impressed by the high-quality after-sales service provided.

2.

★★★★ Plant Engineer, a mortar manufacturing plant (Vietnam)

Equipment failures are inevitable—no one can predict them—but your after-sales service and response time were both very prompt, allowing us to quickly resolve the issue and get the equipment back up and running. You definitely deserve a thumbs-up.

3.

★★★★★ Project Manager, a mortar manufacturing company (Russia)

The automated bagging and palletizing line has completely transformed our end-of-line operations. We've reduced manual labor by 4 workers per shift, and the palletizing robot builds stable, uniform pallets every time. Labor flexibility has been far greater than we expected.

青岛铨航机械设备有限公司
Qingdao Quanhang Machinery Co., Ltd

FAQ

1.

Q: What is the minimum order quantity for your products?

A: For larger equipment such as mixers, our minimum order quantity is one unit; for smaller products such as valves and fittings, the minimum order quantity ranges from 50 to 100 pieces. Please contact our sales representatives to confirm the specific minimum order quantity.

2.

Q: From which port do you ship?

A: Since our company is located in Qingdao, most of our shipments depart from the Port of Qingdao.

3.

Q: Are you a factory or a trading company?

A: We are a manufacturing company with our own factory; all our equipment is produced in our factory's production lines.

4.

Q: Aside from equipment sold separately, do you offer design, manufacturing, and installation services for complete production lines?

A: Yes. We have customers in over 20 countries worldwide who use production lines that we have designed, manufactured, and installed.

5.

Q: What is a ton-bag packaging machine? How does it differ from a standard small-bag packaging machine?

A: A ton-bag packaging machine is a high-precision weighing and filling device specifically designed for large-capacity flexible intermediate bulk containers (ton bags/FIBCs, with capacities ranging from 500 to 2,000 kg). Compared to small-bag packaging machines for valve bags and open-mouth bags, the key differences are a larger weighing system (ton-class), a wider filling spout, and a slower cycle time—yet extremely high per-bag output. It is suitable for the containerized packaging of bulk materials, rather than retail packaging in small bags.

青岛铨航机械设备有限公司
Qingdao Quanhang Machinery Co., Ltd

6.

Q: What types of materials are suitable for ton-bag packaging machines?

A: They are suitable for free-flowing powders, granules, and small chunks of material, such as cement, fly ash, titanium dioxide, calcium carbonate, chemical fertilizers, animal feed, grain, resin pellets, mineral powder, salt, and sugar. For materials prone to generating dust, we recommend installing a dust collection interface; for ultra-fine, lightweight powders, models with negative pressure or air-float feeding systems are available.

7.

Q: How many people are needed to operate a ton-bag packaging machine?

A: Semi-automatic models require 1 person to load and unload bags; fully automatic models (with automatic bag loading, conveyor, and palletizing) can operate unattended, requiring only periodic inspections. Recommended production line configuration: 1 operator who also performs inspections is sufficient to cover the entire line.

8.

Q: Can the dust collection and environmental protection requirements for the ton-bag packaging machine be met?

A: The machine can be equipped as standard with a pulse-jet dust collection interface or an integrated dust hood that connects to the customer's central dust collection system, allowing dust concentrations at the workstation to be kept within national standard limits. For materials that generate high levels of dust (such as cement and fly ash), we recommend selecting negative-pressure filling combined with a fully enclosed bag-clamping mechanism to ensure a more reliable environmental compliance inspection.

9.

Q: Can a ton-bag packaging machine be integrated with a robotic palletizing line?

A: Yes. Standard interfaces support integration with conveyors, metal detectors, robotic palletizers, and in-line stretch wrapping to form a fully automated ton-bag packaging and palletizing line. Through unified control via a PLC bus (Modbus/Profinet), the system achieves unmanned operation from filling to palletizing and shipment.

青岛启航机械设备有限公司
Qingdao Quanhang Machinery Co., Ltd

10.

Q: What is a valve-mouth packaging machine? What is the difference between valve-mouth bags and open-mouth bags?

A: A valve-mouth packaging machine is an automatic filling device that forces material into a bag through a "valve opening" at the bottom or side of the bag. Valve-mouth bags come with a preformed valve opening that automatically closes after filling, eliminating the need for sewing or heat sealing. This results in a neat seal and minimal powder spillage. Open-mouth bags, on the other hand, require separate sewing or heat sealing, which is slower and generates more dust. Valve-mouth machines are better suited for high-speed automatic packaging of powdered materials.

11.

Q: What types of valve-mouth packaging machines are available? How should I choose one?

A: There are four main categories, each suited for different materials:

Impeller-type: Granules/coarse powders; high-speed operation; relies on forced feeding by an impeller;

Pneumatic-floating-type: Powders with poor flowability or prone to bridging; relies on fluidization;

Vacuum-suction type: Ultra-fine, lightweight powders (such as titanium dioxide and carbon black); relies on negative pressure suction to prevent powder loss;

Multi-stream pneumatic conveying: Medium- to fine powders, dilute-phase pneumatic conveying, low breakage. The key factors for selection are the material's particle size, density, flowability, and susceptibility to breakage.

12.

Q: What is the applicable weight range for valve-mouth bagging machines?

A: Common valve-mouth bag sizes are 5 kg, 10 kg, 20 kg, 25 kg, and 50 kg, with 25 kg and 50 kg being the most common for industrial packaging. Custom configurations can accommodate weights ranging from 1 kg to 50 kg. For smaller sizes (≤5 kg), we recommend evaluating the machine's accuracy and feeding method.

青岛铨航机械设备有限公司
Qingdao Quanhang Machinery Co., Ltd

13.

Q: How do I choose between a valve-mouth packaging machine and a ton-bag packaging machine?

A: It depends on the individual bag specifications and intended use: For bags weighing ≤50 kg intended for retail or small-volume applications, use a valve-mouth packaging machine (high-speed, automatic sealing); for bulk packaging ranging from 500 kg to 2,000 kg, use a ton-bag packaging machine (ton-level weighing, bulk packaging). The two are often used in conjunction: the valve-mouth machine produces smaller packages, the ton-bag machine produces larger packages, or they share a common downstream palletizing line.

14.

Q: Does a valve-mouth packaging machine require an automatic bagging machine?

A: Manual bagging is sufficient for operation; however, when production capacity is ≥600 bags per hour or when labor is in short supply, we recommend using a fully

automatic valve-mouth bagging machine, which can save 1–2 operators, improve stability, and reduce powder spillage.

15.

Q: What types of materials can a valve-type packaging machine handle?

A: It can handle virtually all powdered and granular materials, including cement, dry-mix mortar, joint compound, calcium carbonate, titanium dioxide, talc, chemical fertilizers, animal feed, flour, resin powder, activated carbon, and mineral powder, covering industries such as building materials, chemicals, food, animal feed, and metallurgy.

16.

Q: Is daily maintenance of a valve-type bagging machine difficult? What are the wear parts?

A: Maintenance requirements are minimal. The main wear parts are the bag-clamping O-rings, seals, impellers/screw blades, filter elements, and sensor calibration. We recommend cleaning the dust from the machine after each shift, lubricating it monthly, and periodically calibrating the weighing system. Annual maintenance costs are typically less than 3% of the equipment's price.

17.

青岛铨航机械设备有限公司
Qingdao Quanhang Machinery Co., Ltd

Q: Can a valve-mouth packaging machine be integrated with a palletizing system and stretch wrapping to form a complete production line?

A: Yes. Valve-mouth packaging machine + automatic bagging + conveyor + robotic palletizer + in-line stretch wrapping = a fully automatic valve-mouth packaging and palletizing line, which is the mainstream complete-line solution for building materials and chemical powder manufacturing plants.

18.

Q: What is a vacuum-sealed valve-mouth packaging machine?

A: It is a valve-mouth packaging machine that creates a vacuum inside the valve-mouth bag during the filling process and uses the negative pressure inside the bag to draw powdered material into it. Unlike positive-pressure filling, the material is "drawn" into the bag rather than "blown" or "pushed" in, making it particularly suitable for ultra-fine, lightweight powders and minimizing dust and residual air inside the bag.

19.

Q: Why is it necessary to evacuate the air from valve bags? Can't we just skip this step?

A: For ultra-fine, lightweight powders (e.g., <10 µm), standard positive-pressure or centrifugal filling methods can cause significant dust dispersion, result in "false bulging" due to air trapped inside the bag, and lead to powder leakage from the seal. Evacuating the air completely removes all air from the bag, compacts the material, and prevents powder leakage, ensuring accurate weighing and neat packaging. This is an essential process for handling such materials.

20.

Q: What types of materials are suitable for packaging with a vacuum-sealed packaging machine with a negative pressure valve?

A: For example: carbon black, titanium dioxide, light calcium carbonate, fumed silica, pigments, dyes, milk powder, protein powder, ultrafine talc, ultrafine cement admixtures, and other powders that are low in density, have a fine particle size, and are prone to airborne dispersion.

21.

Q: What is the packaging accuracy of a vacuum-sealed negative-pressure valve-type packaging machine?

A: Because the negative-pressure suction is smooth and free of pneumatic shock, the accuracy can reach ±0.2%–0.3% (e.g., ±50g–75g for 25 kg), which is superior to most pneumatic models and suitable for the precise measurement of high-value, ultra-fine powders.

青岛启航机械设备有限公司
Qingdao Quanhang Machinery Co., Ltd

22.

Q: What parameters should be provided to the manufacturer when selecting a packaging machine?

A: Material name, true/bulk density, particle size distribution, moisture content, target bag weight, production capacity, bag type and material, whether it is food-grade or explosion-proof, and on-site pneumatic, electrical, and dust collection conditions.

23.

Q: What is a multi-stream pneumatic valve-mouth packaging machine?

A: It is a packaging machine that uses compressed air to transport material via "dilute-phase pneumatic conveying," dividing it into multiple parallel streams that

are simultaneously filled into valve-mouth bags. “Multi-stream” refers to multiple feed channels arranged in parallel, which ensures more uniform filling, fuller bags, and higher speeds.

24.

Q: What exactly are the advantages of the “multi-stream” design in a pneumatic valve-mouth packaging machine?

A: Compared to single-stream pneumatic feeding, the parallel multi-stream configuration ensures more uniform material distribution, faster filling, and reduces the likelihood of material shifting within the bag. Additionally, the smaller diameter of each stream results in a more stable airflow, minimizing tube blockages and powder spray. Overall, the machine offers superior cycle time and stability compared to conventional single-tube pneumatic feeding systems.

25.

Q: What is an air-float valve-mouth packaging machine?

A: It is a packaging machine that introduces a small amount of air into the feed channel to fluidize the powdered material (so that it flows like a liquid), and then uses air flotation and low pressure to feed the material into valve-mouth bags. The core principle involves using air to break up material bridges and air flotation to feed the material, thereby solving the problem of “poor material flow.”

青岛铨航机械设备有限公司
Qingdao Quanhang Machinery Co., Ltd

26.

Q: What materials are best suited for packaging with an air-float valve-type packaging machine?

A: Powdered materials with poor flowability that are prone to bridging and caking, such as dry-mix mortar, putty powder, zinc oxide, kaolin, heavy calcium carbonate, bentonite, pigment slurry powder, and certain feed premixes. However, it is less efficient than the impeller-type machine for free-flowing granules.

27.

Q: Why can air flotation solve the problem of “material not feeding/bridging”?

A: Conventional gravity or screw conveyors are prone to material bridging and blockages in hoppers when handling viscous or fine powders. Air flotation uses microporous air distribution at the bottom to break up the bridges and reduce the angle of friction, ensuring continuous material flow and significantly reducing the blockage rate, thereby eliminating the need for frequent hopper tapping.

28.

Q: What is an impeller-type valve-mouth packaging machine?

A: It is a packaging machine that uses a high-speed, multi-blade impeller to "forcefully push/fling" material from the feed inlet into valve-mouth bags. The impeller provides continuous positive-pressure feeding; with its simple design and extremely high speed, it is the preferred choice for high-speed packaging of granules and coarse powders.

29.

Q: Why is the impeller-type machine the fastest?

A: The impeller-type machine features continuous, forced feeding and eliminates downtime associated with air-assisted acceleration or vacuum extraction. A single-nozzle machine can handle 4–8 bags per minute, while a multi-nozzle line can reach 1,200–2,000 bags per hour, making it the most efficient solution for packaging powders and granules at medium to high production capacities.

30.

Q: Does the impeller conveyance system crush the material? What are the advantages and disadvantages compared to pneumatic (air-conveyed/vacuum) systems?

青岛铨航机械设备有限公司
Qingdao Quanhang Machinery Co., Ltd

A: The impact on granules and coarse powders is minimal; however, if the material is fragile (such as brittle granules or crystals), mechanical contact with the impeller may cause minor damage. In such cases, an air-conveyed or multi-stream system with low-breakage design should be selected.

Advantages: Fast speed, no reliance on compressed air or vacuum pumps, robust construction, and low maintenance.

Disadvantages: Weaker control over dust escape for ultrafine powders, potential breakage of fragile materials, and slightly higher noise levels. Selection should be based on material characteristics and production capacity priorities.

31.

Q: What is a cold-stretch film wrapping machine?

A: It is a packaging machine that uses pre-stretched PE film to wrap products from top to bottom at room temperature (without heating), relying on the film's elasticity to shrink back and tightly enclose the product. Compared to heat-shrink machines, it

eliminates the need for a heating oven and consumes no gas or electricity, which is why it is called “cold-stretch.”

32.

Q: What is the difference between a cold-stretch film wrapping machine and a heat-shrink film wrapping machine?

A: The key difference lies in the use of “heat”: Heat-shrink wrapping requires a heating oven to shrink the film, which results in high energy consumption, the presence of an open flame, and thicker film; cold-stretch wrapping relies on the film’s elastic recoil, making it energy-efficient, safe, and using thinner, more economical film. It also operates at high speeds and carries no risk of heat-induced deformation, making it particularly suitable for heat-sensitive products, food items, and chemical drums.

33.

Q: What is the packaging speed (production capacity) of the Cold Stretch Wrapping Machine?

A: The semi-automatic model handles approximately 20–40 pallets per hour, while the fully automatic in-line model can reach 60–120 pallets per hour, depending on product size and cycle time. It is faster than a heat-shrink line (since it eliminates heating time).

青岛铨航机械设备有限公司
Qingdao Quanhang Machinery Co.,Ltd

34.

Q: Why choose cold drawing over heat shrinking? How does it save energy?

A: Heat shrinking ovens must be continuously heated to 150–220°C, which consumes a huge amount of electricity or natural gas and poses a fire risk; cold drawing operates at room temperature, requires no external heat source, and produces no emissions, meeting the requirements for green factories and export environmental standards. Additionally, the film does not undergo thermal aging and retains a stiffer texture.

35.

Q: Does cold-drawn film provide good protective packaging? Does it keep out dust and moisture?

A: Cold-drawn film fits snugly against the product, providing excellent protection against dust and moisture, as well as preventing the stack from coming apart and securing the load during transport. UV-coated or anti-static film is available as an

option to meet specific operational requirements. For heavy stacks, we recommend using pallet wrap in combination with cold-drawn film for double protection.

36.

Q: What is a fully automatic valve-mouth bagging machine?

A: It is a machine that automatically completes the entire process of “bag retrieval—bag separation—mouth expansion—bagging—clamping,” precisely placing empty valve-mouth bags over the discharge nozzle of a valve-mouth packaging machine without the need for manual handling. It serves as a critical front-end component in the automation of valve-mouth packaging.

37.

Q: What are the advantages of a fully automatic valve-mouth bagging machine compared to manual bagging?

A:

Three key advantages:

① Labor savings (saves 1–2 bagging operators per line);

② Increased speed and consistent quality (stable bagging cycle time; no slowdown due to operator fatigue);

③ Reduced dust emissions (sealed bagging is more precise than manual bagging, resulting in less dust). The payback period is typically less than one year.

青岛铨航机械设备有限公司
Qingdao Quanhang Machinery Co., Ltd

38.

Q: What is the bagging success rate and stability like? Is it difficult to switch bag types and sizes?

A: Mature machine models achieve a bagging success rate of ≥99%. They feature detection and alarm systems for missing bags, stacked bags, and misaligned bags, automatically rejecting defective bags and replenishing them to ensure continuous production.

By adjusting bag type parameters via the HMI and quickly changing suction cups or clamps, changeover time is approximately 10–30 minutes, supporting flexible production of small batches and multiple varieties.

39.

Q: Can a bagging machine be added to an existing production line?

A: In most cases, yes. We'll need the design drawings for the existing line and the specifications of the current packaging machine. We'll then match the discharge nozzle and cycle time of the existing packaging machine and perform a custom interface modification to automate the existing line.

40.

Q: What is a robotic palletizing and packaging line?

A: It is a cluster of equipment centered around an industrial palletizing robot, comprising automated packaging (valve bags/ton bags), conveying, automated pallet feeding, robotic palletizing, and in-line stretch wrapping/shrink wrapping. The system automatically stacks individual packages or ton bags into standard pallet stacks, with the entire process being fully unmanned.

41.

Q: What equipment makes up a complete robotic palletizing line?

A: Typical components:①Automatic packaging machine (valve-mouth bags/ton bags); ②Fully automatic bagging machine (valve-mouth line);③Checkweigher/metal detector;④Roller/belt conveyors;⑤Automatic pallet warehouse (for pallet supply); ⑥Palletizing robot (including gripper);⑦In-line stretch wrapper or cold-stretch film wrapper;⑧Control system (PLC + MES interface).

青岛铨航机械设备有限公司
Qingdao Quanhang Machinery Co., Ltd

42.

Q: What types of products are suitable for robotic palletizing lines?

A: Valve bags (cement, fertilizer, feed, powdered materials), ton bags (mineral powder, chemicals), boxed goods, barrel-packed goods, and virtually all other uniformly packaged items. Robots offer high flexibility and can handle multiple product types and pallet configurations simultaneously.

43.

Q: How is the palletizing accuracy and stability?

A: Repeatability is typically ±0.5 mm–1 mm. The system offers stable gripping and placement with a low package drop rate. When equipped with a vision system or sensors, it can adapt to package position deviations, ensuring neat and safe pallet configurations.

44.

Q: How do I choose the right type of packaging equipment for my products?

A: When selecting packaging equipment, the following factors should be considered:

① Product characteristics: including product dimensions, shape, weight, and material

② Packaging format: such as bagging, boxing, bottling, or canning

③ Production capacity requirements: Determine the equipment speed based on the production line's output needs

④ Level of automation: Choose between fully automatic, semi-automatic, or manual equipment

⑤ Budget range: Select the equipment with the best cost-performance ratio based on your investment budget

⑥ Space constraints: Consider equipment dimensions and workshop layout requirements

45.

Q: How can we verify that the quality of equipment packaging meets standards?

A: Packaging quality verification primarily includes the following aspects:

青岛铨航机械设备有限公司
Qingdao Quanhang Machinery Co., Ltd

• Sealing test: Checking the integrity of the packaging seal

• Visual inspection: Ensuring the packaging appears neat and free of wrinkles

• Measurement accuracy: Verifying that weighing or measurement meets standards

• Production efficiency: Confirming that the nominal production speed is achieved

• Pass rate statistics: Calculating the pass rate after continuous production of a certain quantity

• Stability testing: Assessing stability during 8 hours of continuous operation

46.

Q: Can operators with no programming background use collaborative robots?

A: Yes. Thanks to visual programming, ordinary employees can learn how to operate the robot in about half an hour and complete simple programming in one hour, without needing to be proficient in a programming language.

47.

Q: What types of packaging can the robotic arm handle?

A: It can handle a variety of packaging formats, including cardboard boxes, plastic crates, bottles, bags, drums, and cartons, and is widely used in industries such as animal feed, chemicals, food, beverages, beer, plastics, and refractory materials.

48.

Q: How long does it take to recoup the cost of investing in a robotic arm?

A: Collaborative robotic arms typically recoup the investment in 6–12 months on average; palletizing and small robotic arms usually achieve a positive ROI within 1–2 years by replacing manual labor and increasing production cycle times, depending on labor costs and production line cycle times.

49.

Q: Can the robotic arm be integrated with an existing packaging line?

A: Yes. Based on proven control technology, the robotic arm can be flexibly integrated into existing production lines and work in coordination with conveyors, packaging machines, stretch wrappers, and strapping machines.

青岛启航机械设备有限公司
Qingdao Quanhang Machinery Co., Ltd

50.

Q: Do collaborative robots require safety guards?

A: Traditional safety guards are not required. Collaborative robots feature built-in force sensors and 10-level collision detection, and provide 16 safety I/O ports, enabling them to operate safely in human-robot collaborative environments.

51.

Q: Can it operate in harsh or hazardous environments?

A: Yes. The robotic arm can replace human workers in harsh or hazardous environments—such as those involving chemicals, fertilizers, high temperatures, and dust—ensuring operational safety and stable, continuous operation.