# Future of Robotics: The Tri-Co (Coexisting-Cooperative-Cognitive) Robots

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Huazhong University of Science and Technology

**September 18 2019, Shanghai**

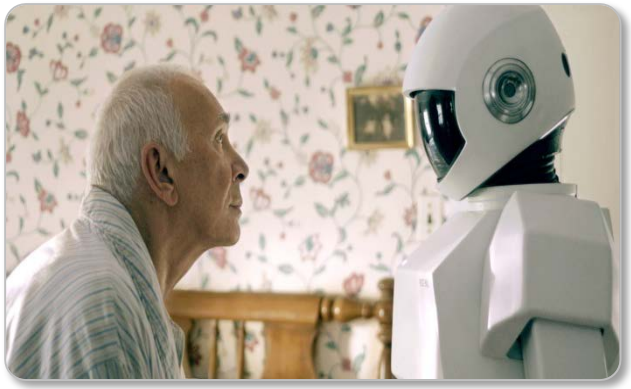
# Outline

- Future Robots
- NSFC Robot Research Plan
- Recent Work in Our Group

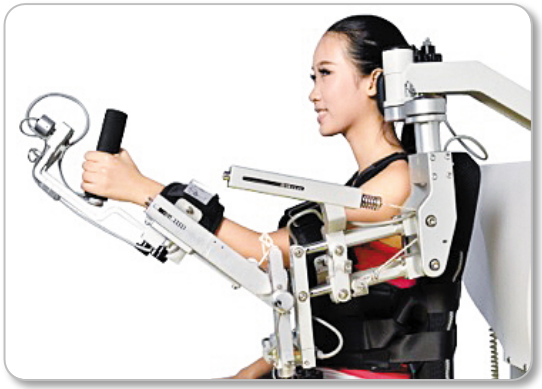
# Robots Have been Widely Used

**Since the first industrial robot was born in 1959, the robot has played an important role in solving practical problems.**

**Manufacturing Upgrading**



**Aged People Nursing**



**Rehabilitation**

**Defense Security**

**Space Exploration**

**Resource Exploration**

**Invention of Robots：Replace , Serve and Expand Human**

# Problems of Robots in Reality

## However, robots in reality …

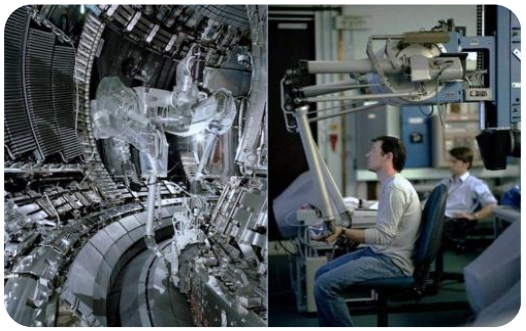
### Industrial Robots

Poor online perception
Poor ability of
real-time operation
Structured environment

### Service Robots


Insufficient
man-machine
cooperation ability

### Special Robots

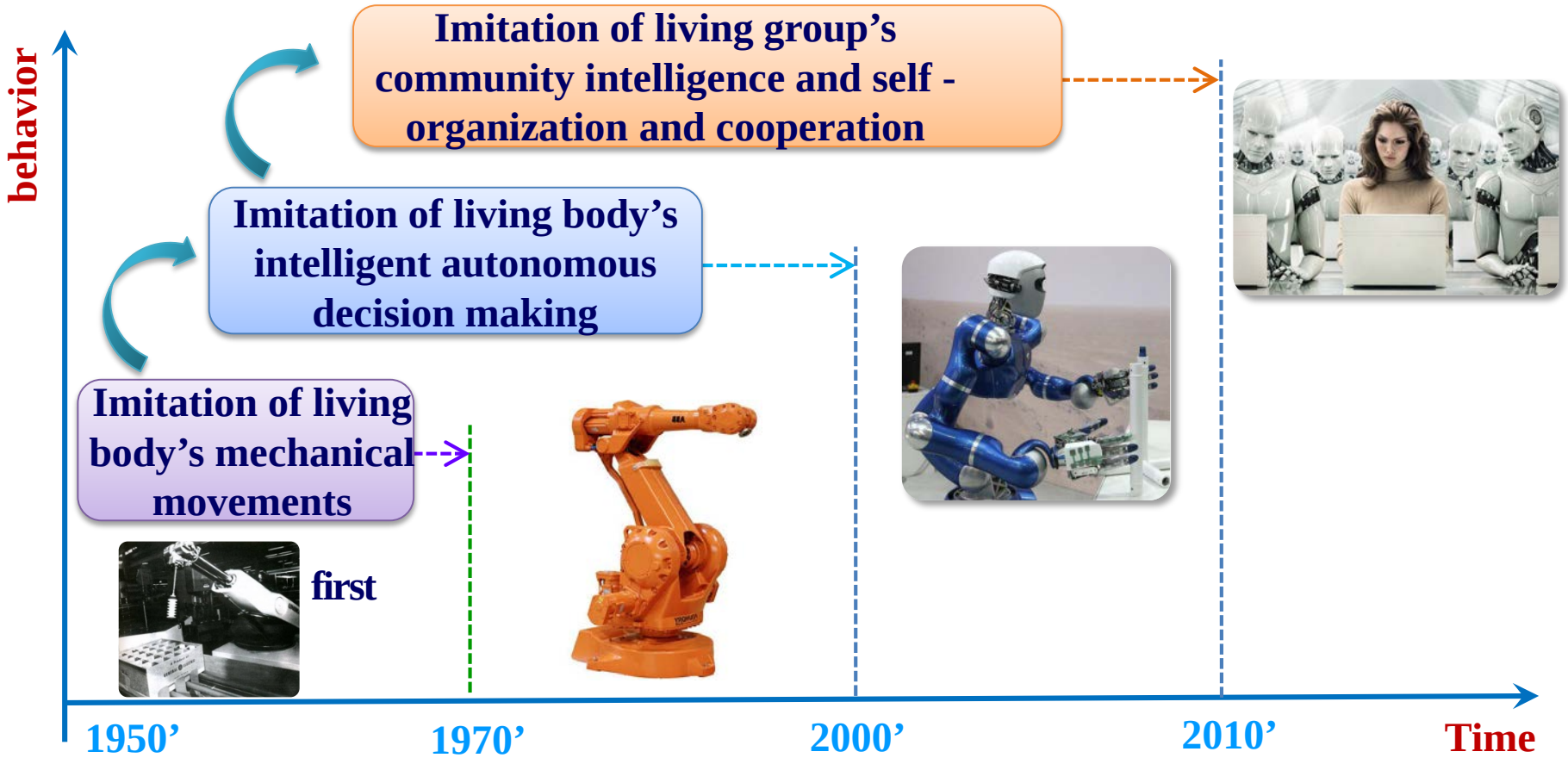


Rely on remote
operations to complete
a specific task

There are still big gaps between the reality and the expectation.

# Development of Robotic Technology

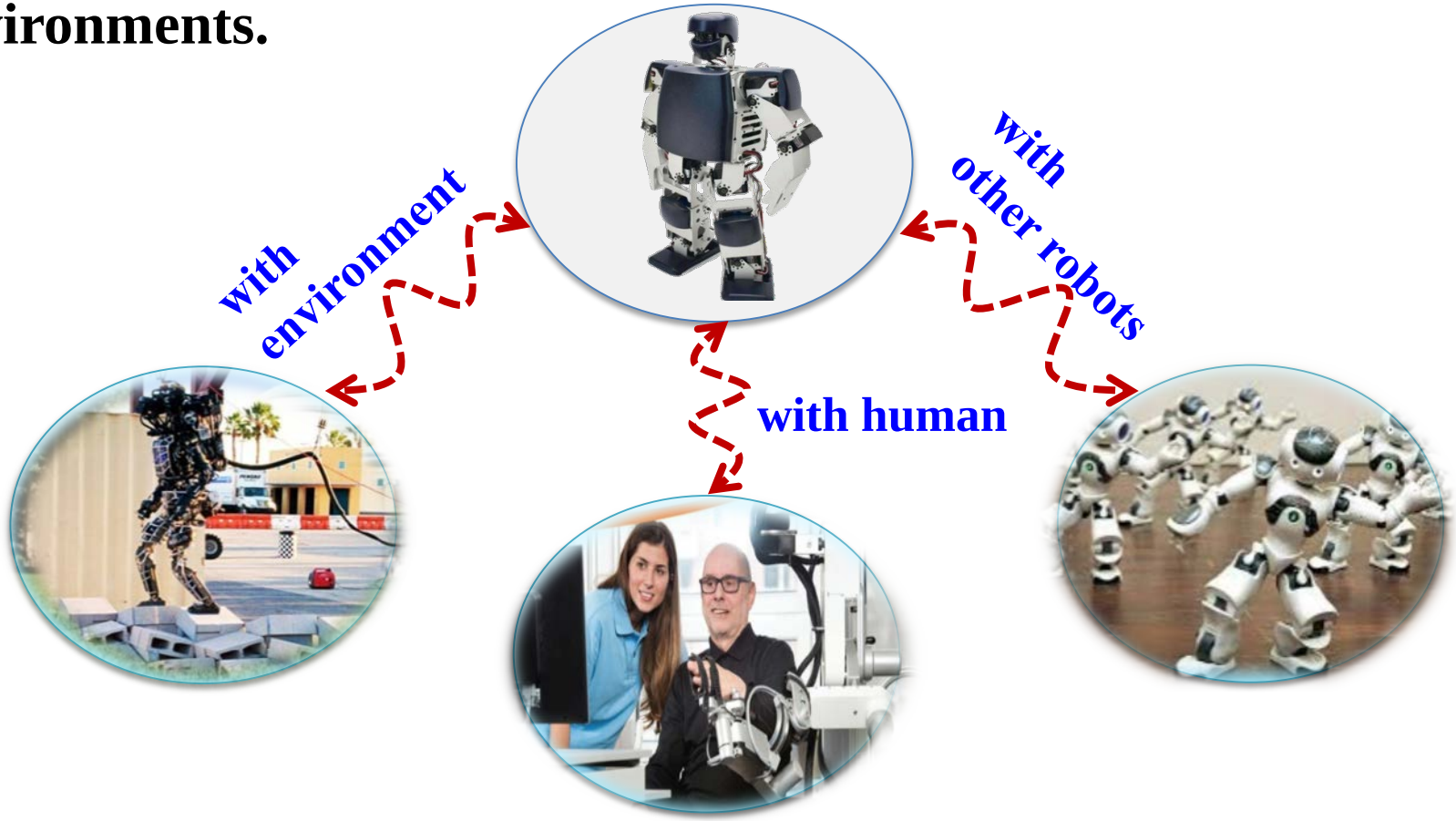
**Robotic behavior has experienced the following stages of development:**




**Simple Interaction with Parts** ⇨ **Complex Interaction with Environment, Human and other Robots**

# Technical Characteristics of Future Robots

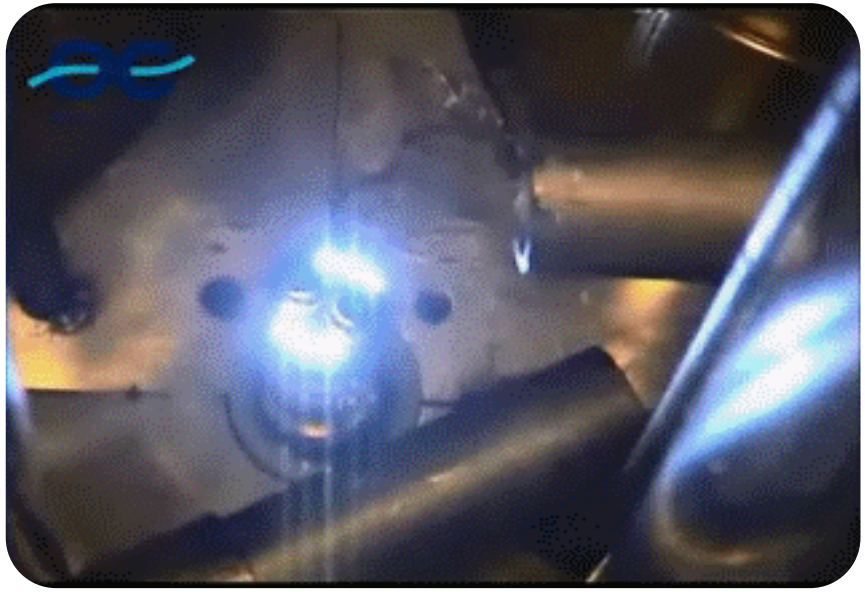
**Future robots should have the abilities to interact naturally with the operating environment, the operator and other robots, and also abilities to adapt to complex tasks and dynamic environments.**



# Technical Characteristics of Future Robots

***Robot-Environment*** | ***Robot-Robot*** | ***Robot-Human***

**The robot is highly adaptable to the environment**



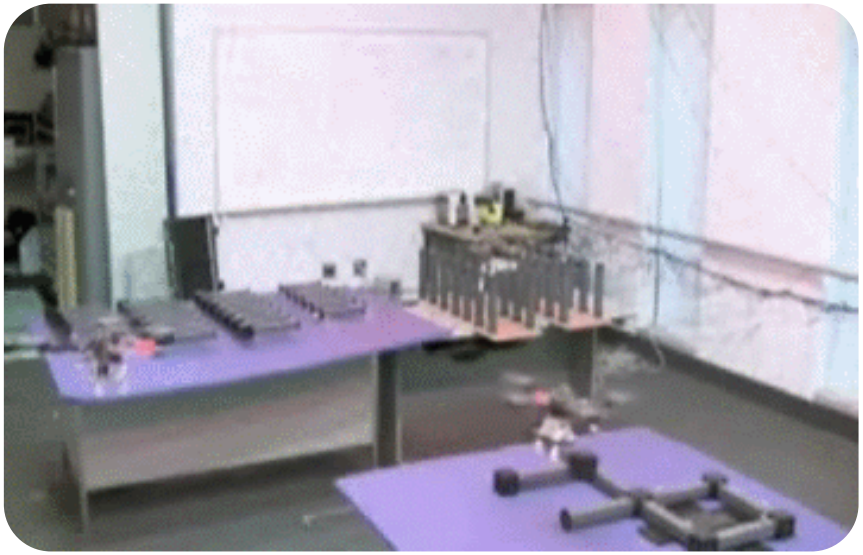
***Walking robot*: gravel, snow and ice; Mountain climbing, obstacle avoidance, ...**

***Continuum robot:*** **narrow space, deep cavity environment, body cavity, ...**

# Technical Characteristics of Future Robots

*Robot-Environment* | ***Robot-Robot*** | *Robot-Human*

**Multi-robot and large-scale cluster robots complement each other**



***Individual autonomy*: the ability to have independent observation, judgment, decision making and action**

***Group collaboration* : with the characteristics of group perception, cognition, game and motivation**

# Technical Characteristics of Future Robots

*Robot-Environment* | *Robot-Robot* | ***Robot-Human***

## Robots work together with Human

***Structure*** : safe and comfortable to provide the necessary movement of human body: limb extension / enlargement

***Perception***: a precise understanding of the human behavior intent - the thought that is reached

# Outline

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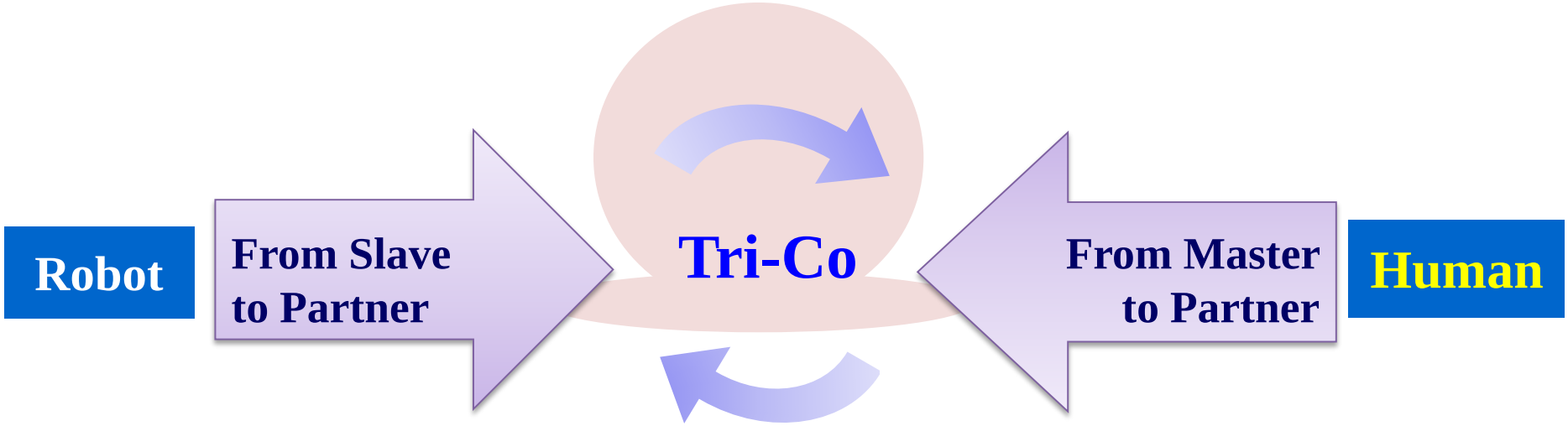
# Robotics Research in China

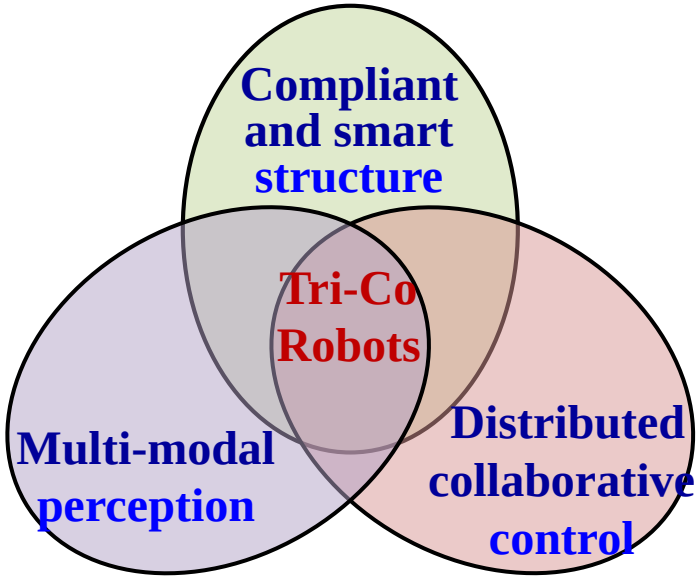
**The National Natural Science Foundation of China launched the "Coexisting-Cooperative-Cognitive Robots" (Tri-Co Robots ) plan fundamental research of future robotics.**



# What is Tri-Co Robots?

**Compliant:**
*Rigid-flexible-soft* coupled systems
**Dexterity:**
Super redundant degree of freedom

**Sensing:**
The functions of *multi-mode* sensors
**Cognition:**
Intention understanding of environment and human behavior




**Autonomy:**
*Self - discipline* of individual behavior
**Collaboration:**
Group intelligence and collaboration

**Compared with the intelligent robot, Tri-Co Robots can better understand the unstructured dynamic environment, and has the flexibility of structure; can better understand the human behavior intentions, and achieve the *Natural Interaction and Collaboration* between human-robot / robot group with certain rules.**

# Mission of Tri-Co Robots

- **Fundamental Research of Robot**
- **Scientific Connotation of Tri-Co Robots**
  - — Intelligent Robots ➔ Tri-Co Robots
- **Leading the Future Development of Disciplines**
  - — Fundamental Support: New theories and new methods in structure, perception and control
  - — Key Breakthrough: Compliant Mechanism , Multi-modal Perception , Polymorphic Distributed Operating System
- **Academic Frontiers & Major National Demands**
  - — Academic Frontiers： Soft-Flexible Robots, Man-Machine Natural Interaction, Group Intelligence
  - — Major Demands： Manufacturing, Rehabilitation Medicine, Defense Security …

# Tri-Co Robots: Implementation Plan

- Execution Period: 2017 – 2024 (8 years)
- Total Budget: 200 Million RMB

| Project Category | Budget/Project (RMB) | Total Budget (RMB) |
|---|---|---|
| General Project | 0.8 million | 60 million |
| Key Project | 3.5 million | 80 million |
| Integrated Project | 15 -20 million | 60 million |

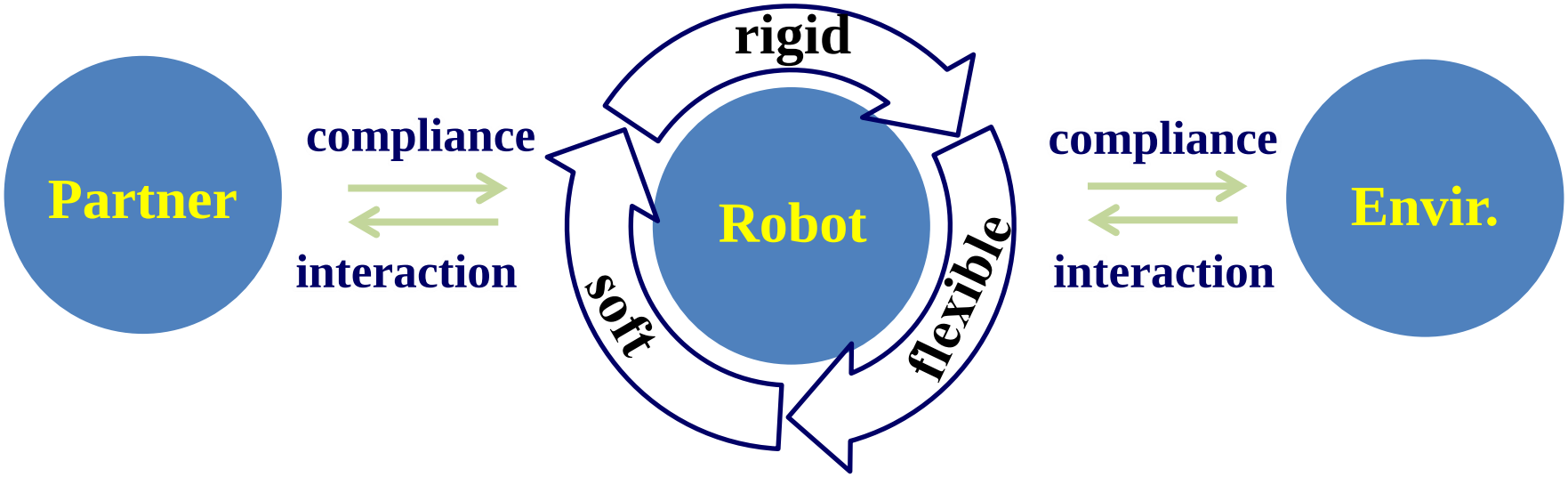
# Tri-Co Robots Plan: Research contents and objectives

## Content 1： Mechanism and dynamics of rigid-flexible-soft coupling robots

① Motion / force transfer principle of rigid-flexible-soft coupled systems

② Variable stiffness mechanism of soft smart structures

③ Human-robot-environment interaction dynamics



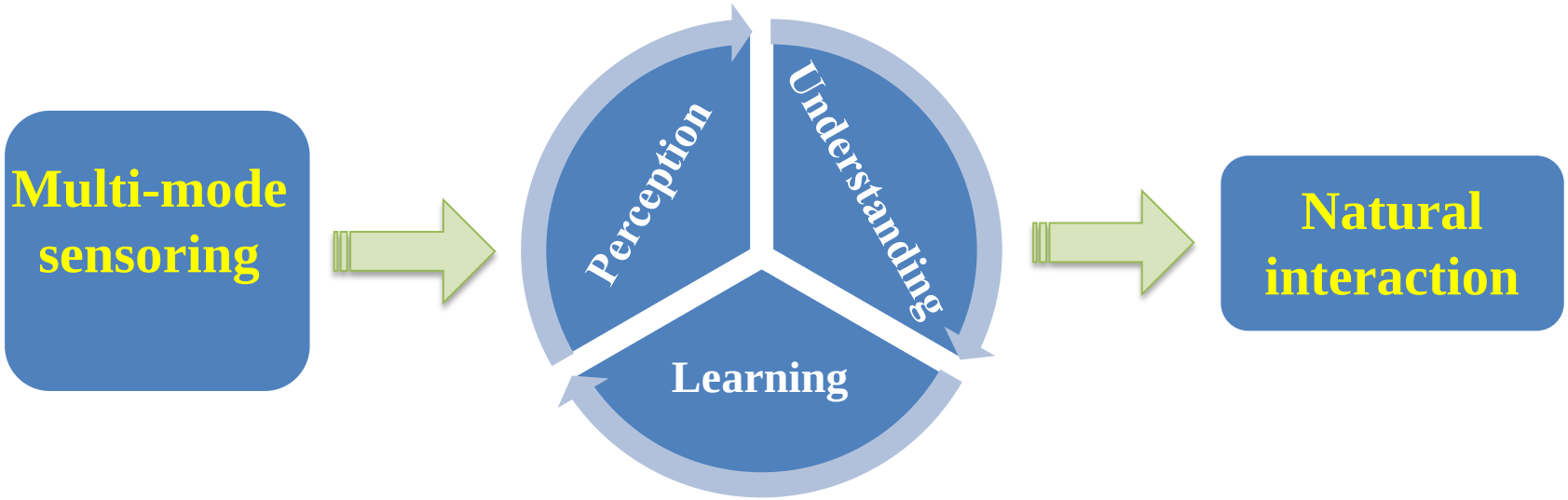
# Tri-Co Robots Plan: Research contents and objectives

## Content 2： Natural interaction of human and robots

① Integrated design of multi-mode sensors

② Real-time accurate understanding of behavior intention

③ Human-robot interactive autonomous learning

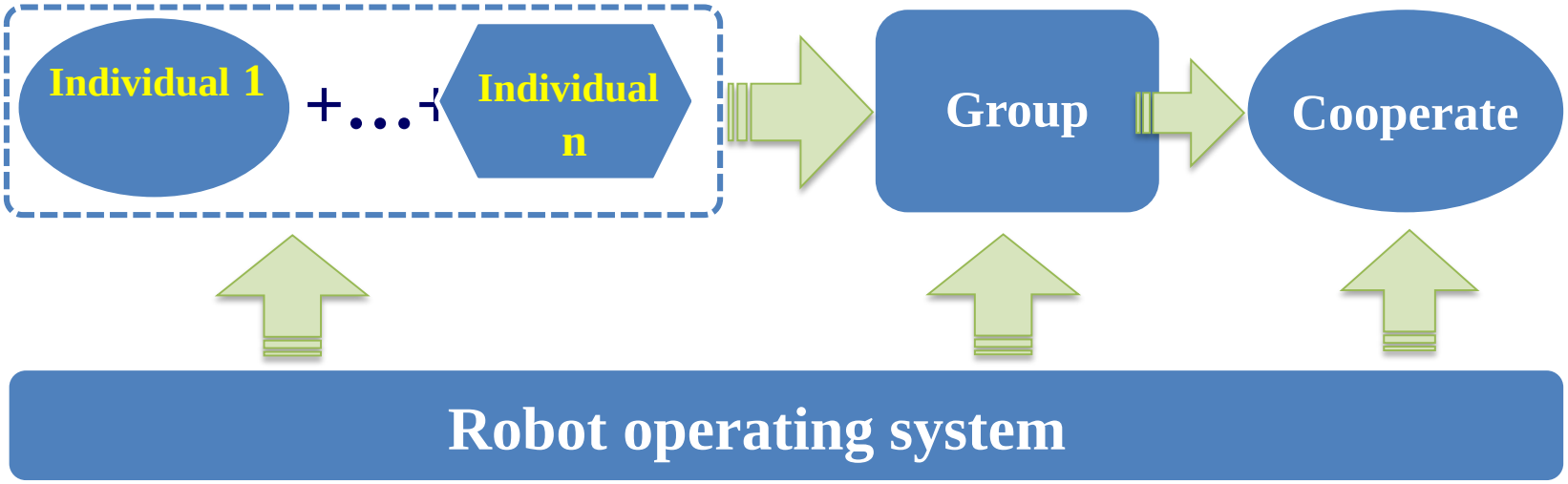


## Content 3: Group intelligence and operating system

① Autonomous operation in unstructured environment

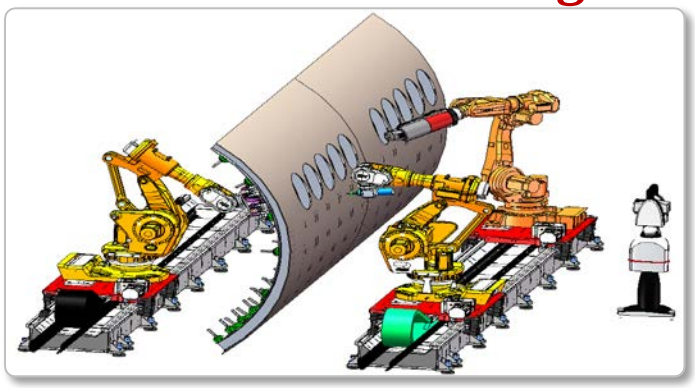
② Multi-robot cooperation and intelligence control

③ Distributed robot operating system

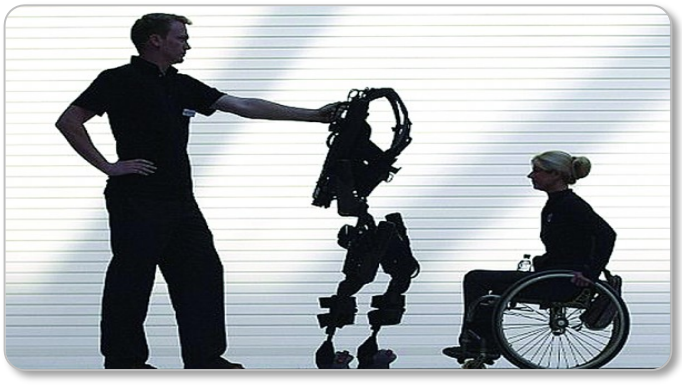


# Tri-Co Robots Plan: Applications

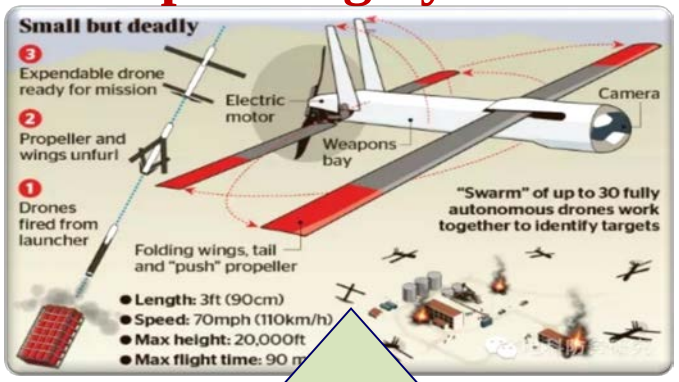
## Robotic Machining



## Medical Rehabilitation



## Operating System

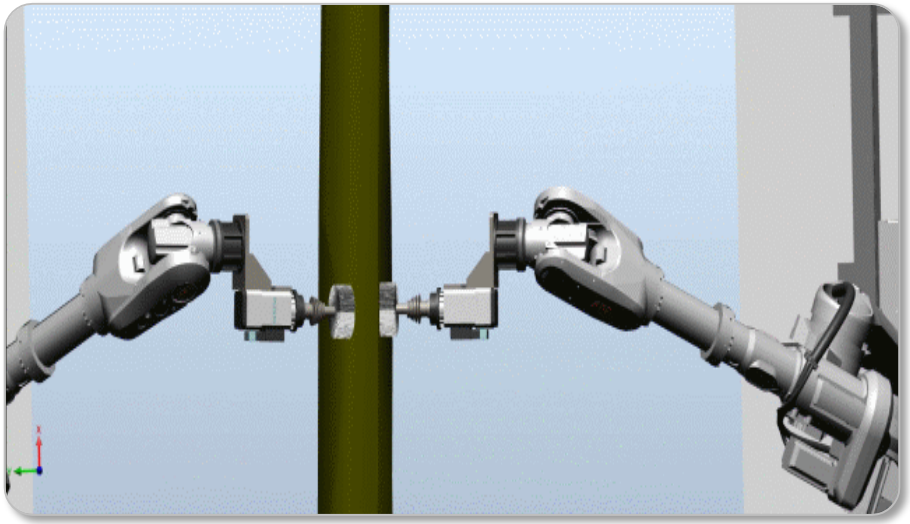


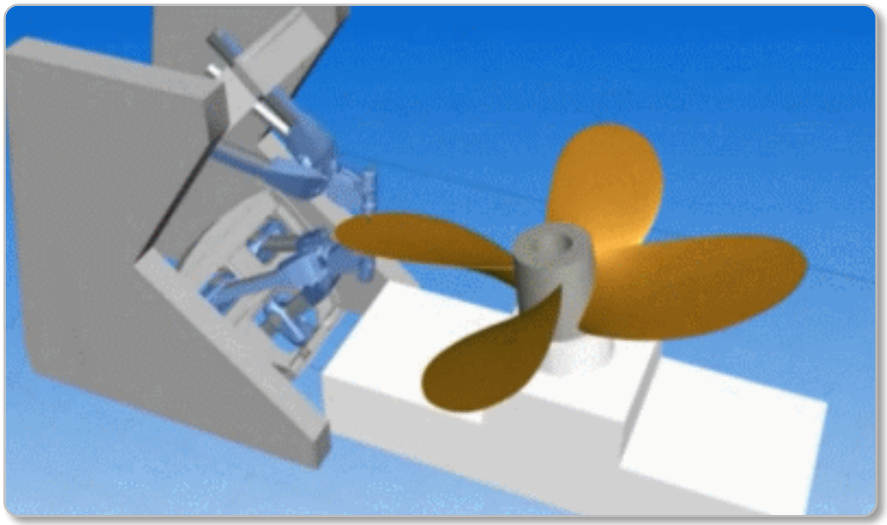

## System integration platform

# Tri-Co Robots Plan: Applications

## Craftsmen—Robot equipment

- The robot structure and driver with high dexterity, variable stiffness and lightweight
- The robot compliance control based-on process knowledge and multi-sensor information





The high-performance of robot main body and the intelligent control based on process knowledge

The variable stiffness control of rigid-flexible-soft coupled systems can form active compliance ability of devices, and realize high quality manufacturing of complex parts

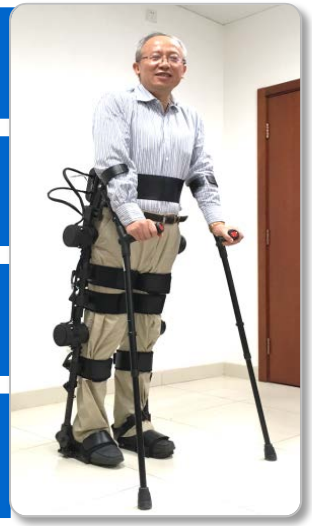
# Tri-Co Robots Plan: Applications

## Thoughtfulness—Rehabilitation Robot

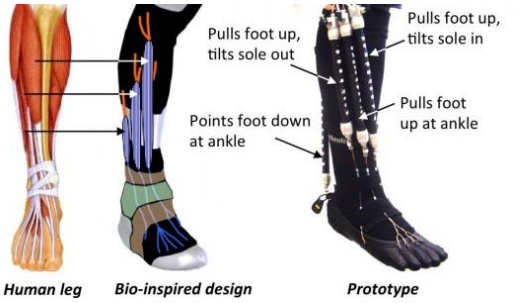
- Bionic structure, compliant mechanisms
- Real-time perception based on multi-mode information

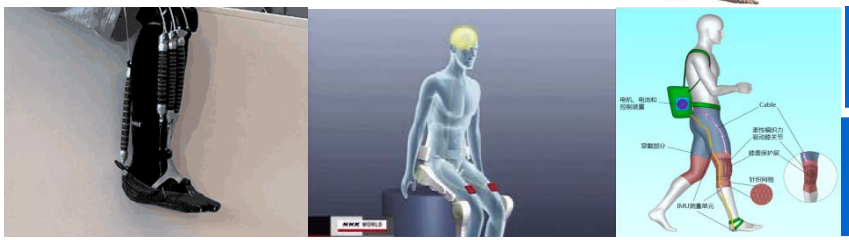
### Current passive rehabilitation

- Rigid structure
- Instruction control
- Presupposed track
- Stick assist



### Future active rehabilitation



- Flexibility
- Intention perception
- Bionic assist
- Balance control

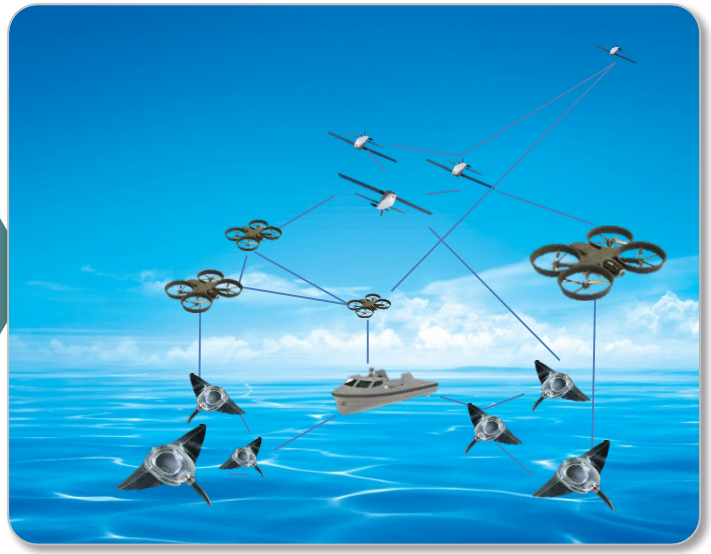
**Intention perception and compliant motion of human body**

# Tri-Co Robots Plan: Applications

## Cooperation—Swarm Special Robot

- Autonomous control and swarm formation of robot with heterogeneity and cross-domain
- The resource and behavior management based on distributed operating system

- Scale of swarm robot： 10-100
- Work domain： 2-3（air, underwater…）
- Specie of robot： 3-5（fixed wing, boat… ）
- Specie of task： over 3(communication, patrol…)



The patrol and explore of swarm robot with heterogeneity and cross-domain

**Autonomous control, swarm formation and cooperation**

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Huazhong University of Science & Technology

华中科技大学无锡研究院
HUST-Wuxi Research Institute

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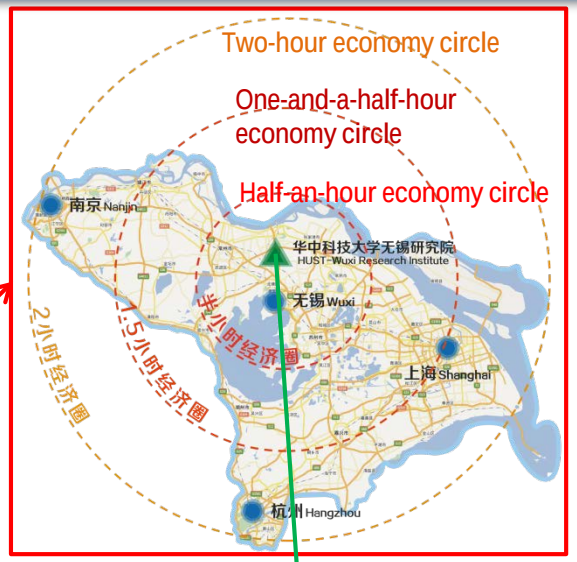
# Connecting "the last mile" of university achievements transformation

## 打通高校科技成果转化“最后一公里”

# Location 地点


**HUST-Wuxi Research Institute** located in Wuxi, that is a city on the Yangtze River between Suzhou and Nanjing, and is located in the south of Jiangsu Province, half way between the cities of Shanghai and Nanjing.





# Initiators 举办方

## WUXI Goverment

中国無锡 Wuxi China

**无锡市政府**

The birthplace of Chinese national industry；中国民族工业发祥地

Hometown of famous academicians/professors；院士之乡

GDP over trillion RMB in 2017
2017年万亿GDP

## Huazhong University of Science and Technology

**华中科技大学**

A famous university of science and engineering in China; 中国著名工科院校

Leading the way in mechanical engineering；机械工程排名第一方阵

6 well-known academicians；6名知名院士


## Jiangsu Industrial Technology Research Institute

江苏省产业技术研究院
JIANGSU INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE

A new R&D platform in Jiangsu province；新型研发平台

Science and technology innovation experimental filed；科技创新改革实验田

Strategic cooperation with nearly 20 well-known international universities；与20多家全球知名院校战略合作

JITRI
JIANGSU INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE

# Purpose & Mission 目标与任务

**Focus**
**聚焦**

- **High-end equipment manufacturing industry**
  高端装备制造业

**Target**
**目标**

- **Breaking through key generic technologies**
  突破行业关键共性技术
- **Promoting industrial transformation and development** 助推产业转型升级
- **Creating economic and social values.**
  创造经济社会效益
- **Build internationally renowned New R & D institutions** 建成国际知名新型研发机构

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# Purpose & Mission 目的与任务

## Method 方式

- Government-industry-university-research-user deep integration 政-产-学-研-用深度融合
- Equipment manufacturing industry chain collaborative innovation 装备制造产业链协同创新

## Mission 任务

- Industrial technology research and development 产业技术研发
- The transfer and transformation of sci-tech achievement 科技成果转移转化
- Incubation of high tech companies 高科技公司孵化培育
- Gathering and training of global high-end talents 全球高端人才集聚培养

# History 发展历史

| 2012 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| Registered and established | Marched into 30000 m² R&D base | Joining JITRI R&D income reached 50 million | Ranked first in province R&D staff reach 200 | Enterprise operation R&D income Expected to 100 million |
| 注册成立 | 入驻研发基地 | 加入省产研院 研发收入5000万元 | 省院排名第一 员工突破200人 | 市场化运营 研发收入近亿 |



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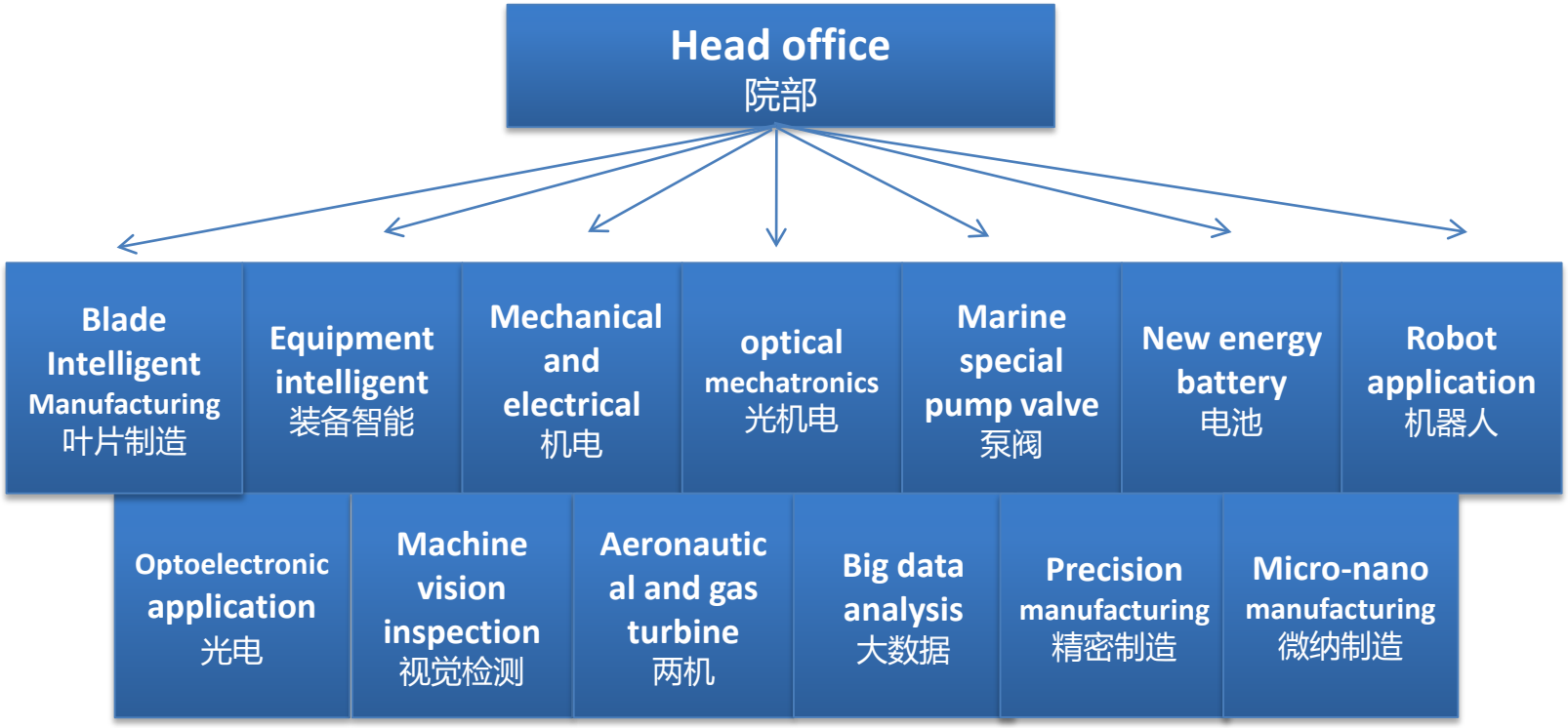
JIANGSU INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE

# Organizational structure 组织架构

## 14 Research departments + Head office
## 院部+14个二级研发团队

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# Research Condition 研发条件

- **More than 30000 m² of workshop and office space.** 3万平米研发基地
- **More than 50 million RMB advanced Instrument and equipment.** 5000万先进仪器设备
- **Including office room, laboratory, workshop, training Room, lecture hall, maker coffee house…** 配套实验室、中试车间、培训室、创客空间








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JIANGSU INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE

# Human resources 人力资源

**Gathered high-end talents with favorable education background and work experience 集聚高层次人才**

- **Faculty and Staff: 250**
  员工总数超过250人
- **Academician: 1**
  院士1人
- **Professors: 15**
  教授15人
- **Doctor: 20%**
  博士20%
- **Master： 50%**
  硕士50%

**DING Han**

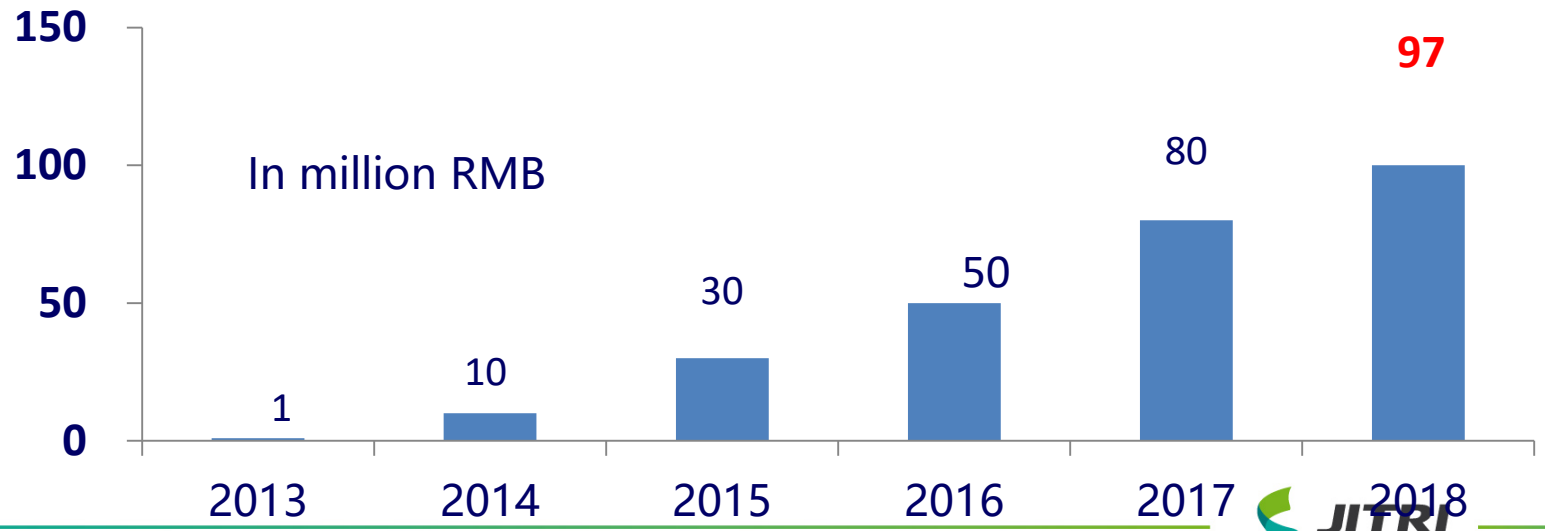
- CAS Academician
- Director of the Institute

**Leading talent**

# Current situations 发展情况

## Projects and benefits 项目效益

- **Gain R&D Service projects from enterprises more than 150 items**
  150多个企业横向科研服务项目
- **Gain R&D projects from governments more than 30 items.**
  30多项政府纵向科研项目
- **The totally income reach RMB 270 million.**
  总科研经费收入达2.7亿元



# Current situations 发展情况

**IP**
**知识产权**

**More than 150 valid patents** 150项知识产权

**TS**
**技术转移**

**Technology transformation more than 21 million** 2100万技术转移

**Cooperation**
**战略合作**

**More than 20 Joint R & D Centers**
20个联合研发中心

**Incubator**
**企业孵化**

**Incubated more than 20 hi-tech enterprises**
孵化20多家高科技企业

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# R&D – High efficient machining for complex surface 复杂曲面零件高效加工

**High efficient machining solution for blade & blisk**

航空发动机叶片叶盘高效低损加工工艺解决方案

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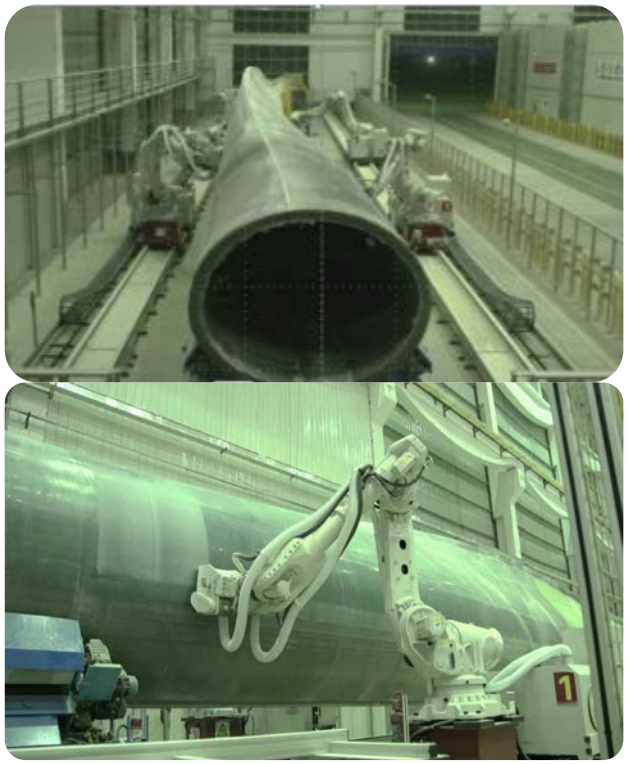
# R&D – Robotic Intelligent Grinding System
# 机器人智能磨抛系统

**Artificial Grinding**
人工打磨



**Robotic Grinding**
机器人打磨

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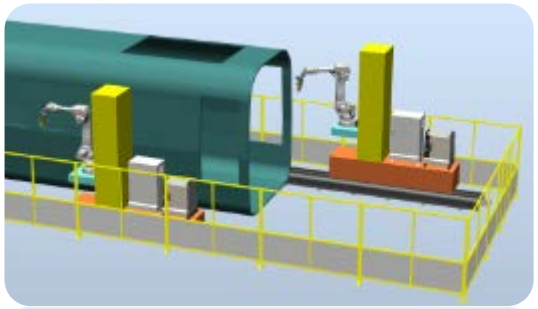
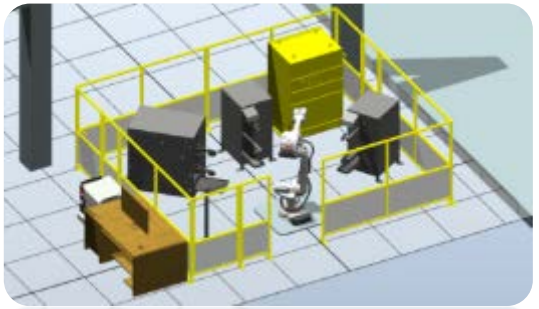
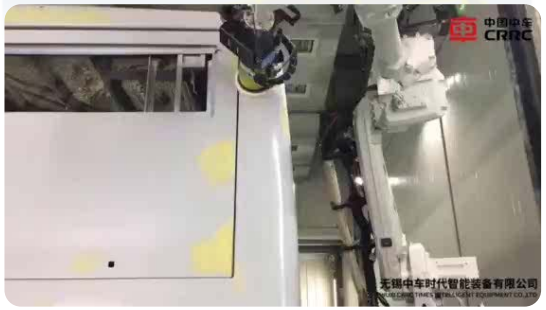
# R&D – Robotic Intelligent Grinding System
# 机器人智能磨抛系统








**High-speed rail**
高铁车体打磨

**Metro**
地铁车体打磨

**Aircraft engine blade**
航发叶片打磨

# R&D – Robotic Intelligent Milling System
# 机器人智能铣削系统

**milling propeller**
船舰螺旋桨铣削

**milling mould**
模具铣削

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# R&D – Vision Guide Assembly Robotic System 视觉导引机器人装配系统

**Vision guide robotic system for industrial product assembly**

视觉导引机器人装配系统（家电、发动机）

# R&D – Intelligent logistics & Storage system
# 智能仓储物流系统


**Intelligent Storage system for SMT materials using sorting robot**

面向SMT行业的智能仓储物流系统

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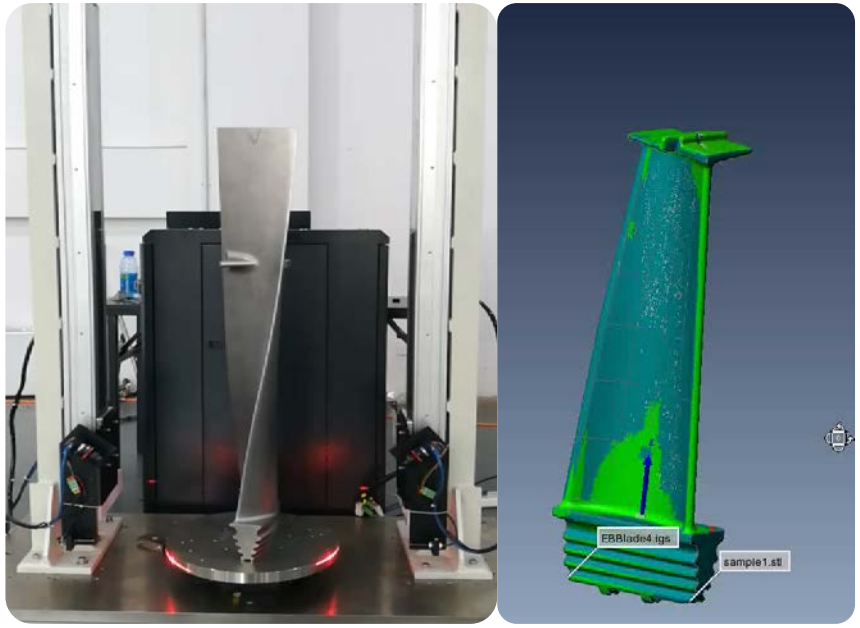
# R&D –Intelligent Machine Vision and Measureing System智能机器视觉检测系统


**3D vision robotic grab system**
3D视觉散乱物料拾取系统




**Laser 3D measuring system**
叶片激光扫描检测系统

# R&D –Intelligent Workshop Planning and Design 智能车间规划设计

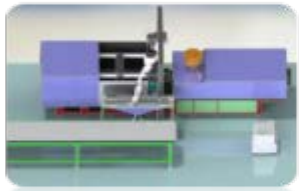

机器人自动装配


内机自适应工装


AGV智能运输车


连接管自动装配线


锁螺母专用机器人


剪水口专用机器人


外机底板柔性工装


外机前面板智能装配线

1、家电行业专用机器人：蒸发器安装机器人、智能锁螺钉机器人、复合高频焊接机器人等
2、智能传感与监测设备：位置/力矩传感器、机器视觉、RFID电子标签、分布式控制等
3、智 能 装 配 设 备： 空调内/外机柔性可重构工装、高精度柔性电子插件机、两器精密翅片穿管机等
4、智能物流与仓储装备：电子车间立体仓库、AGV、空中摩擦线标准吊具等

**Intelligent air conditioning digital workshop d** 美的 Midea

美的空调智能化工厂规划设计

JITRI JIANGSU INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE

# Robotic Machining

## The Role-Changing of Industrial Robots

- **Manipulating Robot**

increasing demand

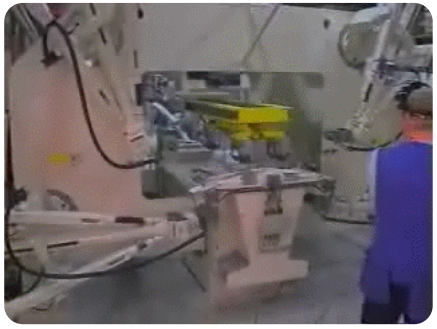
**Features:**

- Rigid Structure
- Off-line programming
- Pre-determined Environment

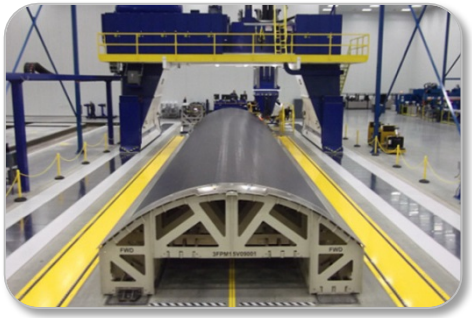
- **Skillful Machining Robot**

**Features:**

- High dexterity
- Dynamic environment
- Human-robot cooperation

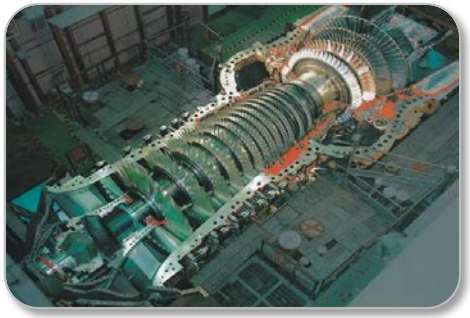


# Large and Complex Surfaces Manufacturing

**Large and thin - walled parts:**

**Skin-type large-scale aviation thin-walled structure parts account for about 30% of the aircraft sheet metal parts.**



**Large Gas turbine blades:**

**Turbine machine requires hundreds of turbine blades, manufacturing cost of blades account for about 1/4 to 1/3 of the total cost.**

**Large wind turbine blades:**

**Large-scale wind power blades with various chord length, thickness, twist angle and airfoil; single blade's length is up to 77.7m, weight up to 28.8 tons.**

**Bottleneck technique of modern manufacturing**

# How to Manufacture Large Surfaces?

## Possible Solution——Industrial Robot

**The EU launched the "Plug-and-produce COmponents and METhods" (COMET) and "Hard Material Small-Batch Industrial Machining Robot" (HEPHESTOS) plans for robotic machining of metal materials.**

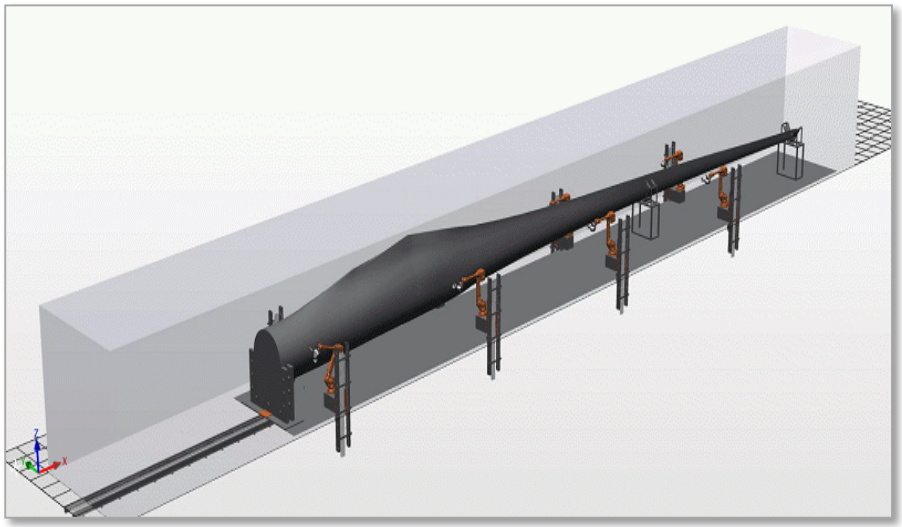
| Project | Duration | Subject | Material | Accuracy |
|---|---|---|---|---|
| COMET | 2010/09-2013/03 | Robotic Milling | Die steel, aluminum, nickel alloy | 0.05 mm |
| HEPHESTOS | 2012/09-2015/11 | Robotic Milling<br>Grinding/Polishing | Hard steel, granite | Grinding: Ra 0.4<br>Milling: 0.05 mm |

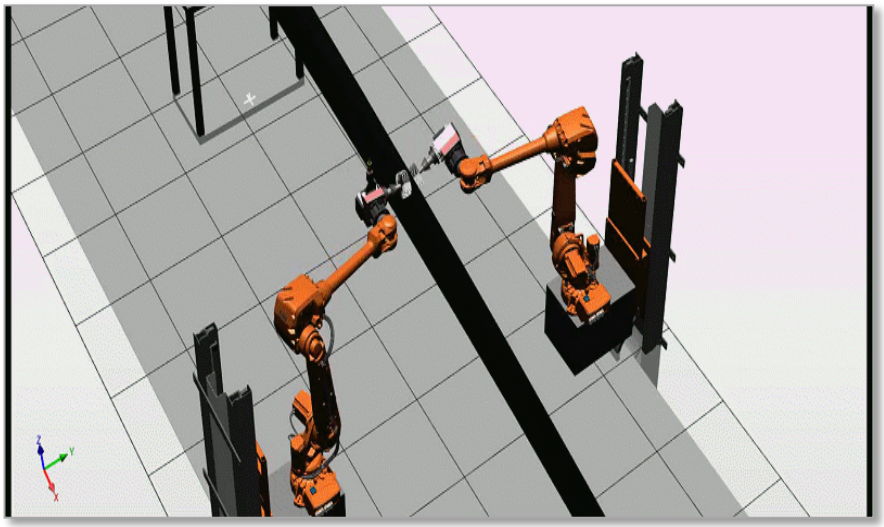
# Advantages of Robotic Machining

## ☐ Multi-robot Simultaneous Machining

- Large workspace
- Flexible operation
- Flexible configuration
- Intelligent control

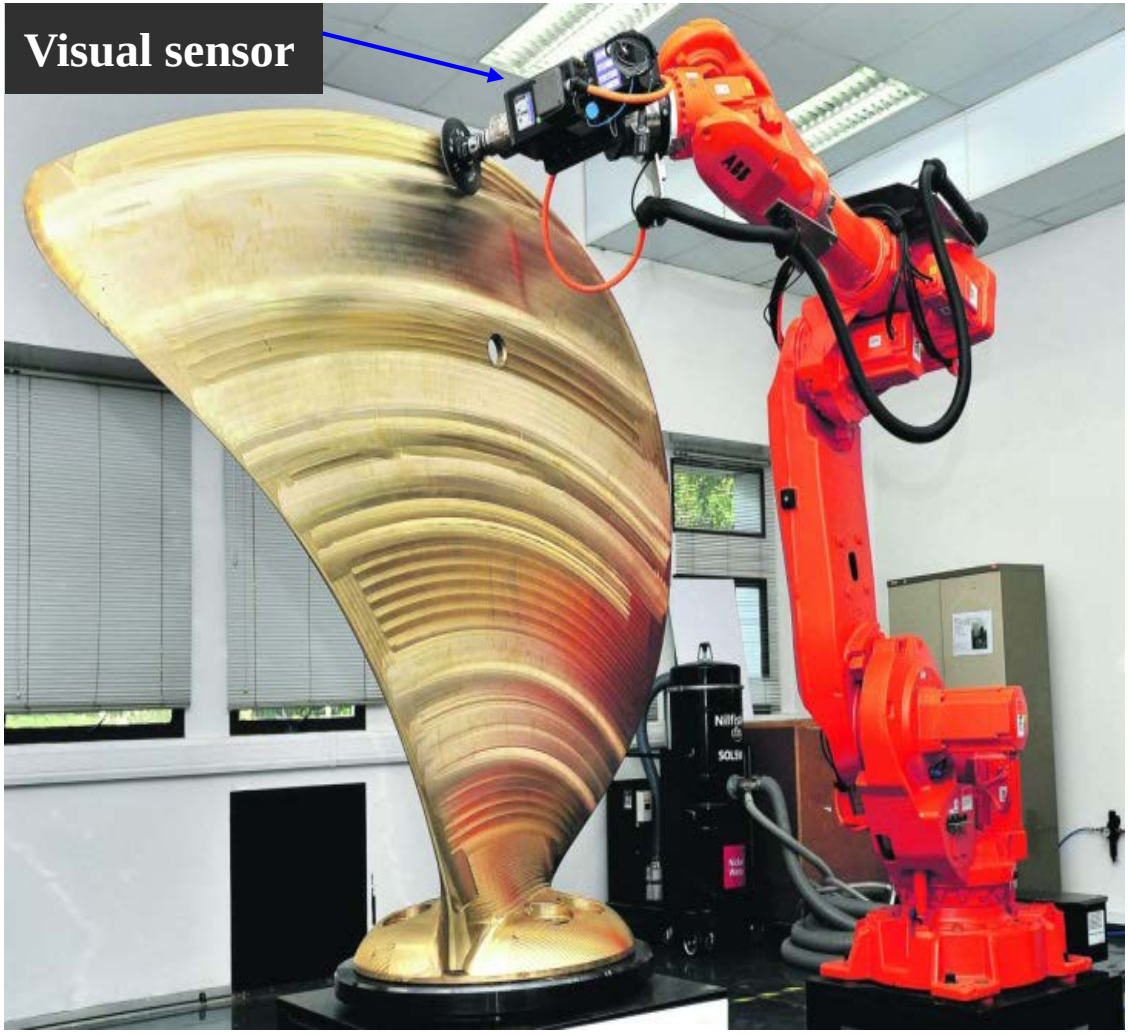
Robotic Machining: Multi-robot +Multi-sensor+Process knowledge

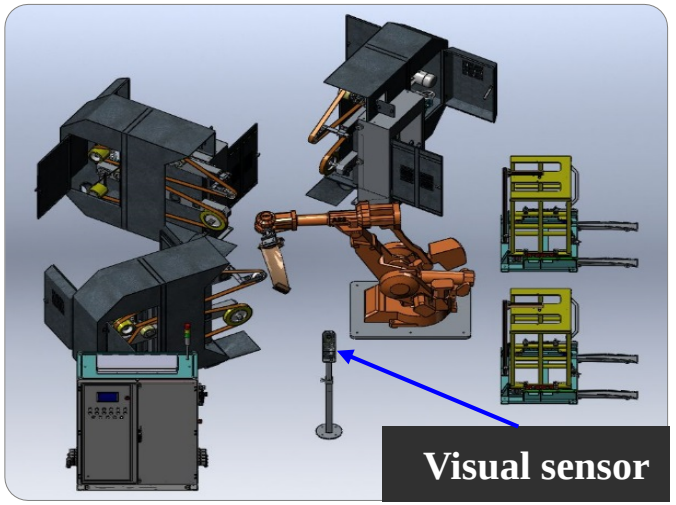


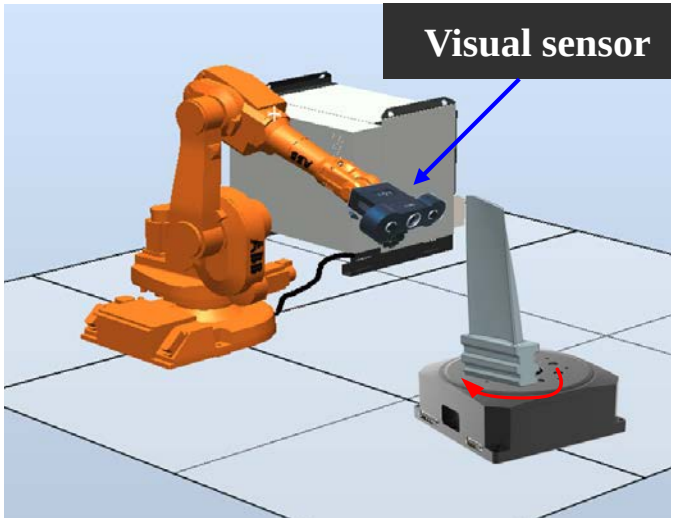


# Characteristic of Robotic Machining

## ☐ Measurement-Machining-Manipulating (3M) Integration



# Challenges of Robotic Machining

- ❑ workpiece geometrical constraints
- ❑ distortion and vibration
- ❑ hard machining material
- ❑ low rigidity and accuracy of robots

→

- Interference-free tool path
- High-efficient tool path optimization
- Distortion control
- Stable machining process control

→

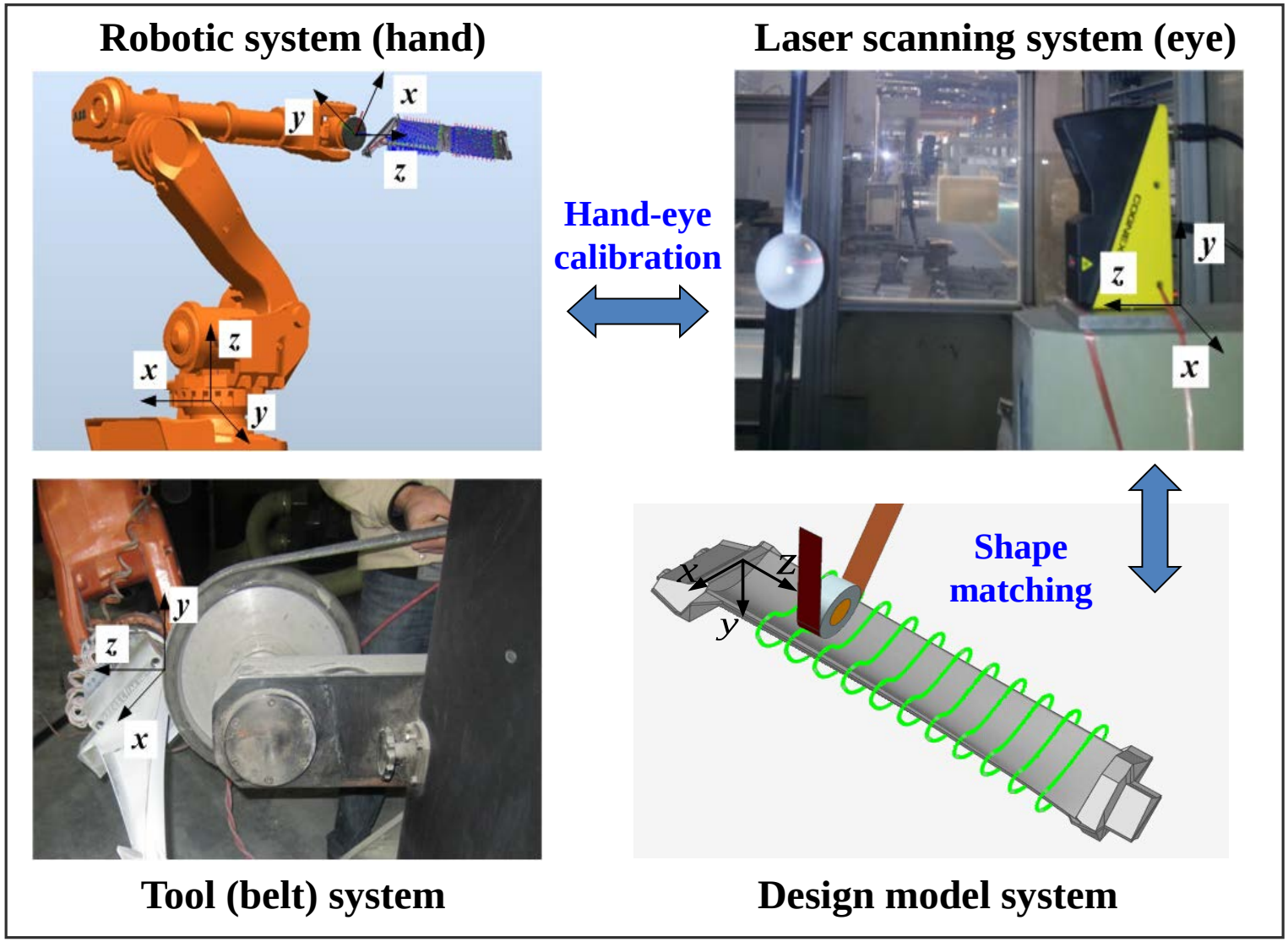
**Geometry**
**Physics**

| Industrial Robots | | Machine Tools | |
|---|---|---|---|
| accuracy | 0.3mm | accuracy | 1-10μm |
| rigidity | 1N/μm | rigidity | 50N/μm |
| programming | No Unified Codes | programming | G codes |

**Robotic Machining is much more challenging than mechine tool!**

# Challenges of Robotic Machining

- How to deal with the integration of multi-coordinate systems?

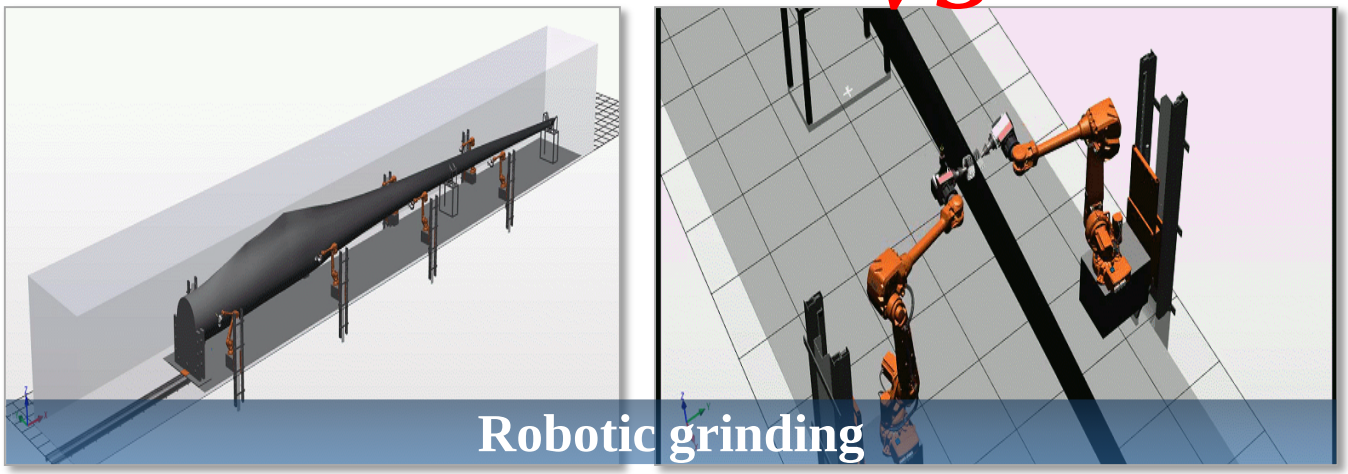


# Robotic Grinding of Large Wind Blades

➞ **Cooperation with CRRC（中国中车）: We are also developing a robotic grinding system for wind power blades.**


- Harmful to health;
- Low efficiency;
- Low surface accuracy;
- Poor result;

*VS*




- Automatic grinding;
- High efficiency and high surface quality;
- Good result;

# Robotic Grinding of Large Wind Blades

→ **Now, we are installing an demonstration line in CRRC: wind power blade robot cooperative grinding system**

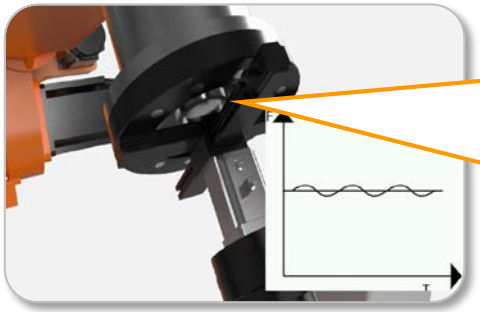
**the system debugging plant in one manufacturing base of CRRC**

# Robotic Grinding of Large Wind Blades

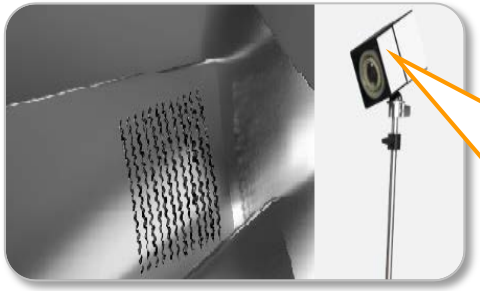
# Robotic Grinding of Aviation Blades

→ **Cooperation with Aero Engine Corporation of China: We have developed 2-DOF adaptive compliant polishing flange for turbine blisks to realize automatic manufacturing.**

Robotic grinding system



Contact force control



Cutter mark dection

**2-DOF polishing flange: adaptive position adjusting to adapt to the contact force and the surface**

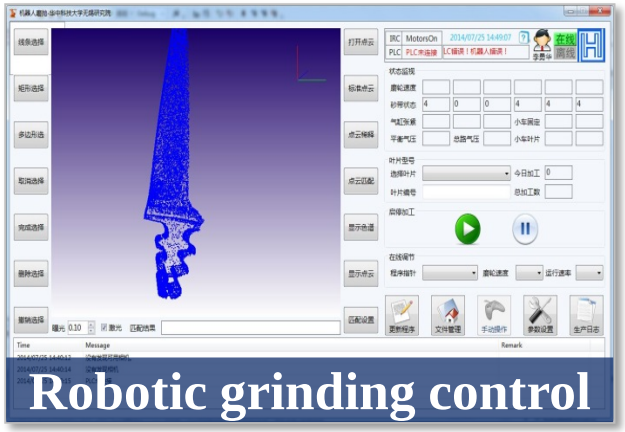
**Cutter mark dection camara: the surface quality judgement**

**Feature: The flange can guarantee the contact force accuracy within ±1N, so that adaptive polishing can be achieved.**

# Robotic Grinding of Aviation Blades

→ **Cooperation with WTB (无锡透平): We have developed robotic grinding systems with force control, and already achieved steam turbine blades grinding in batch.**

**Robotic grinding software**





**Robotic grinding system with force control**



*VS*

# Robotic Grinding of Aviation Blades


**Comparison of grinding and polishing of die - forging blades (600mm) of a titanium alloy：**

| | Manul | Robot |
|---|---|---|
| Grinding time | 45min | 25min |
| Profile accuracy | ±0.15mm | ±0.1mm |
| Roughness | Ra1.6 | <Ra0.8 |
| Consistency | Poor | Good |

# Robot-based Milling Equipment

→ **Cooperation with Aviation Industry Corporation of China: We have developed an integrated 3D measurement and robotic milling equipment for machining of aircraft skins.**

| Robotic Milling Technology | Milling of Aircraft Skins |
| --- | --- |
|  |  |

Main Specifications of the on-line measuring and milling equipment:
scanning accuracy ±0.03mm; machining accuracy ±0.1mm; roughness Ra1.6

# Collaboration Format 合作模式

**Contract research** 合同科研

**Complete the research and development of customer specific tasks through marketization contracts**

**Achievements** 成效

- **Over 100 projects** 超过100个项目
- **Over 100 million contracts income** 合同金额过亿
- **Over 80 customers served** 服务80家以上客户

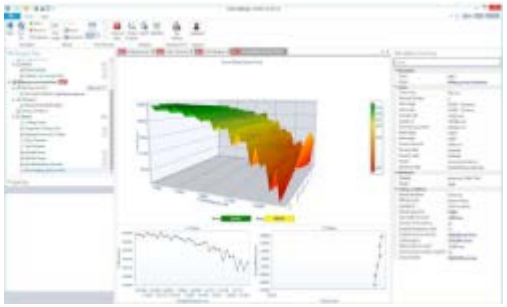
# Collaboration Format 合作模式

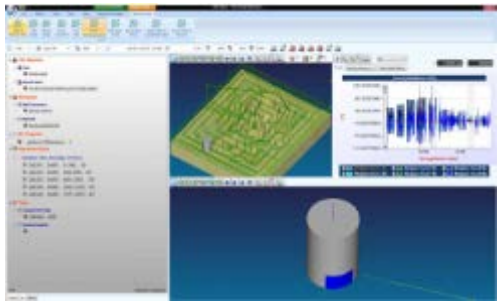
**Technology transfer** 技术转移

**Technology achievements Transfer and Import by Marketization Mode**

**Achievements** 成效

- **Transfer “Robotic grinding technology” to CRRC by 21 million** 机器人磨抛技术2100万转让至中国中车集团
- **Import “Cutpro&Machpro” Simulation technology from MAI** 引进 UBC Cutpro和Machpro高端仿真技术开发应用





# Collaboration Format 合作模式

**Joint Laboratory** 联合实验室

**Establishing joint innovation center or lab with enterprises and research institutes**

**Achievements** 成效

- **15 innovation lab with Local enterprises and research institutes** 15个本土研究机构联合实验室

# Collaboration Format 合作模式

**Business Incubator** 企业孵化

**Complete the research and development of customer specific tasks through market-oriented contracts**

**Achievements** 成效

- **Incubating 20 enterprises** 孵化20家企业
- **Establishing a joint venture company with CRRC, 50 million registered capital** 与中国中车合资孵化智能装备科技公司（5000万注册资本）



# Summary

- A wide range of almost unlimited opportunities in AI and robotics
- With new technologies, robots will become increasingly ubiquitous, Tri-Co robots will be the future of robotics
- Challenging, difficult but exciting road ahead for robotics, especially AI, smart sensors and control

# Thanks!