Lecture 02
Design Challenges with CoBots

Week 01

Friday, 0800-0950, Room 235, New Engineering Building

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Agenda

Week 01, Friday January 15, 2021

A Review of Robot Design Towards Collaboration

A Historical Note on Collaborative Robots

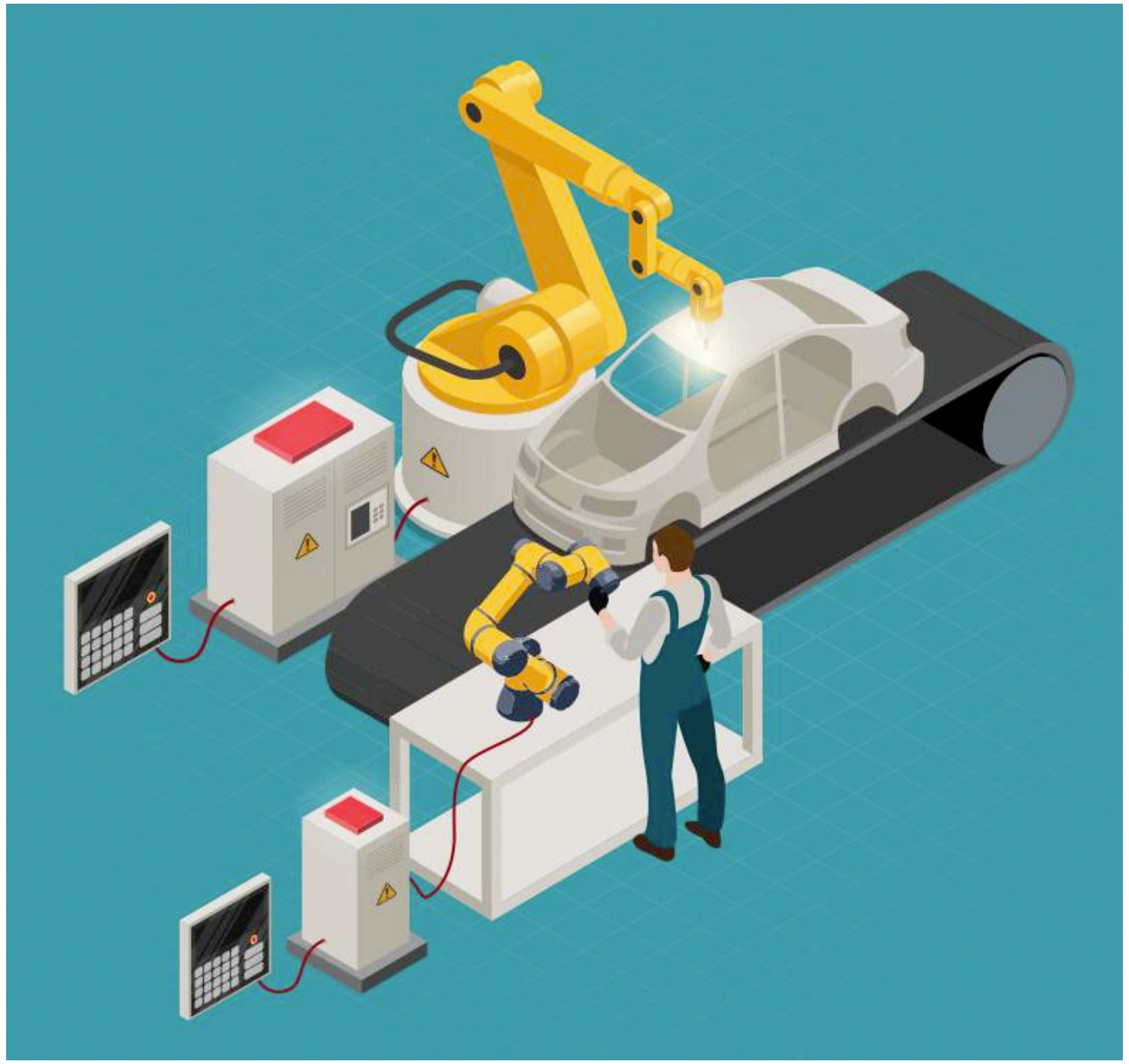
Examples of Engineering Specifications

Tell us about yourself

Factory Robot vs. Collaborative Robot

Factory Robot vs. Collaborative Robot

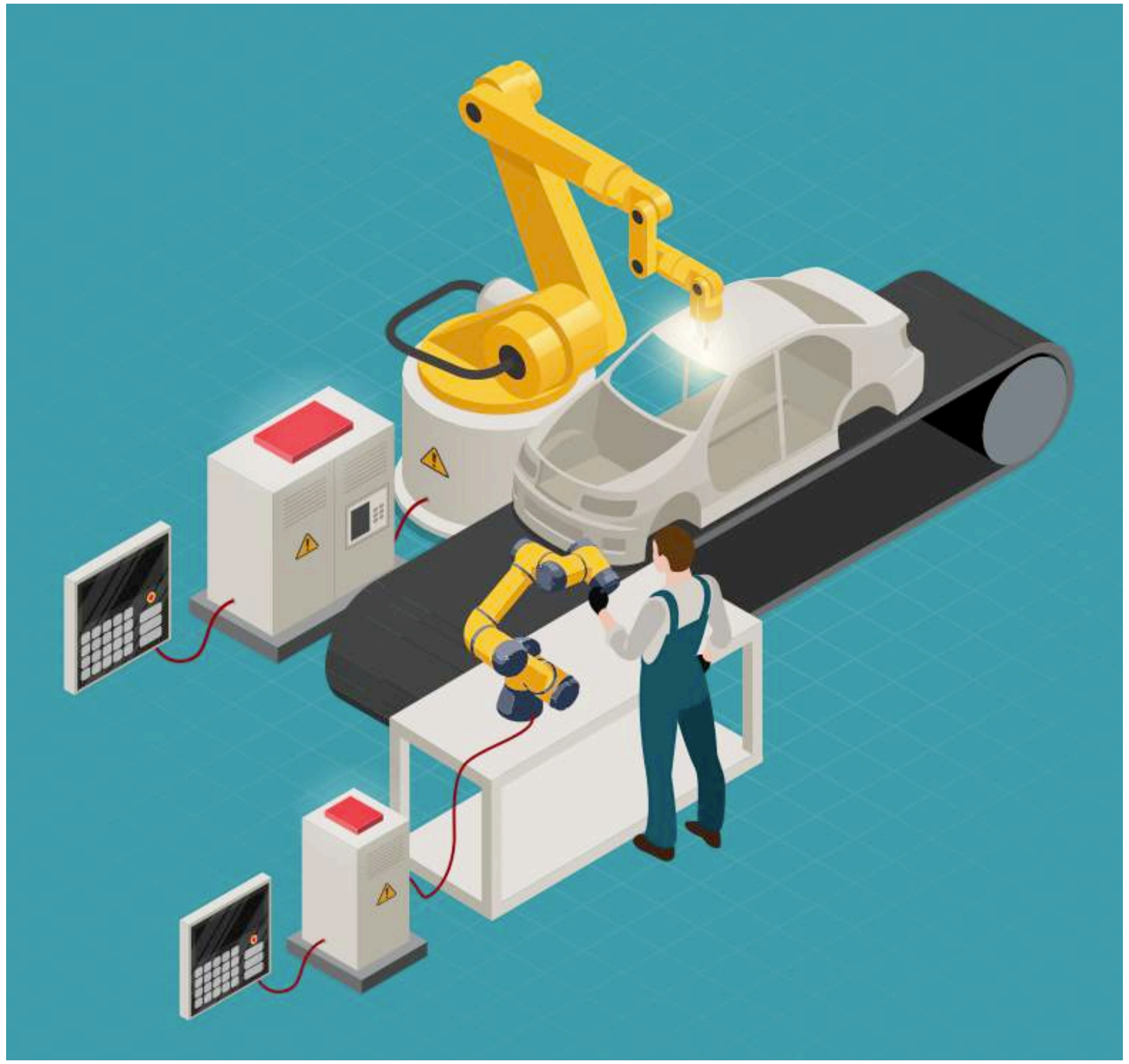
From engineering need to design specifications



Factory Robot vs. Collaborative Robot

From engineering need to design specifications

- Factory robots perform automated programmable movements in manufacturing.



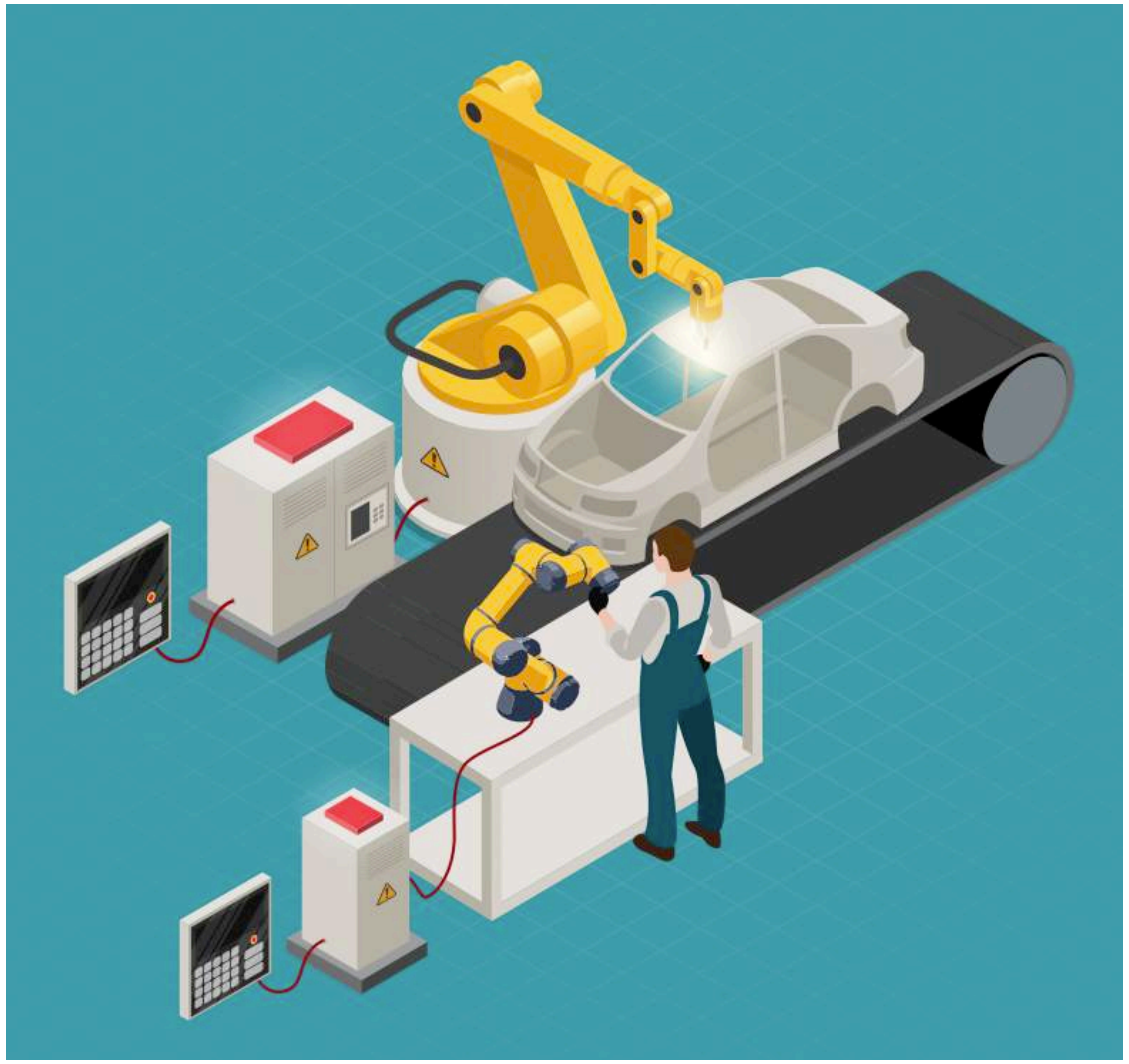
- Cobots work side by side with humans to improve work quality.

Factory Robot vs. Collaborative Robot

From engineering need to design specifications

- Factory robots perform automated programmable movements in manufacturing.

- Mechanical or sensor technologies can help keep factory robots from interfering with human activity.

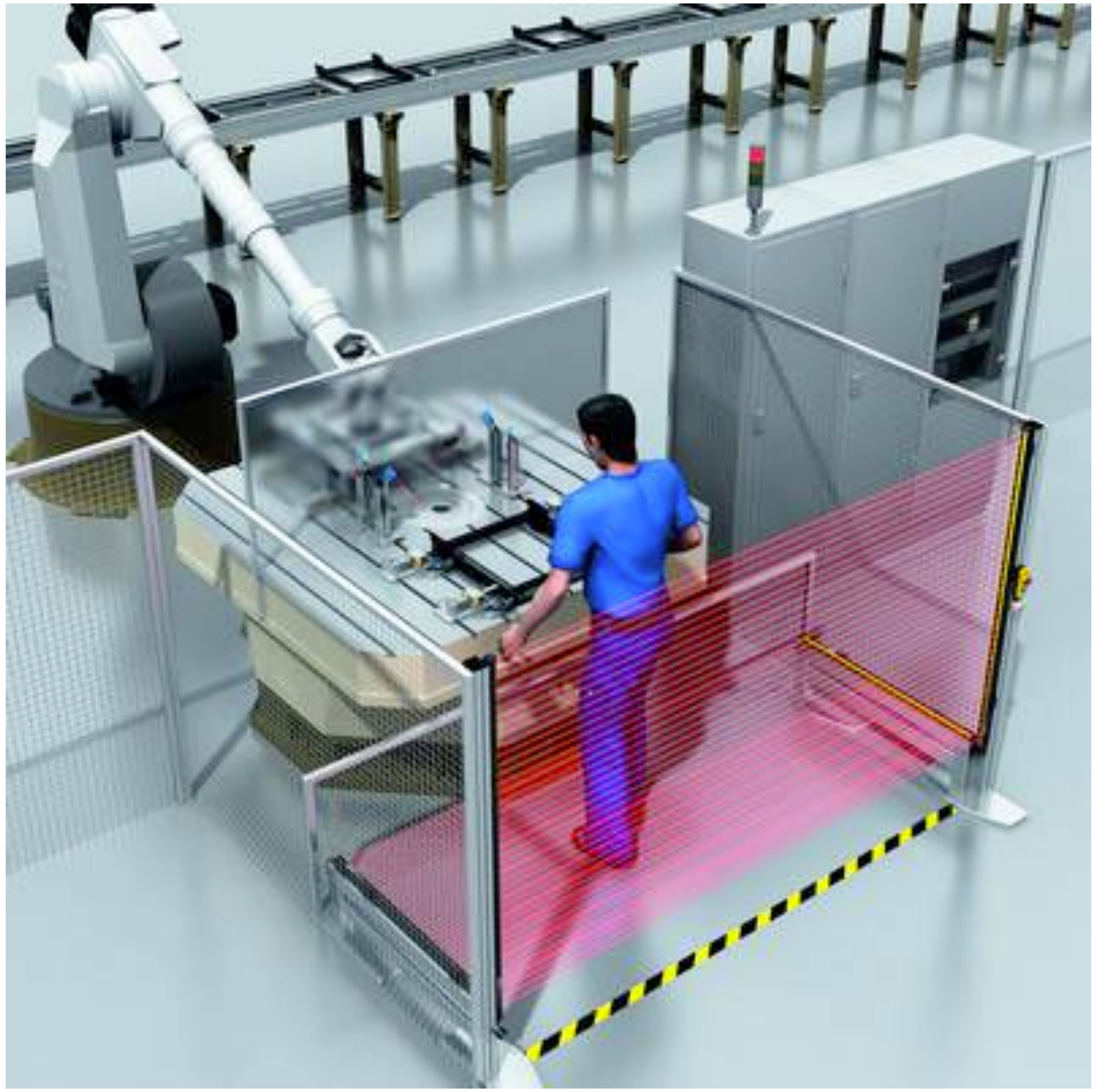


- Cobots work side by side with humans to improve work quality.

- A cobot can sense and stop movement, helping create a safer working environment.

Towards a safer working environment

Mechanical or sensor technologies can help keep robots from interfering with human activity



What type of task is the robot supposed to do?

What type of task is the robot supposed to do?

Different robot types have different advantages depending on the application

- Articulated
- Cartesian
- Selective Compliance Assembly Robot Arm (SCARA)
- Delta
- Cylindrical
- Polar and more …

Articulated Robot

Features a rotary axis and can range from simple three-axis structures to 10 or more joints

- The manipulator connects to the base with a twisting joint.
- A rotary axis connects the links in the manipulator.
- Each axis provides an additional degree of freedom, or range of motion.

Cartesian Robot

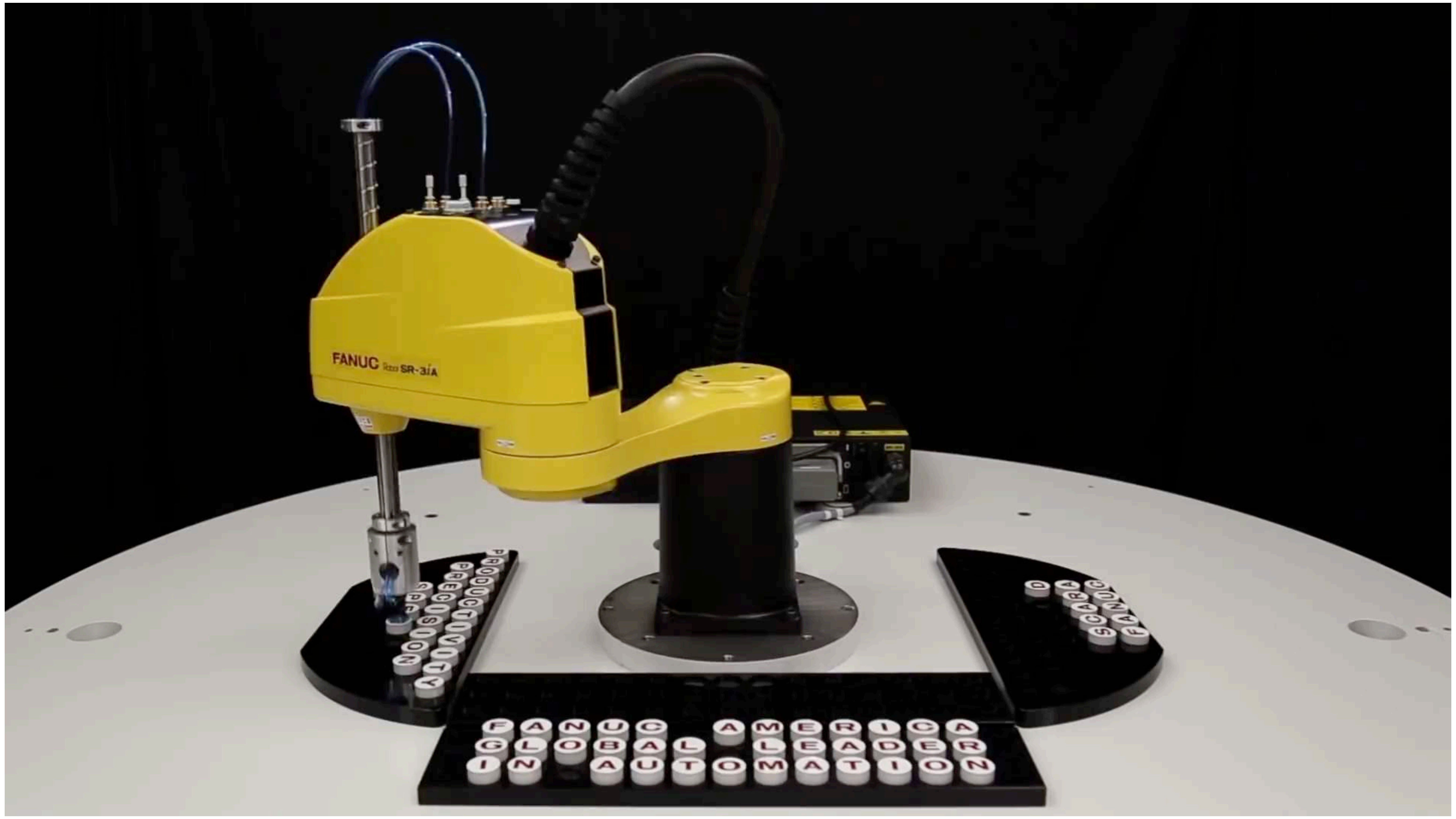
These are also called rectilinear or gantry robots

- Cartesian robots have three linear axes that use the Cartesian coordinate system (x, y and z).
- They may have an attached axis that enables rotational movement.
- Three prismatic joints facilitate linear motion along the axis.

Selective Compliance Assembly Robot Arm (SCARA)

Commonly used in assembly applications

- This selectively compliant manipulator for robotic assembly is primarily cylindrical in design.
- It features two parallel axes that provide compliance in one selected plane.



Delta Robot

These spider-like robots are built from jointed parallelograms connected to a common base

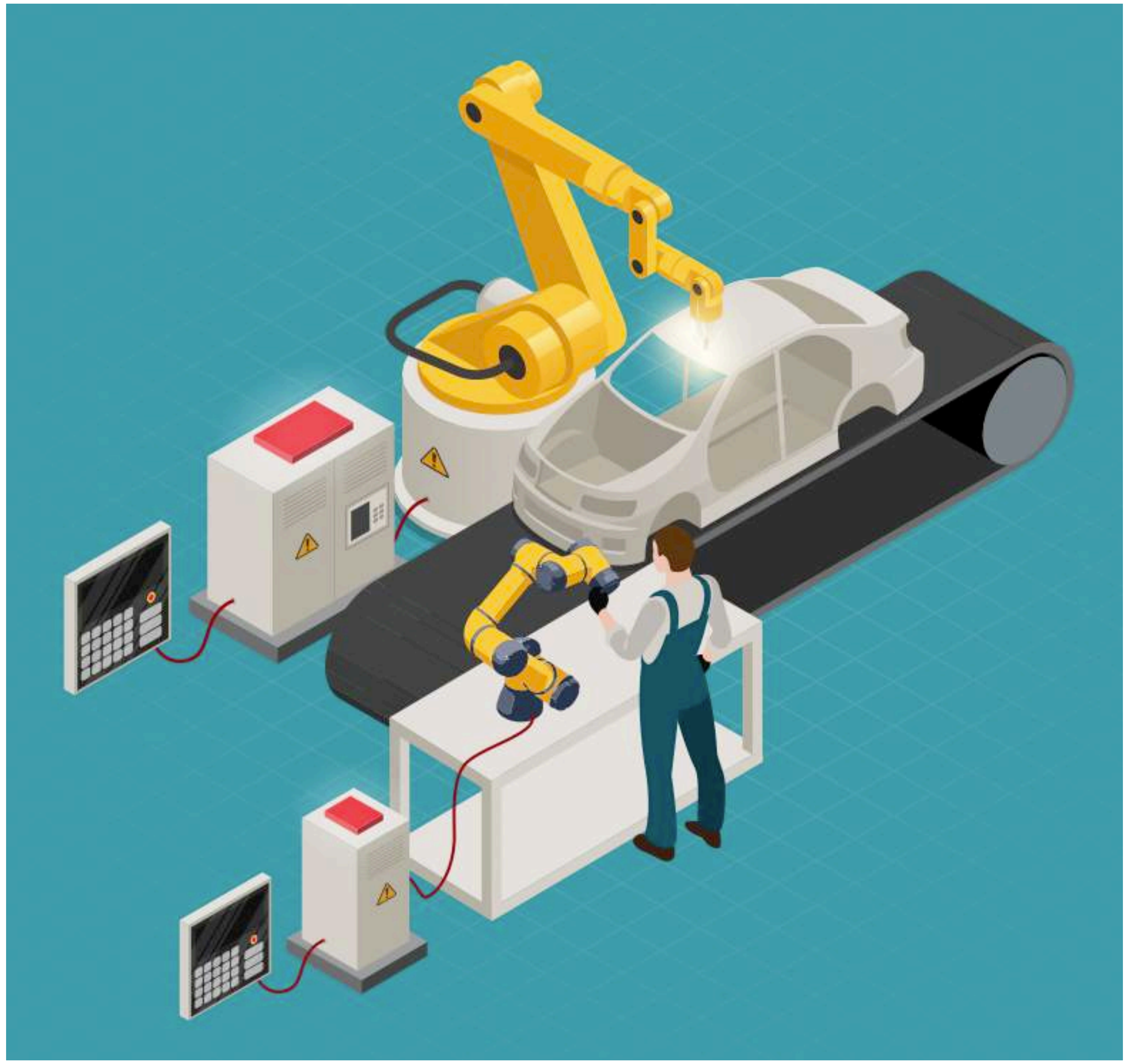
- A delta robot has three axes for the parallelograms; for the end effector, it can have one to three axes.
- The parallelograms move a single EOAT in a dome-shaped work area.
- Heavily used in the food, pharmaceutical and electronic industries, this robot configuration is capable of delicate, precise movements.

What are the Building Blocks of a Robotic System?

What are the Building Blocks of a Robotic System?

Engineering considerations that you need to understand and obtain specifications for

- Controller System
- Manipulator
- Teaching Pendant
- Robotic End Effector
- Vision and Sensors
- …

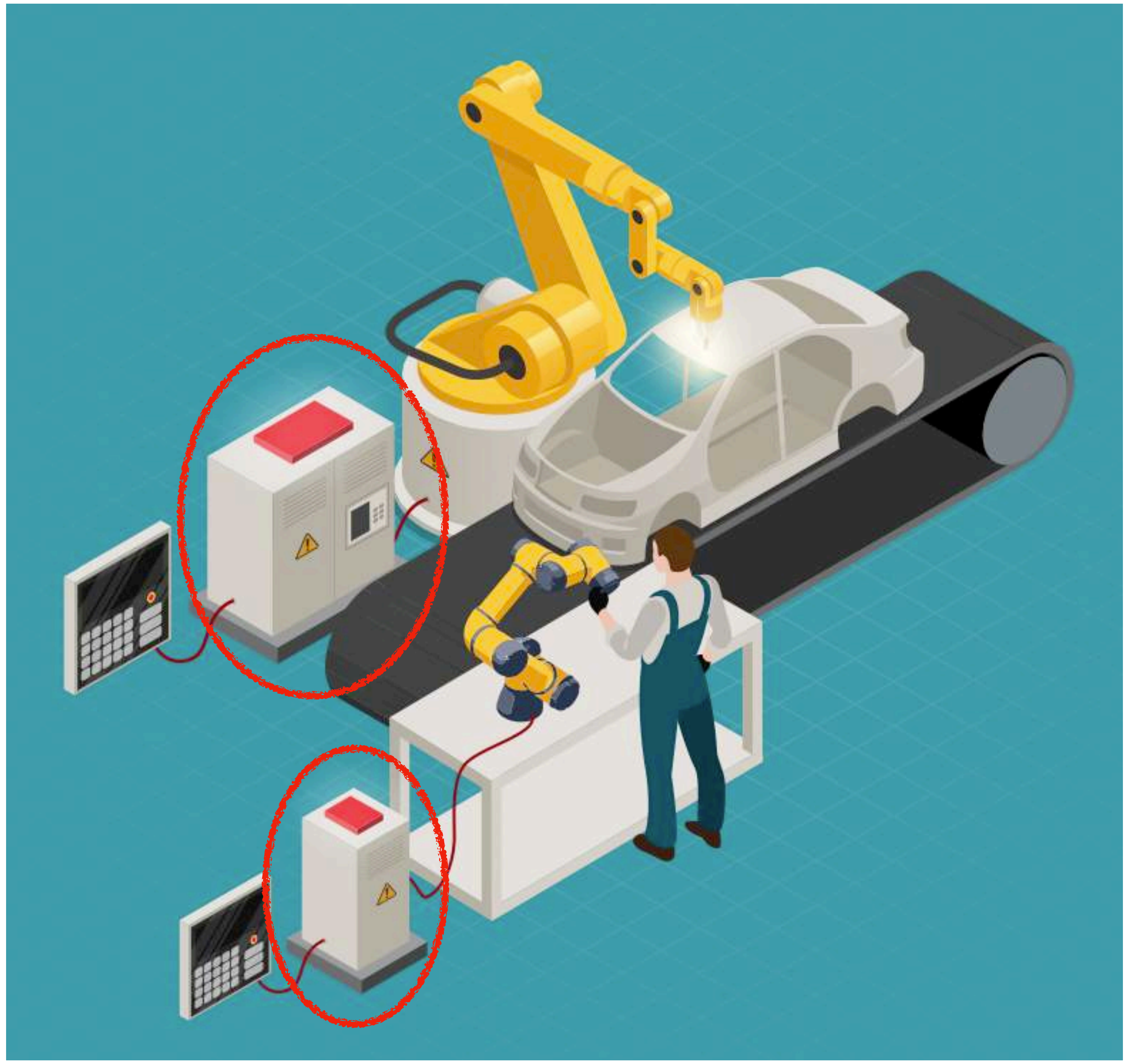


Controller System

The International Organization for Standardization (ISO) 8373:2012

- The ISO 8373 standard states, “A set of logic control and power functions which allows monitoring and control of the mechanical structure of the robot and communication with the environment [equipment and users].”

- This is the robot’s brain, and can include a motion controller, both internal and external communication systems, and any potential power stages.

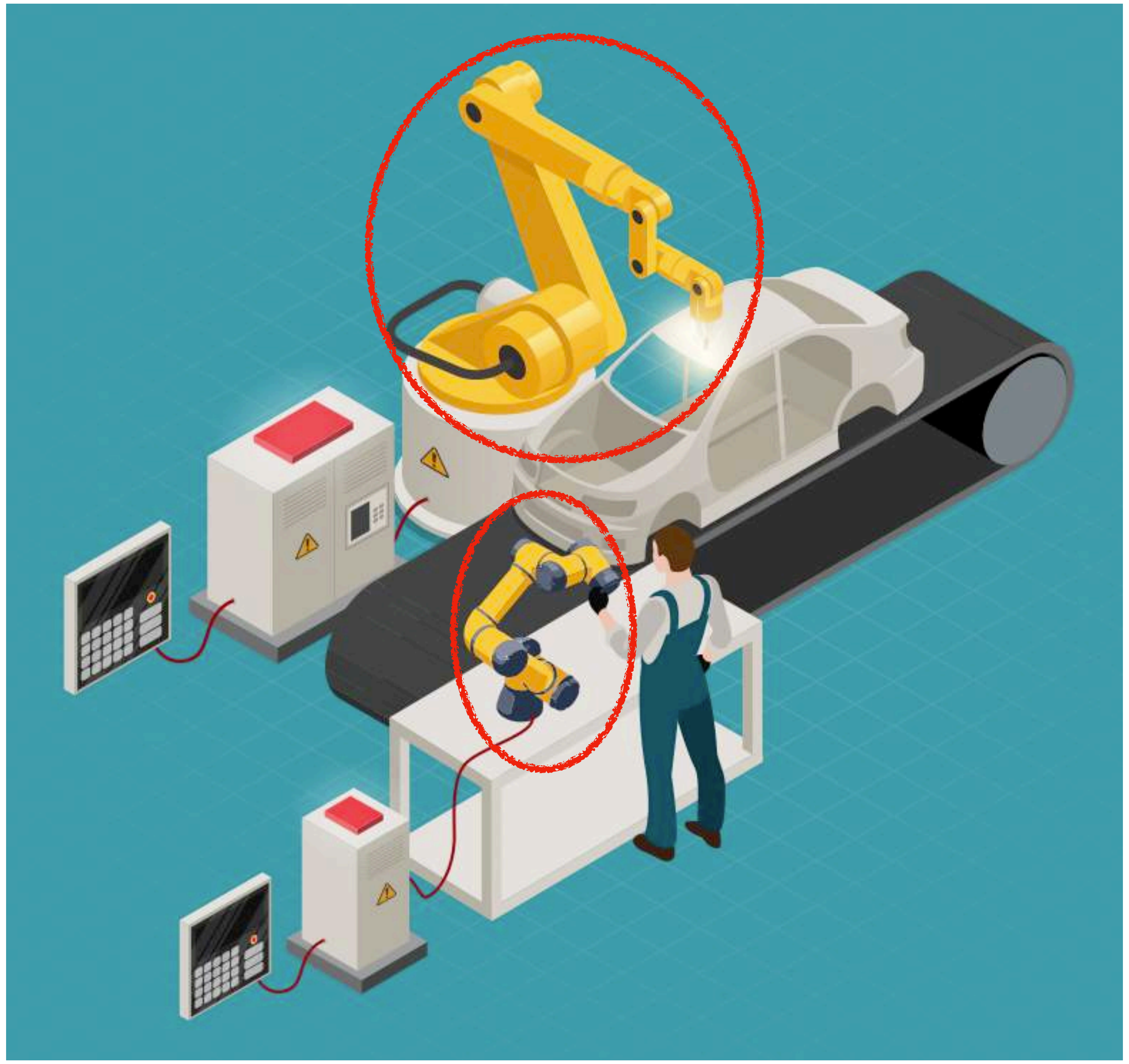


Manipulator (Robotic Arm)

The International Organization for Standardization (ISO) 8373:2012

- The ISO 8373 standard also states "A machine in which the mechanism usually consists of a series of segments, jointed or sliding relative to one another, for the purpose of grasping and/or moving objects (pieces or tools) usually in several degrees of freedom or axes. *A manipulator does not include an end effector*."

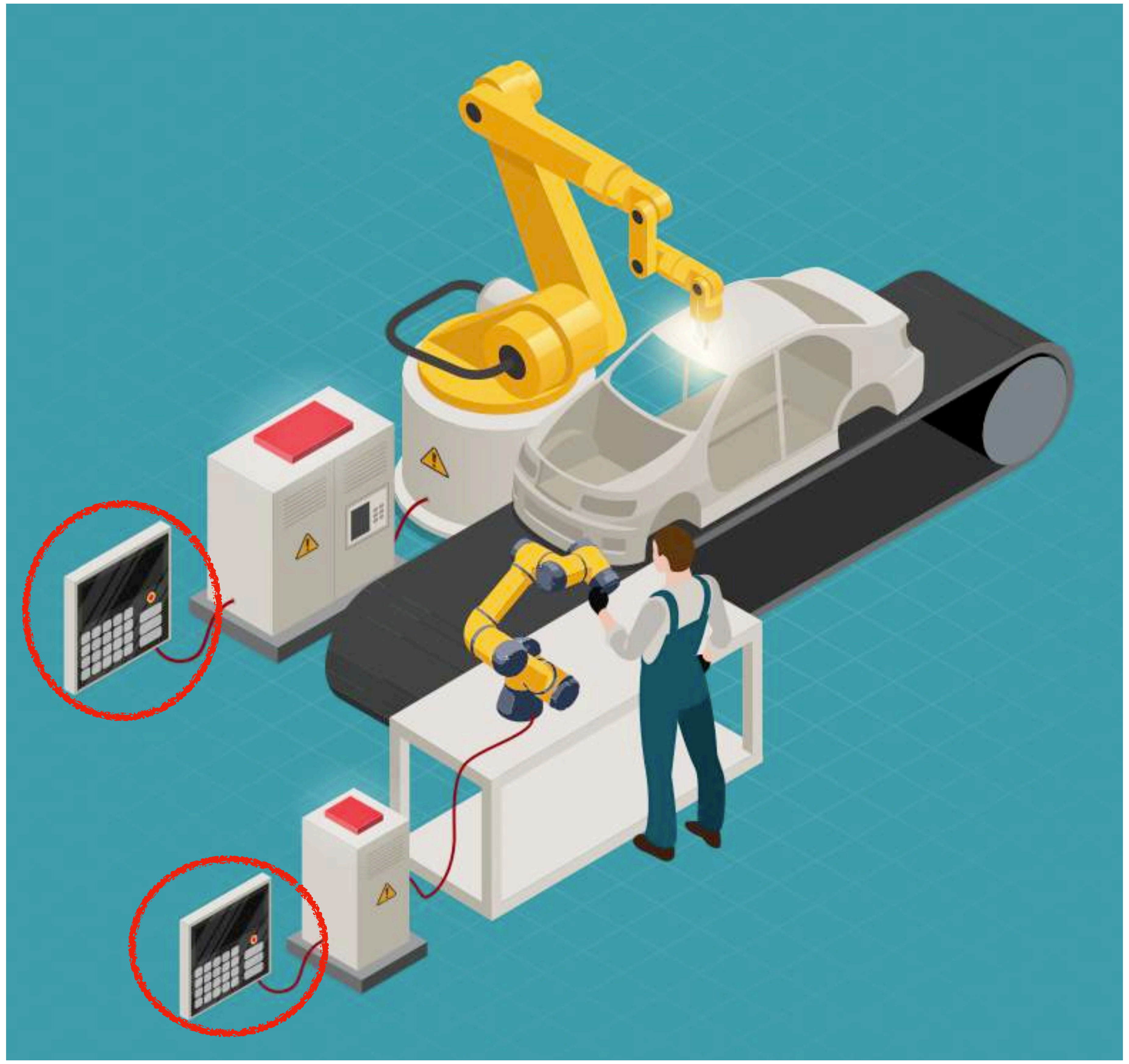
- It's the part of the robot that defines how many axes the robot is implementing to achieve the movement required to perform a task.



Teaching Pendant

The International Organization for Standardization (ISO) 8373:2012

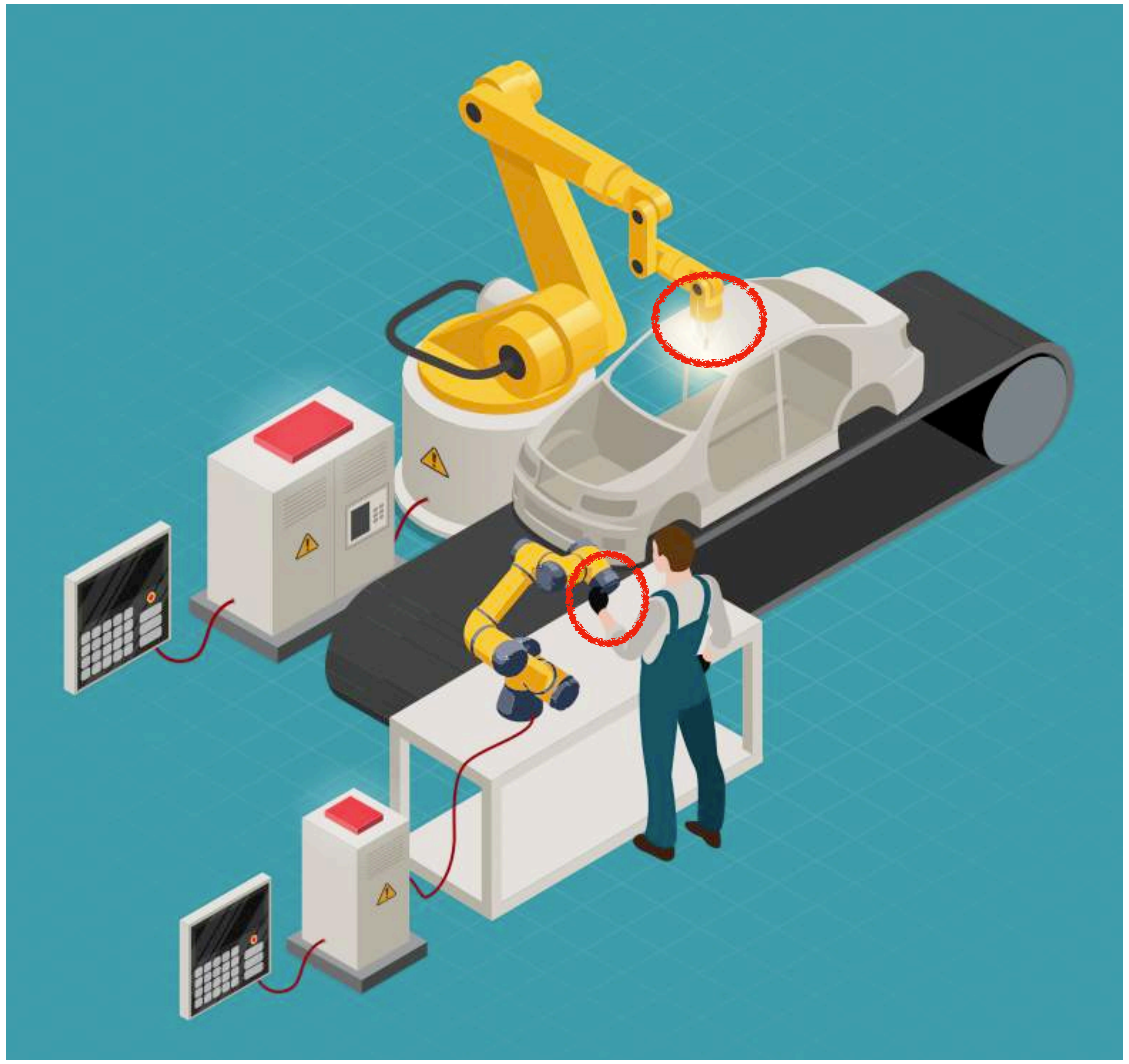
- Multifunctional portable equipment used to program and teach an industrial robot.
- The pendant typically consists of an LCD touch panel, an enable button and an e-stop button.
- The teaching pendant connects to the robot controller system.



Robotic End Effector

The International Organization for Standardization (ISO) 8373:2012

- A device connected on the robot “wrist” or end-of-arm tooling (EOAT).
- The system controller controls the robotic end effector by using either discrete input/output (I/O) for simple tools or industrial communication protocols for more advanced tools.



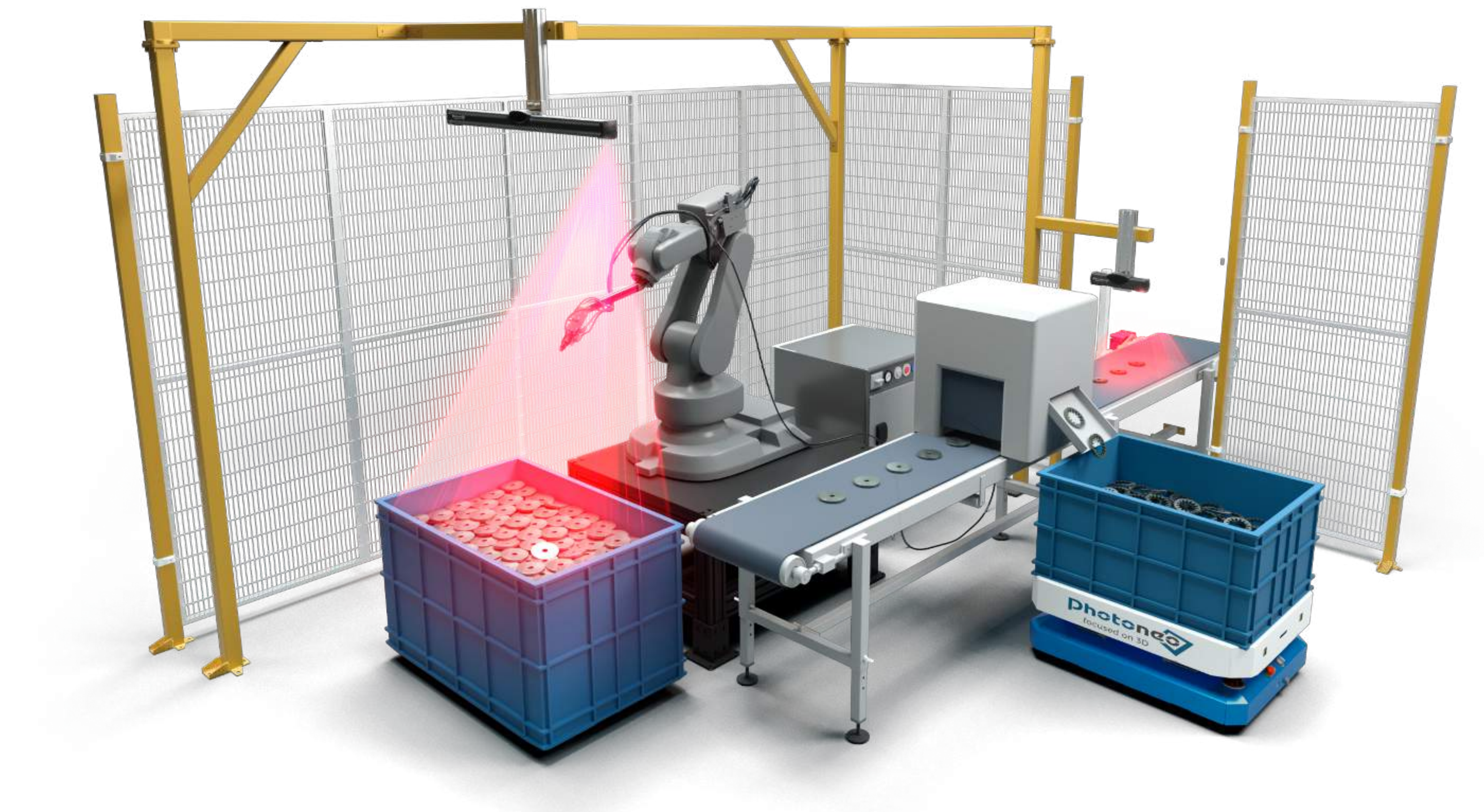
Vision and Sensors

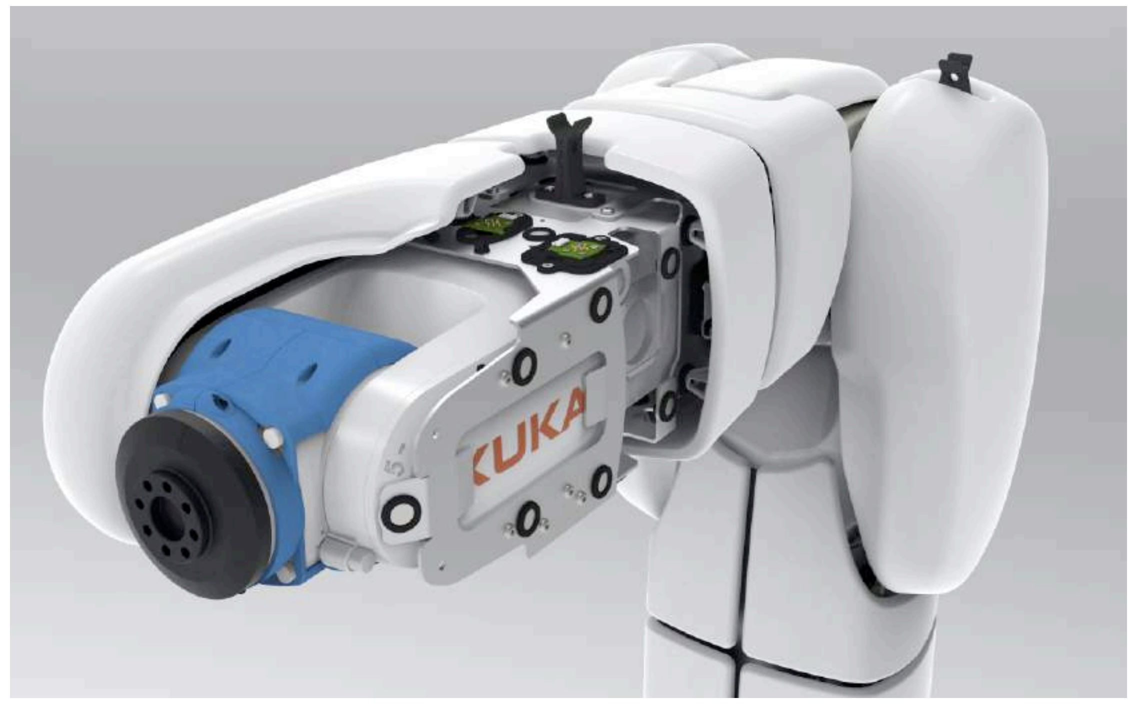
The International Organization for Standardization (ISO) 8373:2012

- These parts of the robot have the ability to scan the surrounding environment and stop (in the case of an industrial robot) or reduce (in the case of a cobot) a robot's speed when humans approach.

- Vision/sensing is implemented with light detection and ranging (LIDAR), a radar-based safety area scanner or 3D cameras.

- In addition to the safety area scanner, cobots sometimes wear a sensor-based "safety skin" that stops the robot arm when a human touches it or is in proximity.



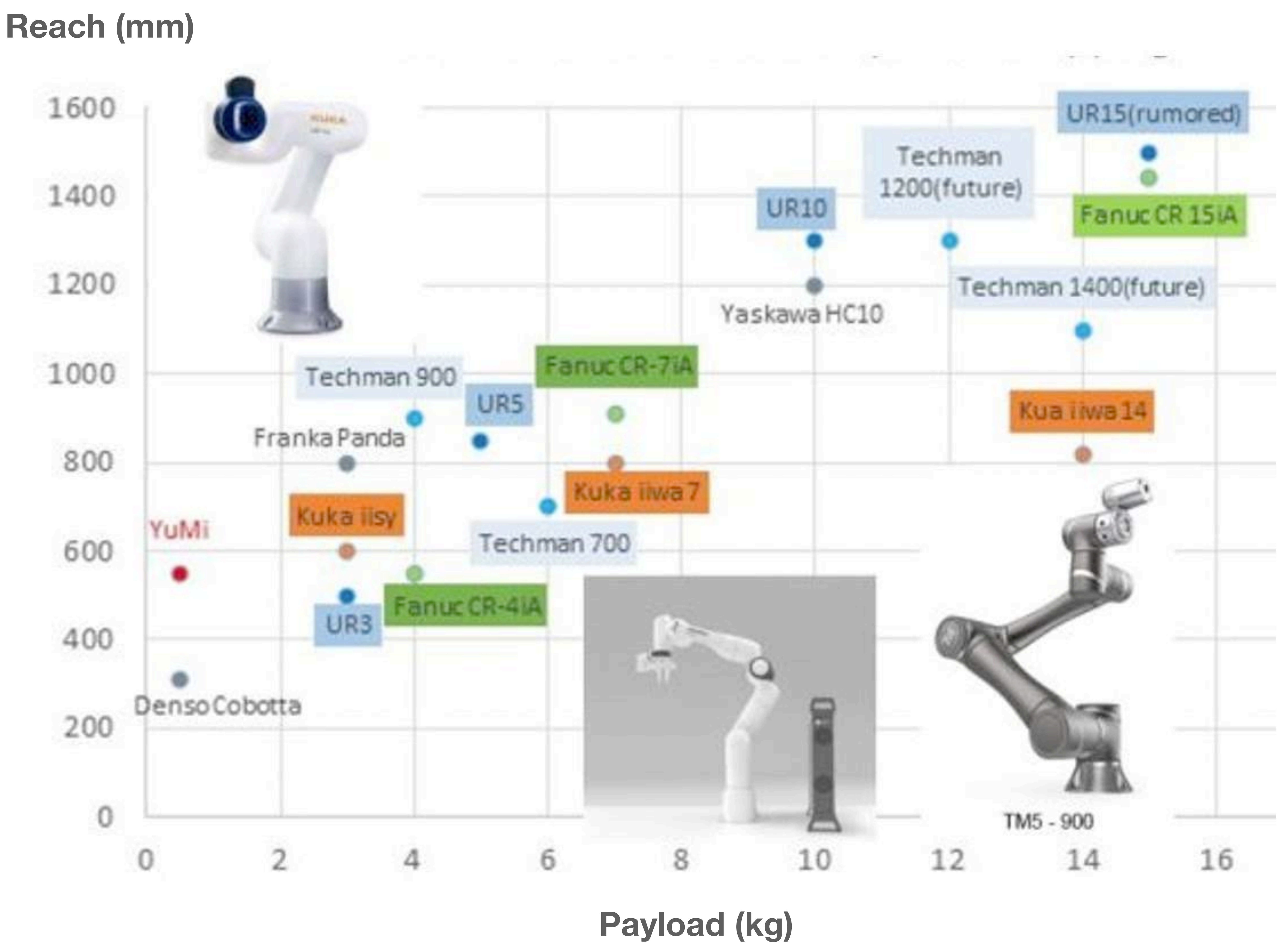


What amount of payload (weight) and reach will the robot have?

What amount of payload (weight) and reach will the robot have?

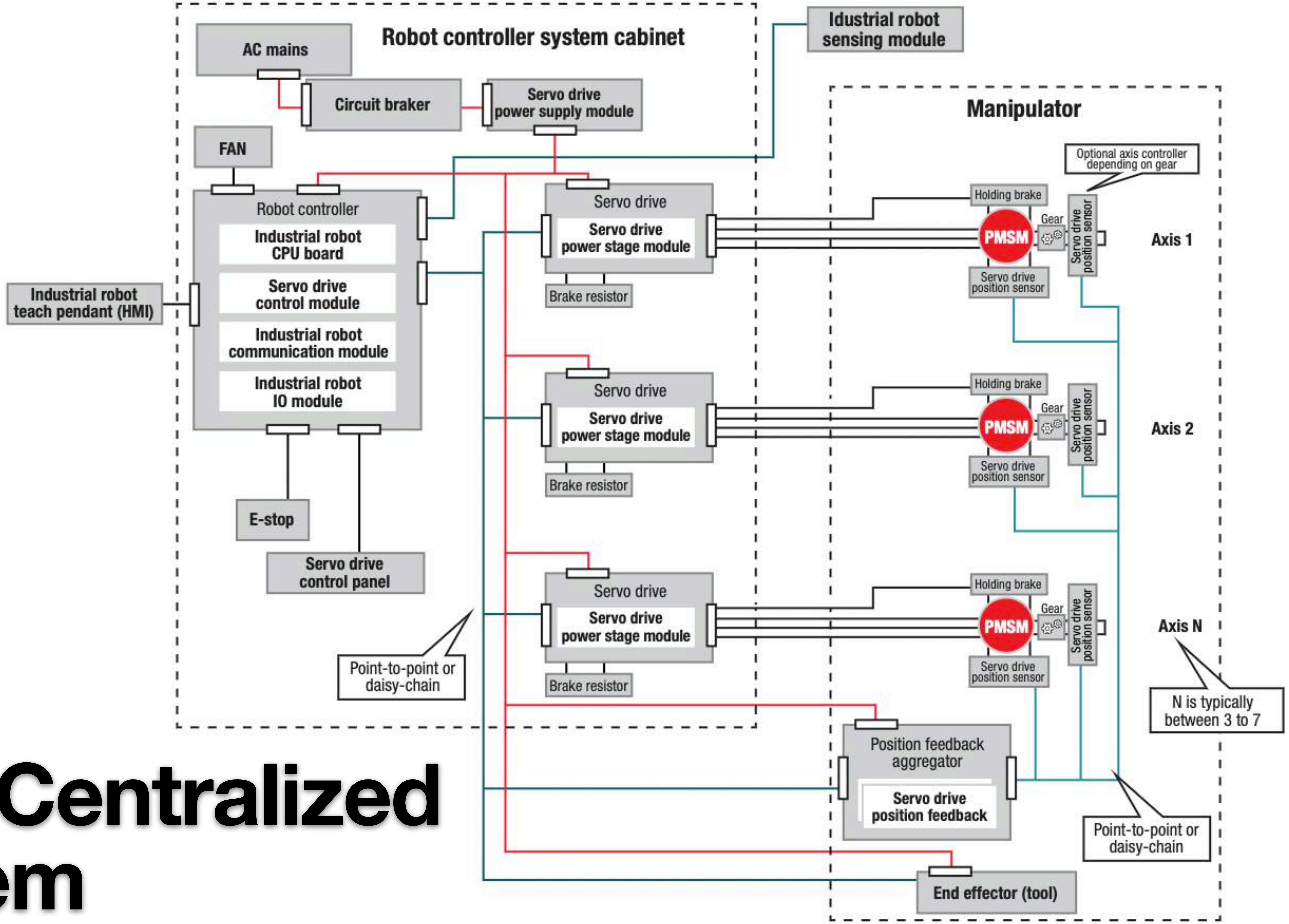
If heavier the object to move, then the motor needs to generate more force

- This force is generated with electric energy and is provided to the motor from the power stage.
- This power requirement is part of deciding whether the robot will be a high- or low-voltage system.
- A high-voltage robot system will require defined isolation architecture for safe operation.



Will the electronics be centralized into the system controller?

- In a centralized system, <u>the robot controller cabinet includes most of the electronic modules</u> that control the robot manipulator
- Usually leading to a larger size of the controller box



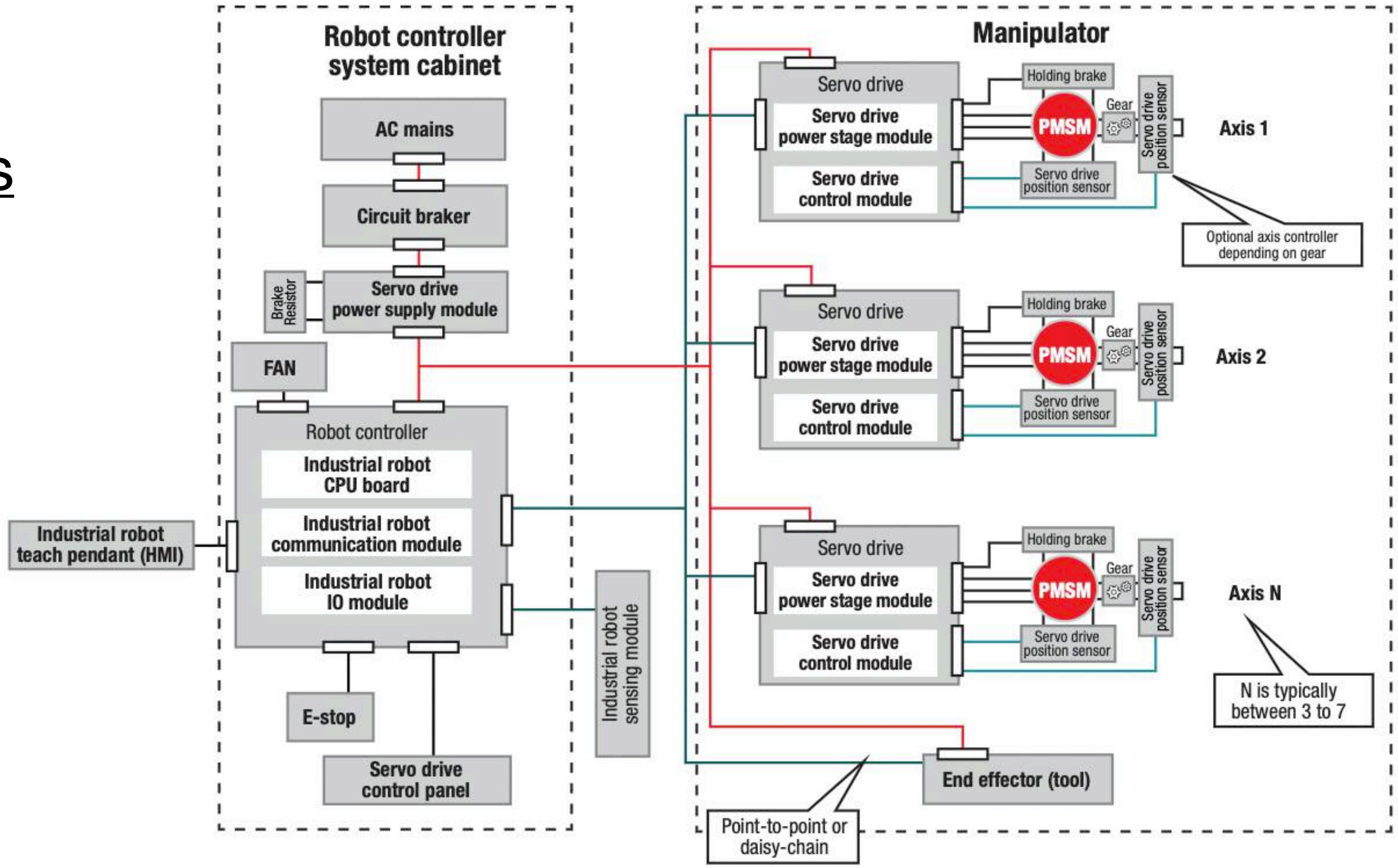
Example of a Centralized Robotic System

Example of a Decentralized Robotic System

some modules move to the robot manipulator to support form factor of the cabinet, cabling and more

- When decentralizing electronic content, it is important to remember that <u>the environments where the electronics are now used are not the same as the environments of a centralized system.</u>

- This environment change necessitates a <u>re-specification of the electronics</u> and typically requires redevelopment of part of the system.



How will the different subsystems of the robot communicate with each other?

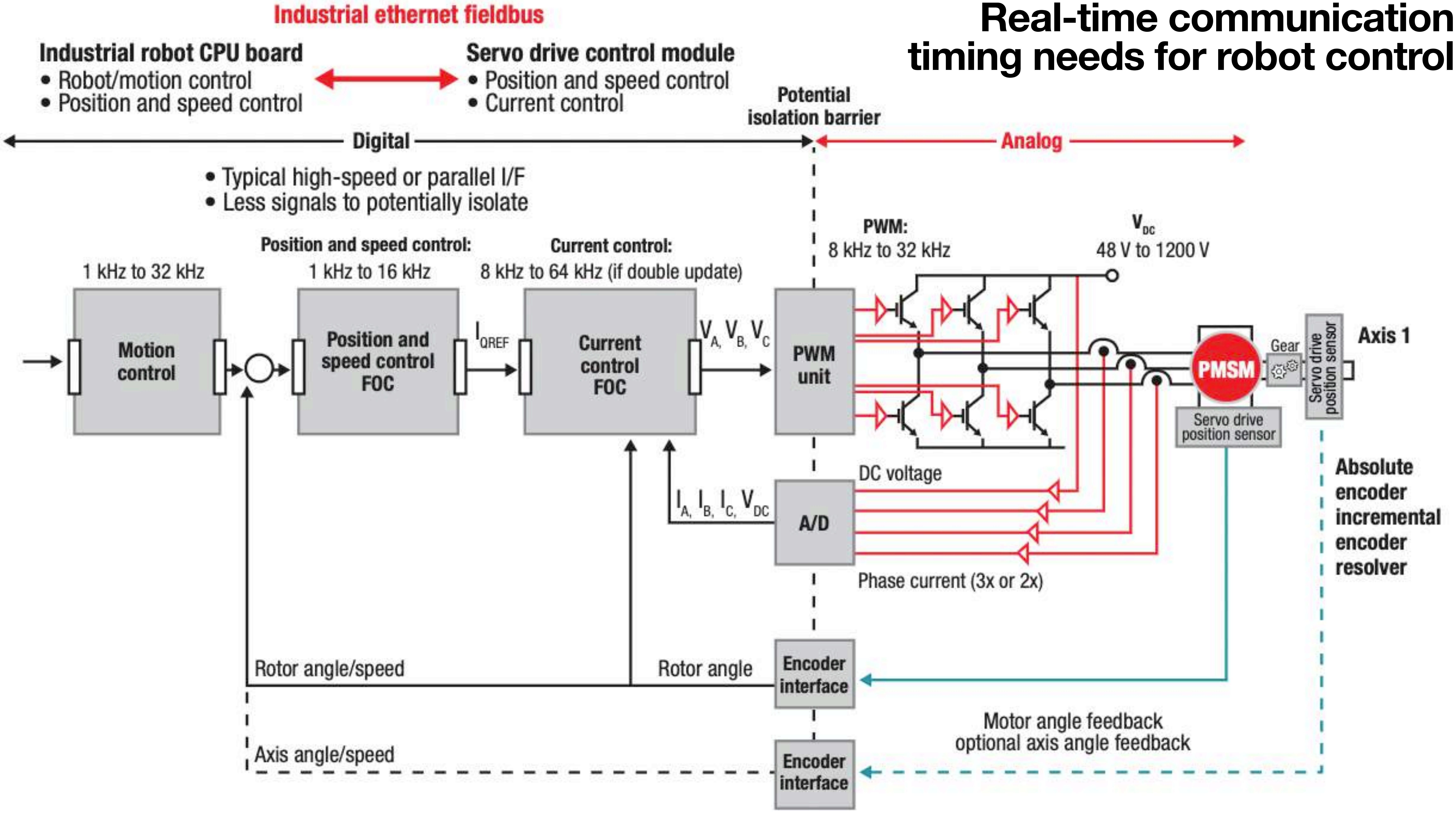
What are the interface requirements?

How does the programming interface work?

Will the robot operate from the user interface or through task programming?

Will you need an extra interface to connect the teaching pendant or joystick in order to enable operator functionality?

Real-time communication timing needs for robot control



Is the robot a nonadaptive robot or an adaptive robot?

Is the robot a nonadaptive robot or an adaptive robot?

Any feedback received from the environment, or ways to react

- A **nonadaptive robot** does not receive feedback from the environment and will execute its task as programmed.
- **Adaptive robots** use input and output data to generate environment data. With this data, the robot can react to environmental changes and stop its task if necessary.
  - It is important to define the environment data to which the robot is reacting. The data might be pre-defined parameters, like material amounts or sizes or shapes for quality definitions.
  - Or it might be uncontrolled parameters, like having people move around the robot or malfunctions that when detected put the robot in a safe state.

A Historical Note on Collaborative Robots

Early Concept of CoBot

From 1994 to 2003

General Motors
GM FOUNDATION

IEEE TRANSACTIONS ON ROBOTICS AND AUTOMATION, VOL. 17, NO. 4, AUGUST 2001 377

Cobot Architecture

Michael A. Peshkin, *Member, IEEE*, J. Edward Colgate, *Member, IEEE*, Witaya Wannasuphoprasit, Carl A. Moore, R. Brent Gillespie, *Member, IEEE*, and Prasad Akella, *Member, IEEE*

Abstract—We describe a new robot architecture: the collaborative robot, or cobot. Cobots are intended for direct physical interaction with a human operator. The cobot can create smooth, strong virtual surfaces and other haptic effects within a shared human/cobot workspace. The kinematic properties of cobots differ markedly from those of robots. Most significantly, cobots have only one mechanical degree of freedom, regardless of their taskspace dimensionality. The instantaneous direction of motion associated with this single degree of freedom is actively servo-controlled, or steered, within the higher dimensional taskspace. This paper explains the kinematics of cobots and the continuously variable transmissions (CVTs) that are essential to them. Powered cobots are introduced, made possible by a parallel interconnection of the CVTs. We discuss the relation of cobots to conventionally actuated robots and to nonholonomic robots. Several cobots in design, prototype, or industrial testbed settings illustrate the concepts discussed.

Index Terms—Cobot, ergonomics, haptics, human/machine interaction, intelligent assist device (IAD), nonholonomic, passive.

US005952796A

United States Patent [19]
Colgate et al.

[11] **Patent Number: 5,952,796**
[45] **Date of Patent: Sep. 14, 1999**

[54] **COBOTS**

[76] Inventors: **James E. Colgate**, 2210 Ashbury, Evanston, Ill. 60201; **Michael A. Peshkin**, 4843 Fargo, Skokie, Ill. 60077

[21] Appl. No.: **08/959,357**

[22] Filed: **Oct. 28, 1997**

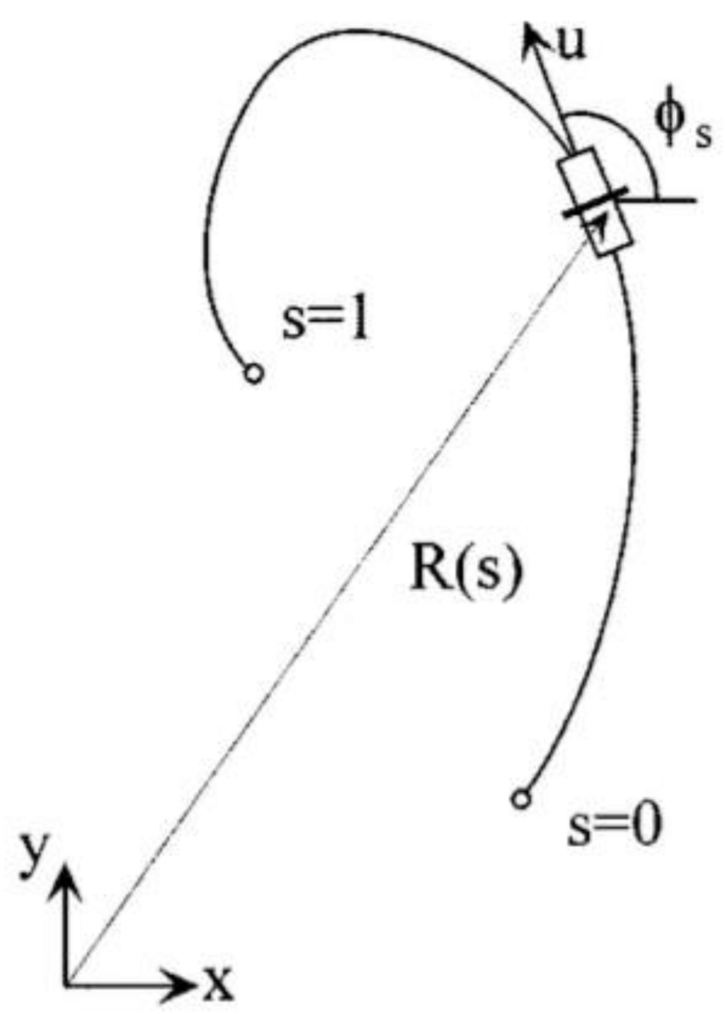
Related U.S. Application Data

[63] Continuation-in-part of application No. 08/605,997, Feb. 23, 1996.

[51] **Int. Cl.**[6] **H02K 7/00**
[52] **U.S. Cl.** **318/1**; 318/568.11; 901/19
[58] **Field of Search** 318/1, 2, 580, 318/587, 568.11, 568.12, 568.14, 625, 560; 901/1, 2, 4, 19, 20, 50; 180/6.44, 6.54–6.62

[57] **ABSTRACT**

An apparatus and method for direct physical interaction between a person and a general purpose manipulator controlled by a computer. The apparatus, known as a collaborative robot or "cobot," may take a number of configurations common to conventional robots. In place of the actuators that move conventional robots, however, cobots use variable transmission elements whose transmission ratio is adjustable under computer control via small servomotors. Cobots thus need few if any powerful, and potentially dangerous, actuators. Instead, cobots guide, redirect, or steer motions that originate with the person. A method is also disclosed for using the cobot's ability to redirect and steer motion in order to provide physical guidance for the person, and for any payload being moved by the person and the cobot. Virtual surfaces, virtual potential fields, and other guidance schemes may be defined in software and brought into physical effect by the cobot.



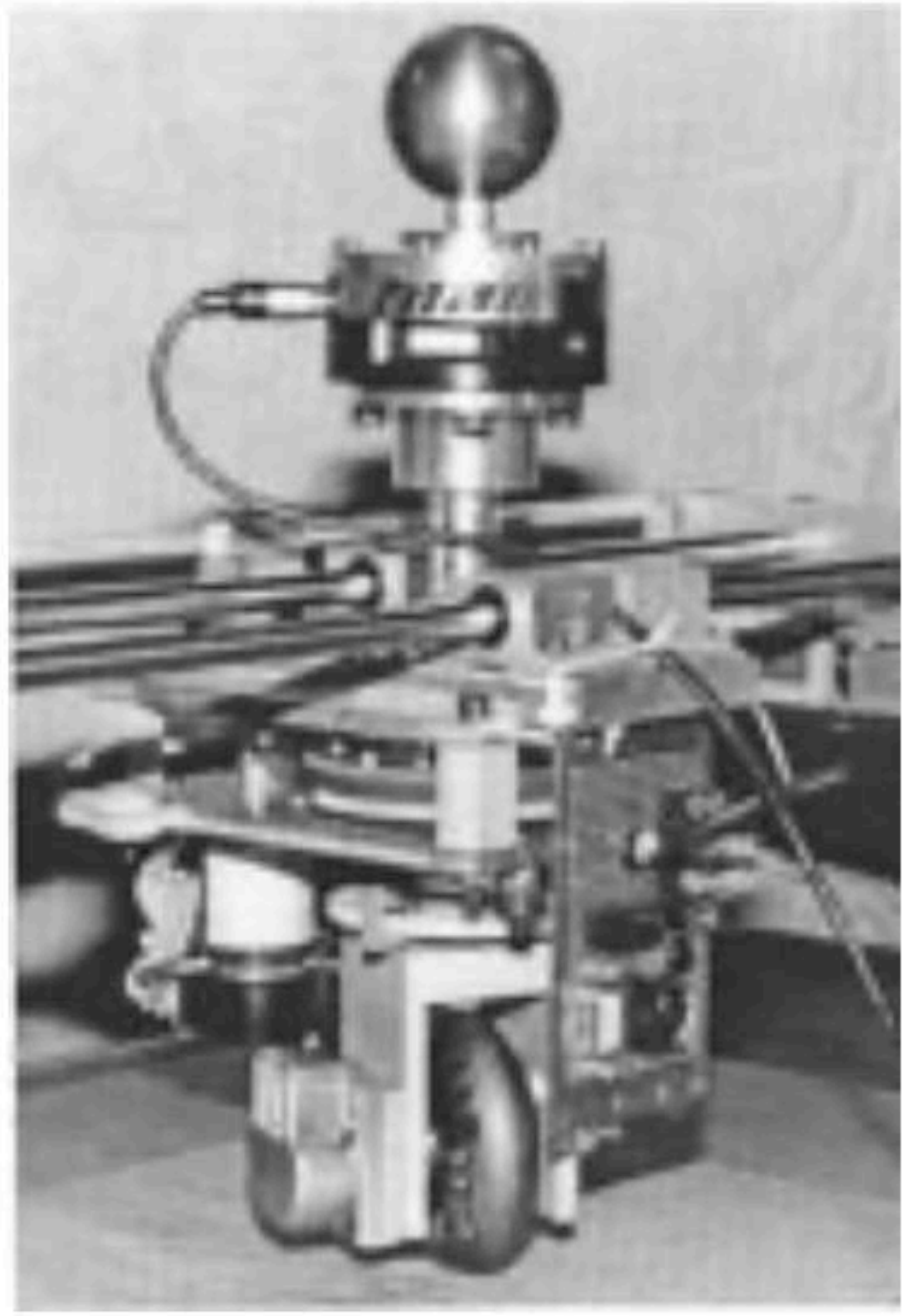
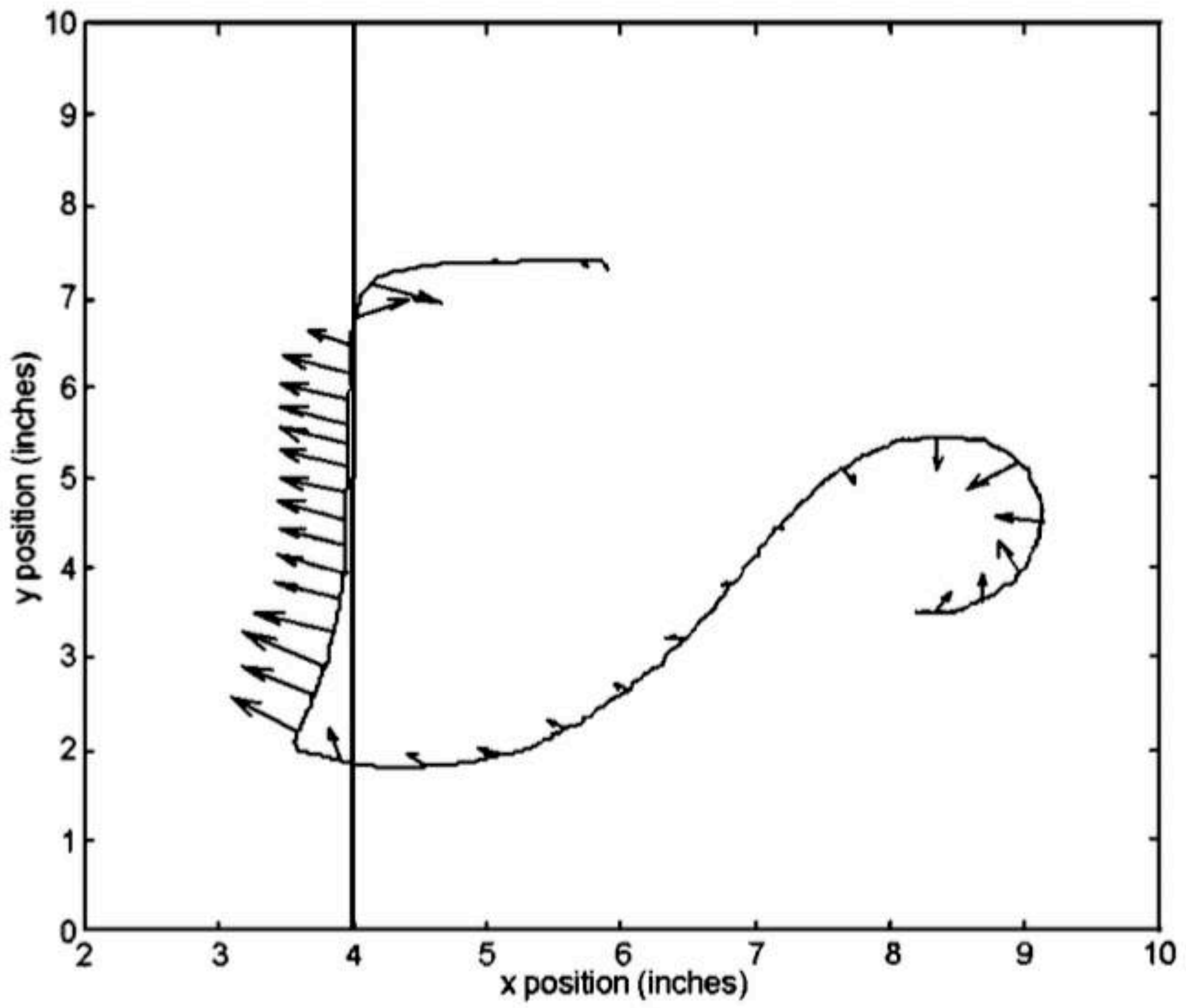
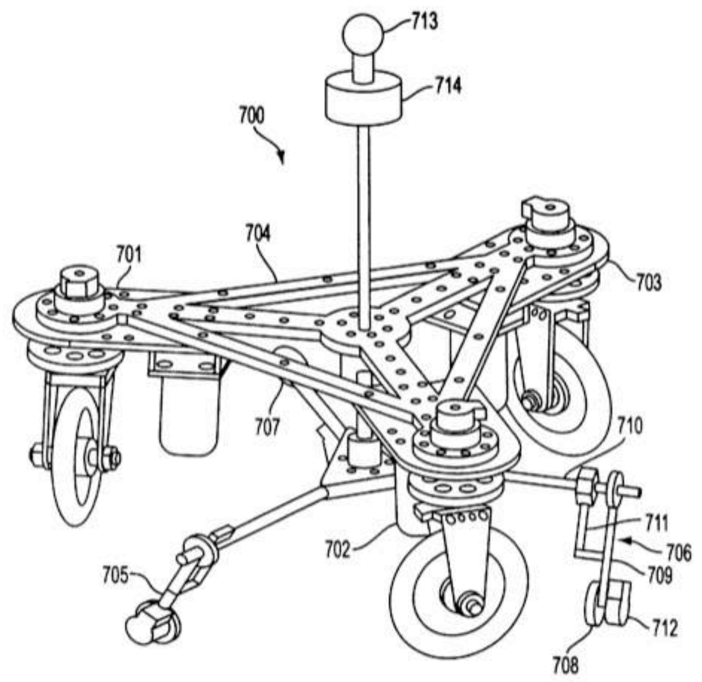
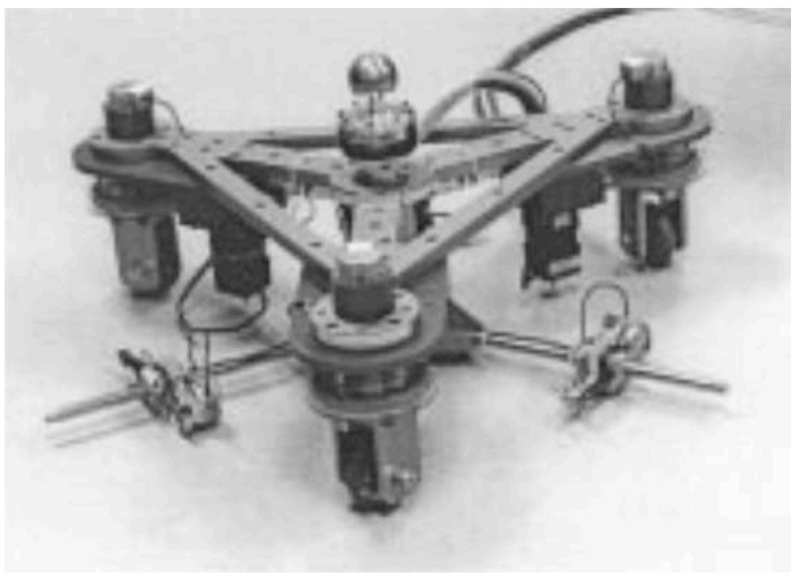


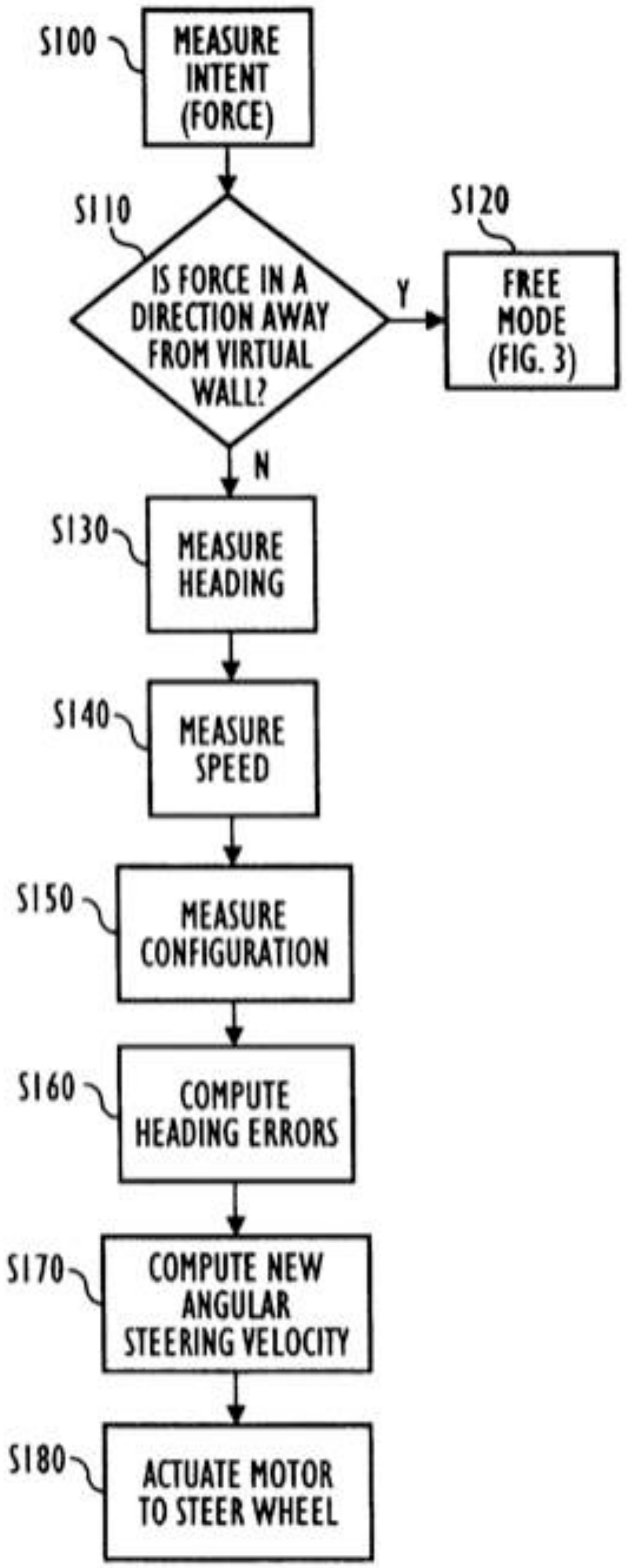
Fig. 1. A single wheel in contact with a planar rolling surface is the simplest cobot, having a 2-D taskspace. From top to bottom are the user's handle, a force sensor to measure the user's applied (xy) force, a rail system which holds the assembly upright and incorporates xy position sensors, a steering motor which can reorient the rolling direction of the wheel, and the "steerable transmission" which is central to all cobots—in this case a single free-rolling Rollerblade™ wheel. An encoder monitors the rolling speed of the wheel.



The trajectory (solid curve) and the applied user force (vectors)



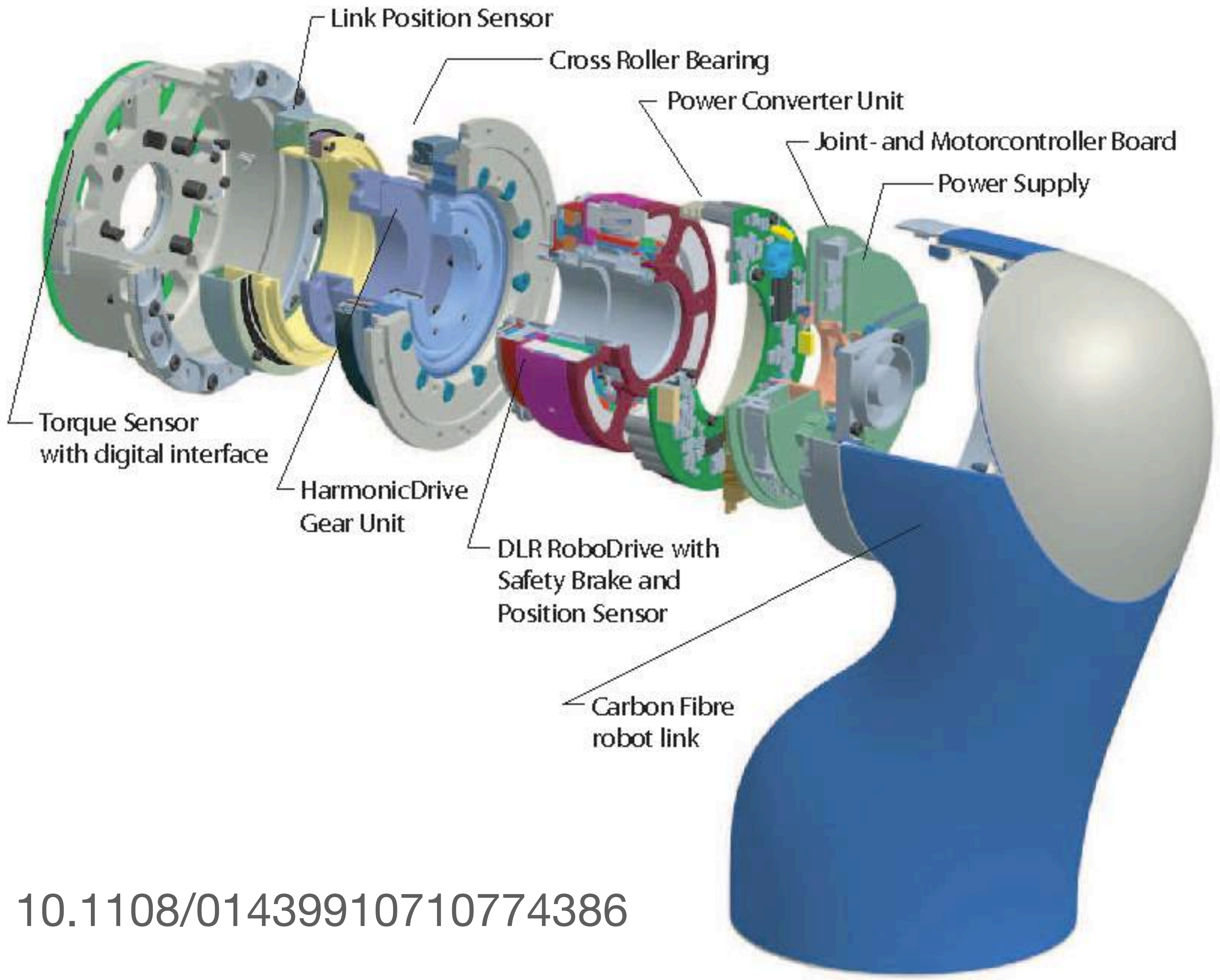




DLR/KUKA

From 2003 to 2013

- Integrated force/torque sensing at joint level

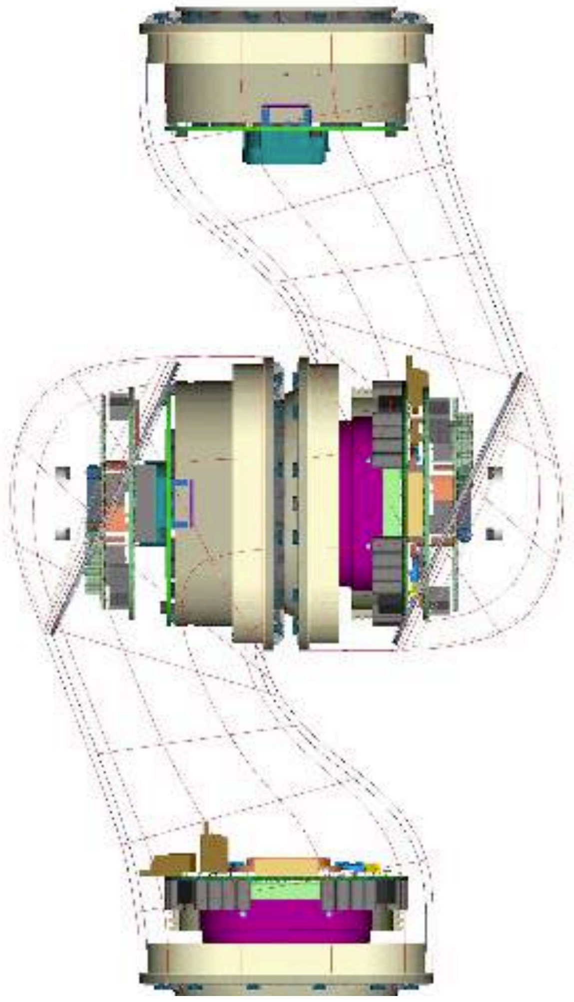


10.1108/01439910710774386

10.1109/ARSO.2011.6301962

LWR-I LWR-II LWR-III KUKA LWR

Fig. 1. The generations of DLR light-weight robots (LWR-I, LWR-II, and LWR-III) and the commercialized version (KUKA LWR).

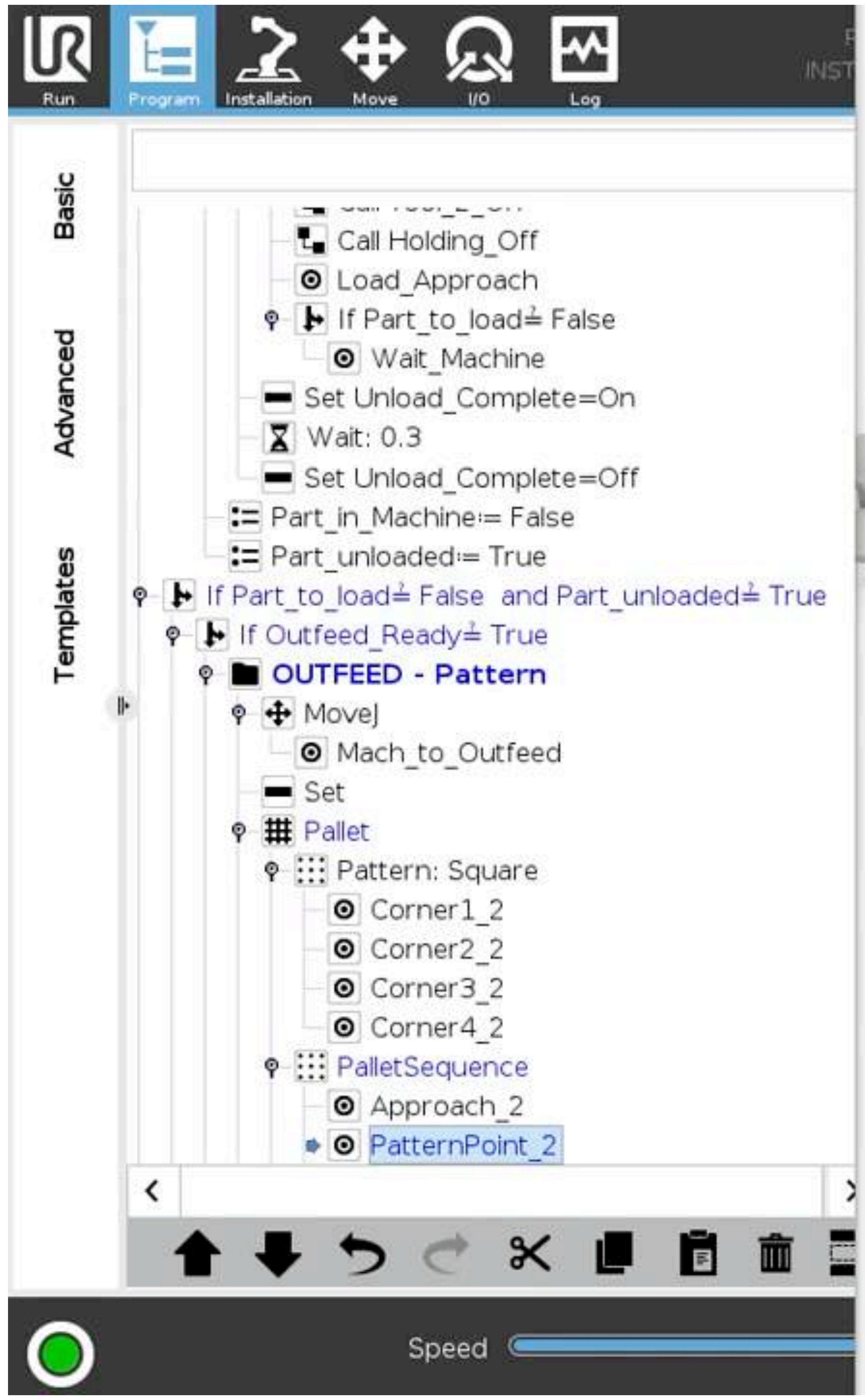


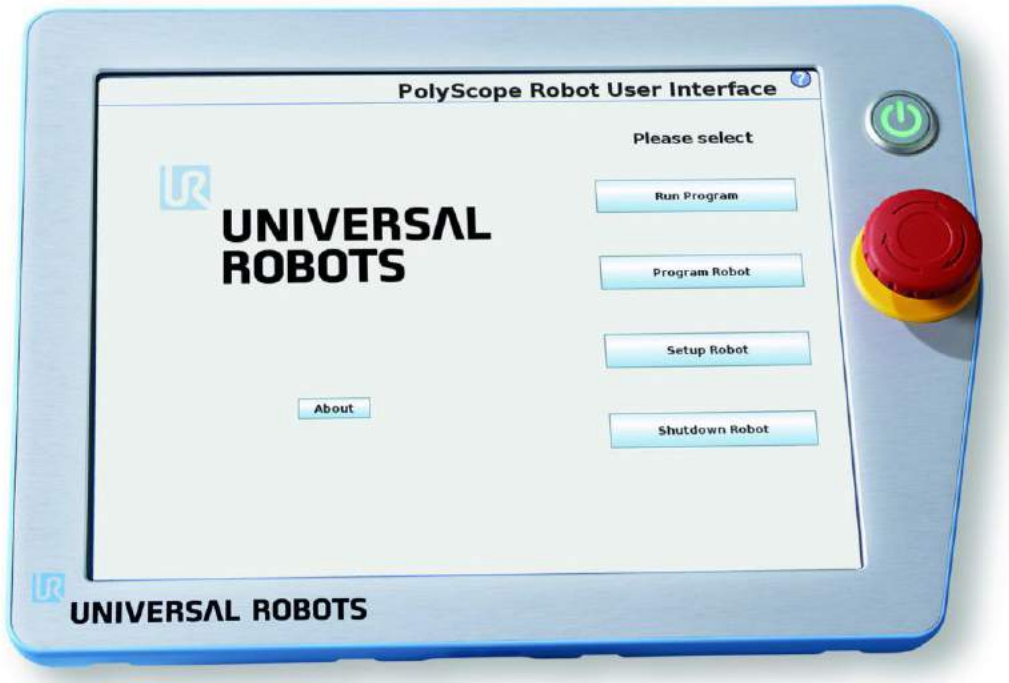
So …

Soft-tissue injury in robotics: 10.1109/ROBOT.2010.5509854

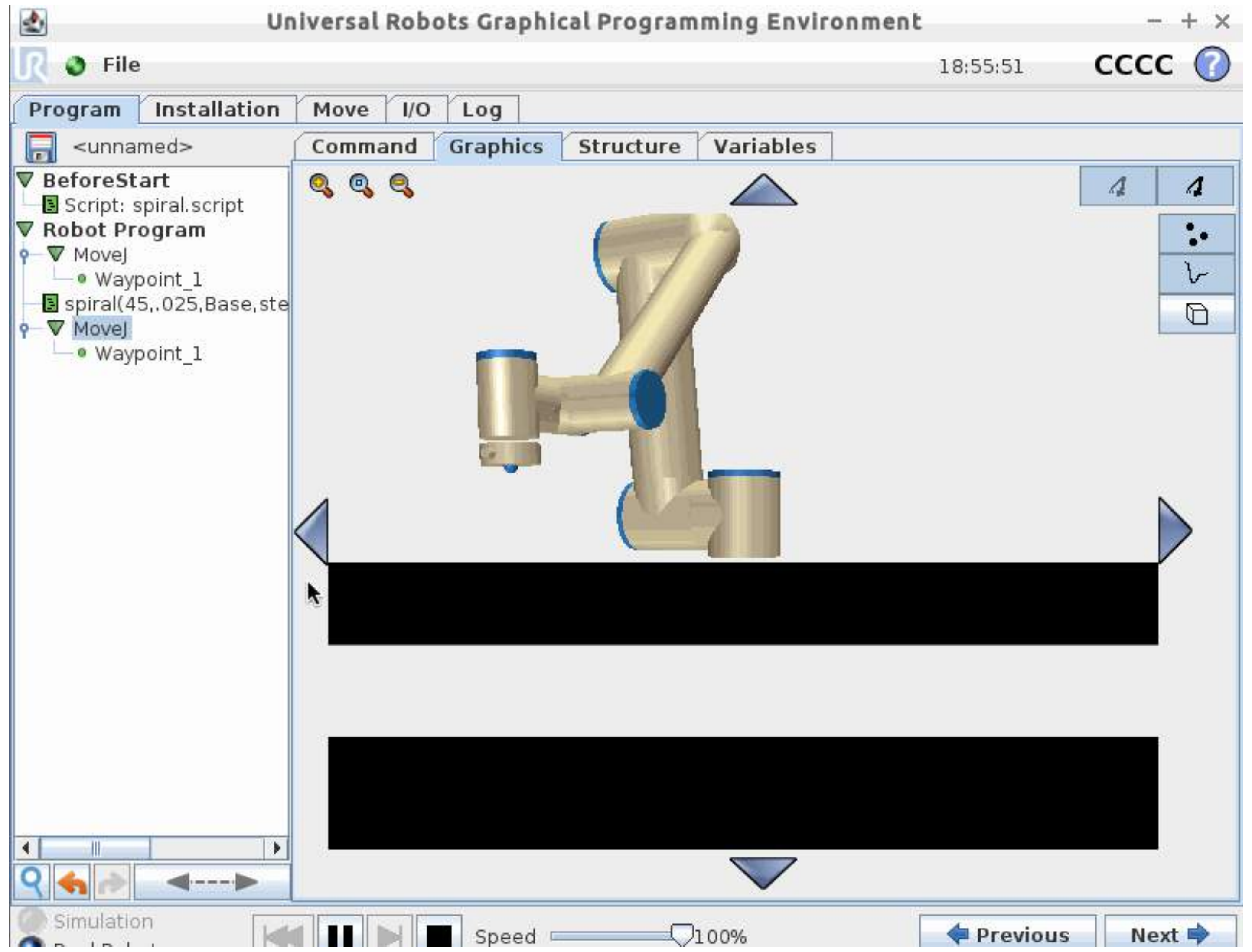
Universal Robots

From 2003 to 2013





- Cheaper to buy, and
- Easier to use



(12) **United States Patent**
Kassow et al.

(10) **Patent No.: US 8,614,559 B2**
(45) **Date of Patent: Dec. 24, 2013**

(54) **PROGRAMMABLE ROBOT AND USER INTERFACE**

(71) Applicant: **Universal Robots ApS**, Odense C. (DK)

(72) Inventors: **Kristian Kassow**, København S. (DK); **Esben Hallundbæk Østergaard**, Odense C. (DK); **Kasper Støy**, Odense C. (DK)

(73) Assignee: **Universal Robots ApS**, Odense S. (DK)

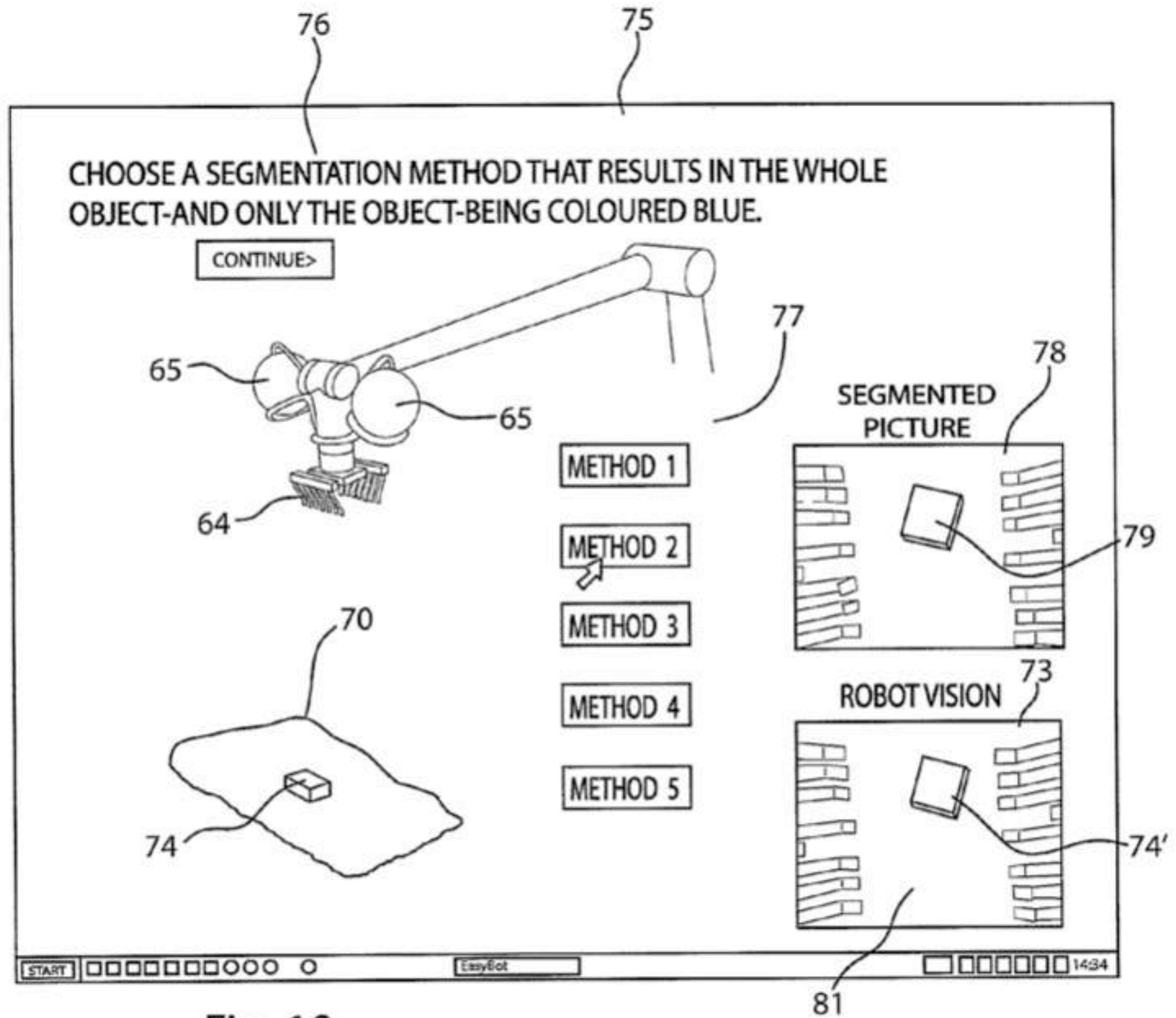
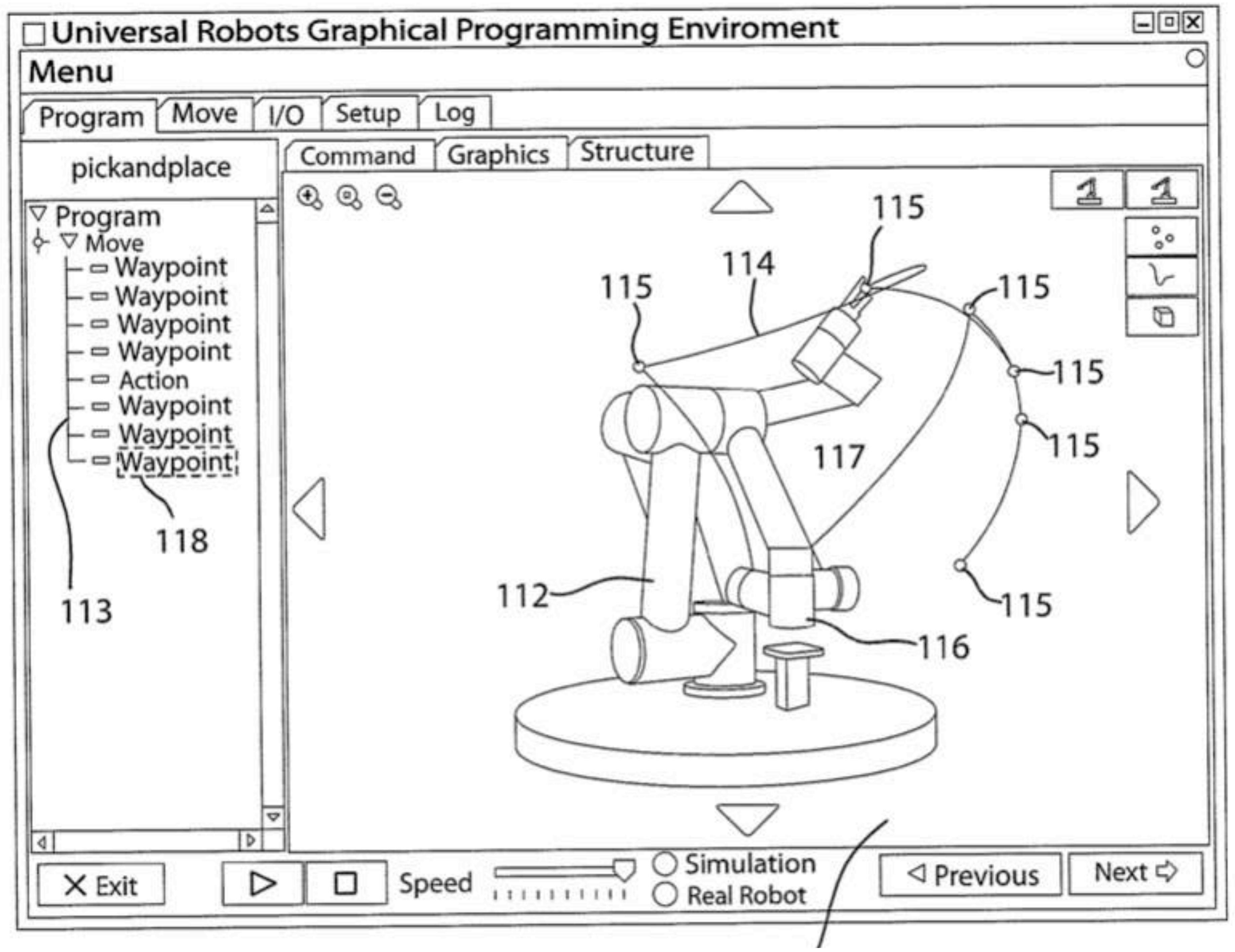


Fig. 19



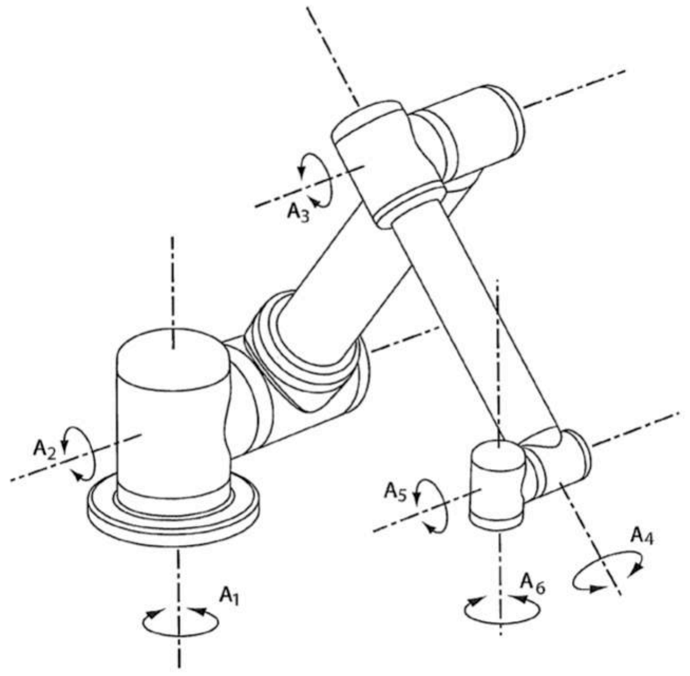
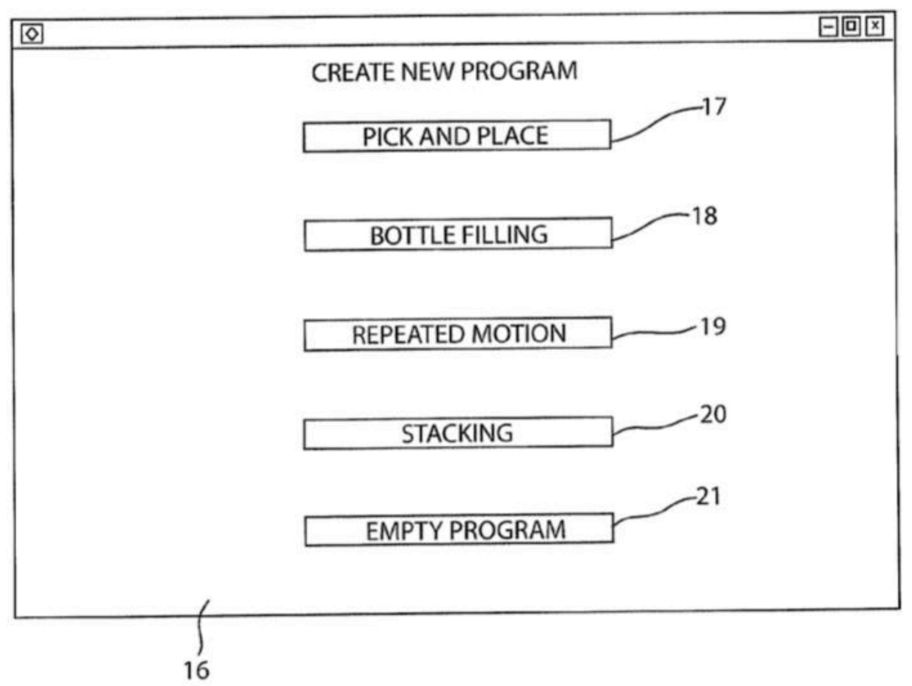


Fig. 24



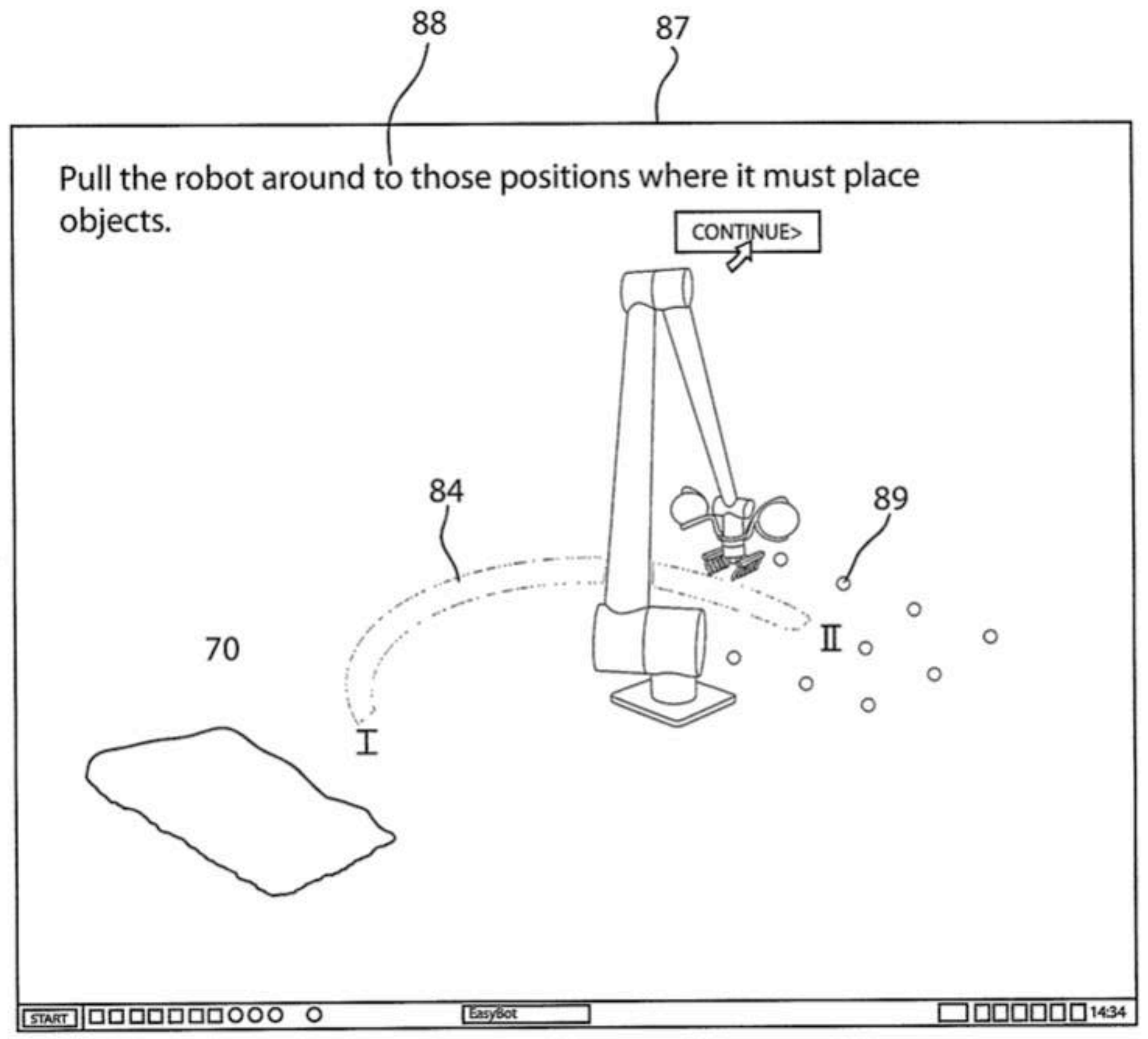


Fig. 22

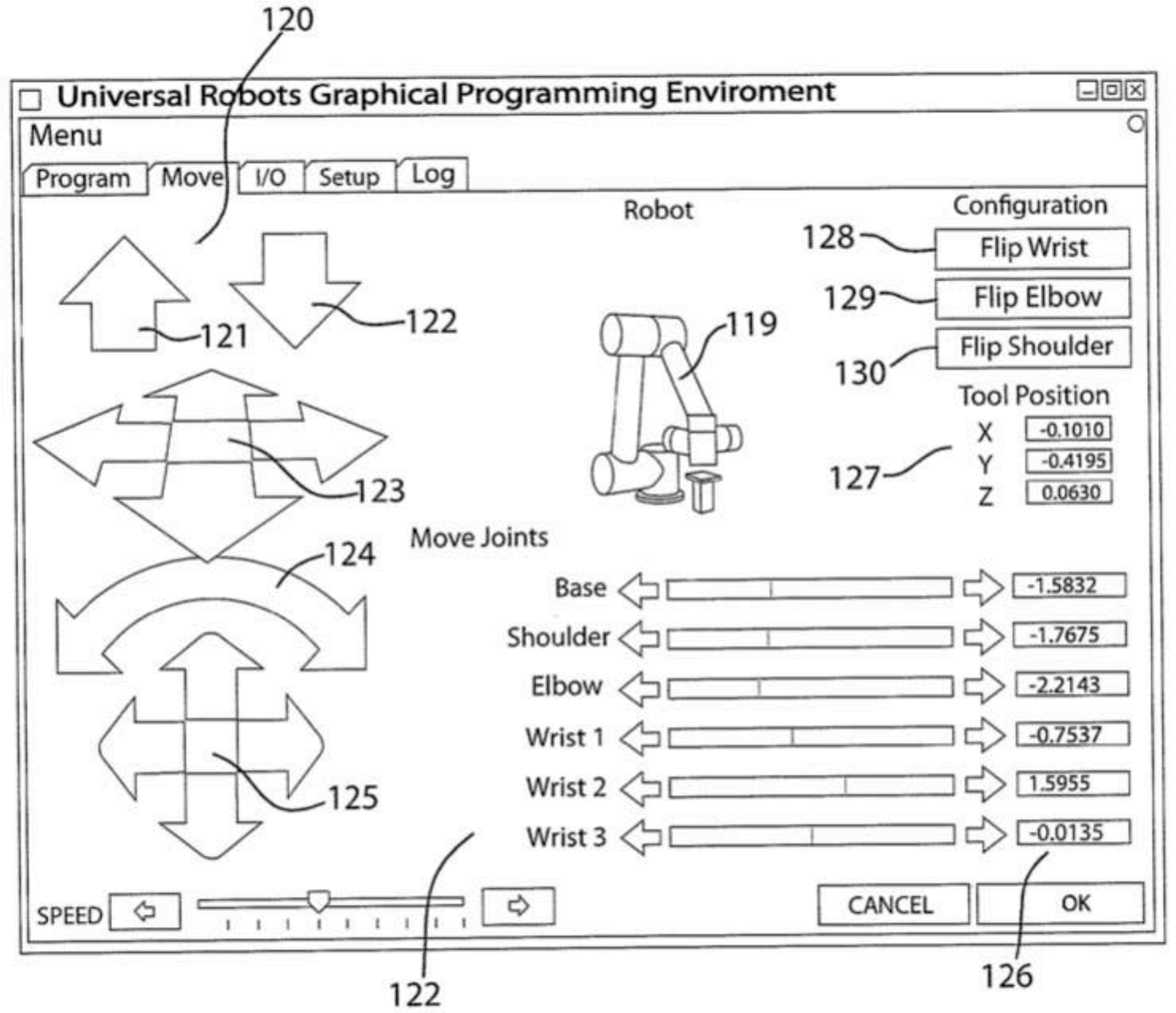


Fig. 25

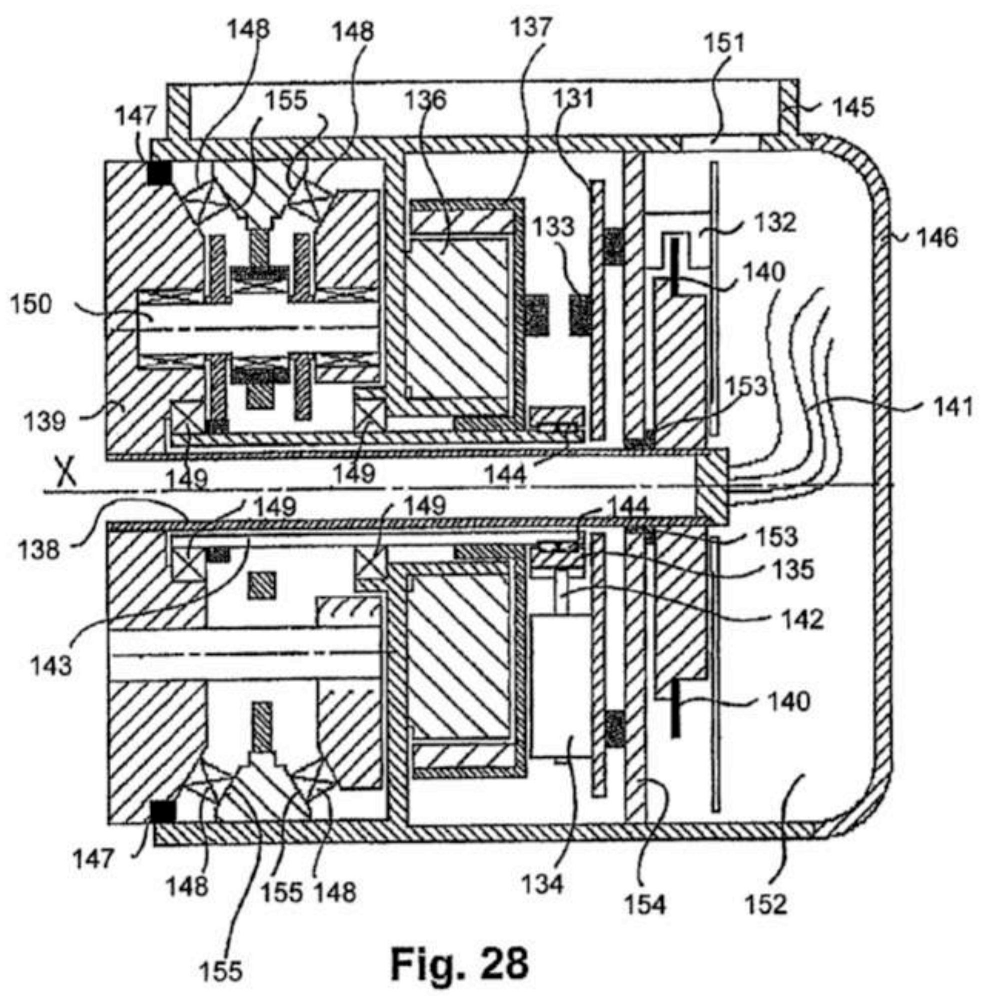
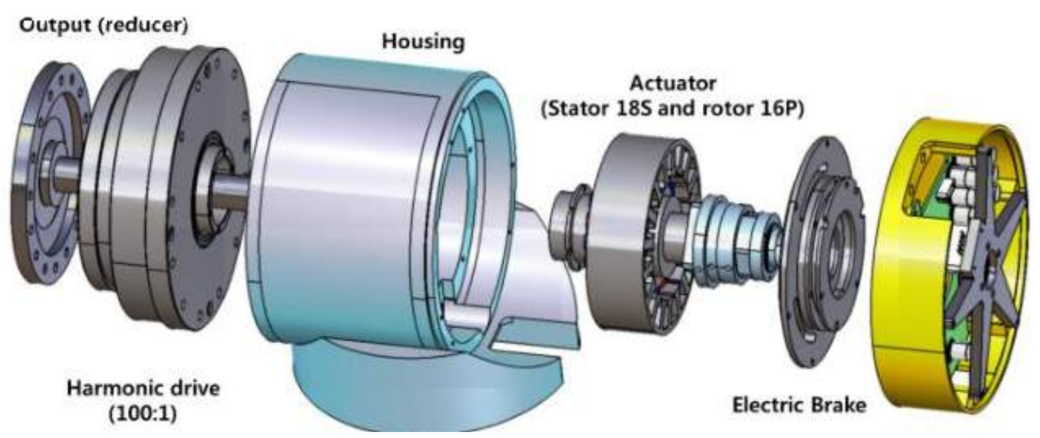


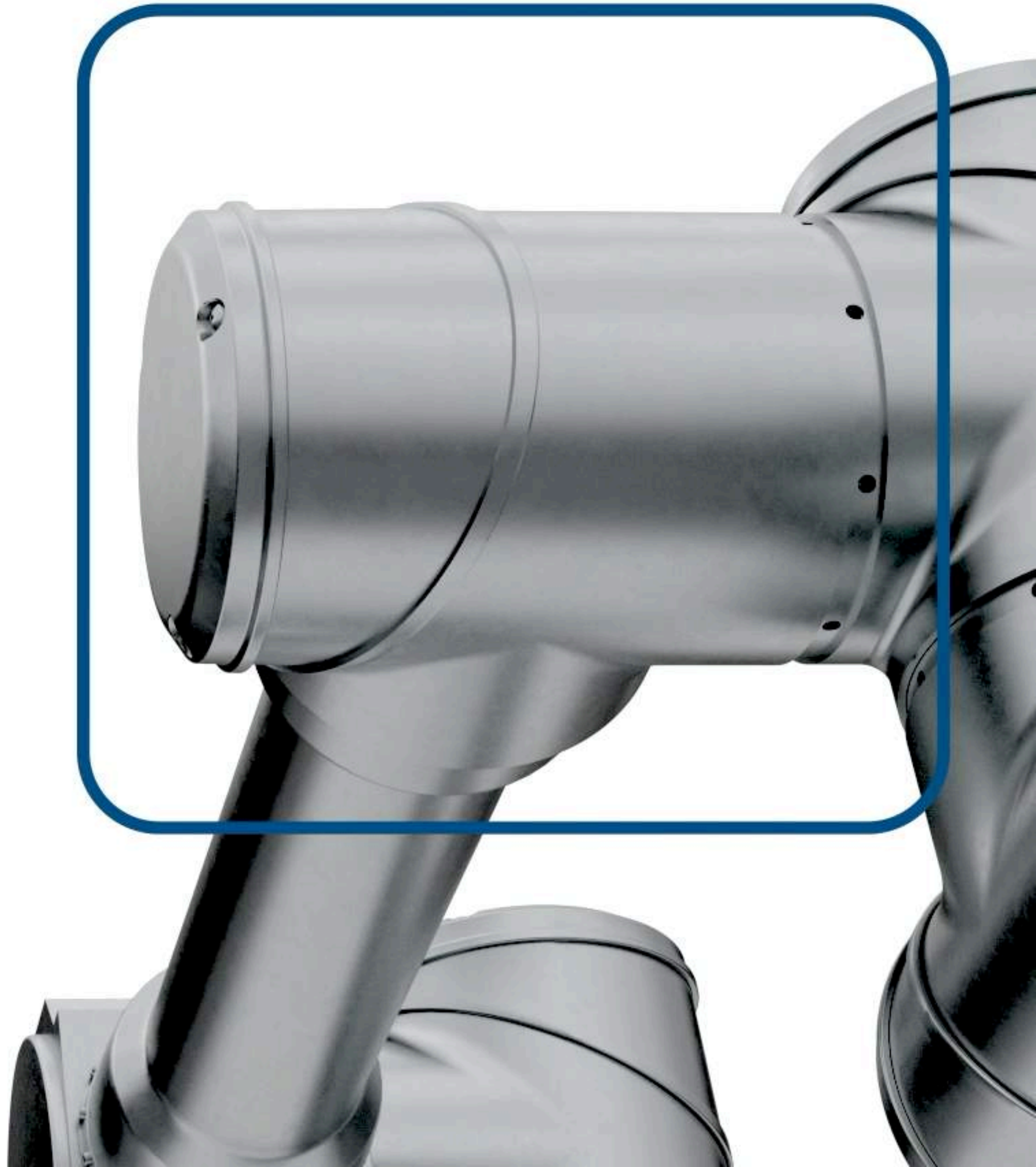
Fig. 28

Patented design by UR



A similar design from
10.1109/TMAG.2017.2752080

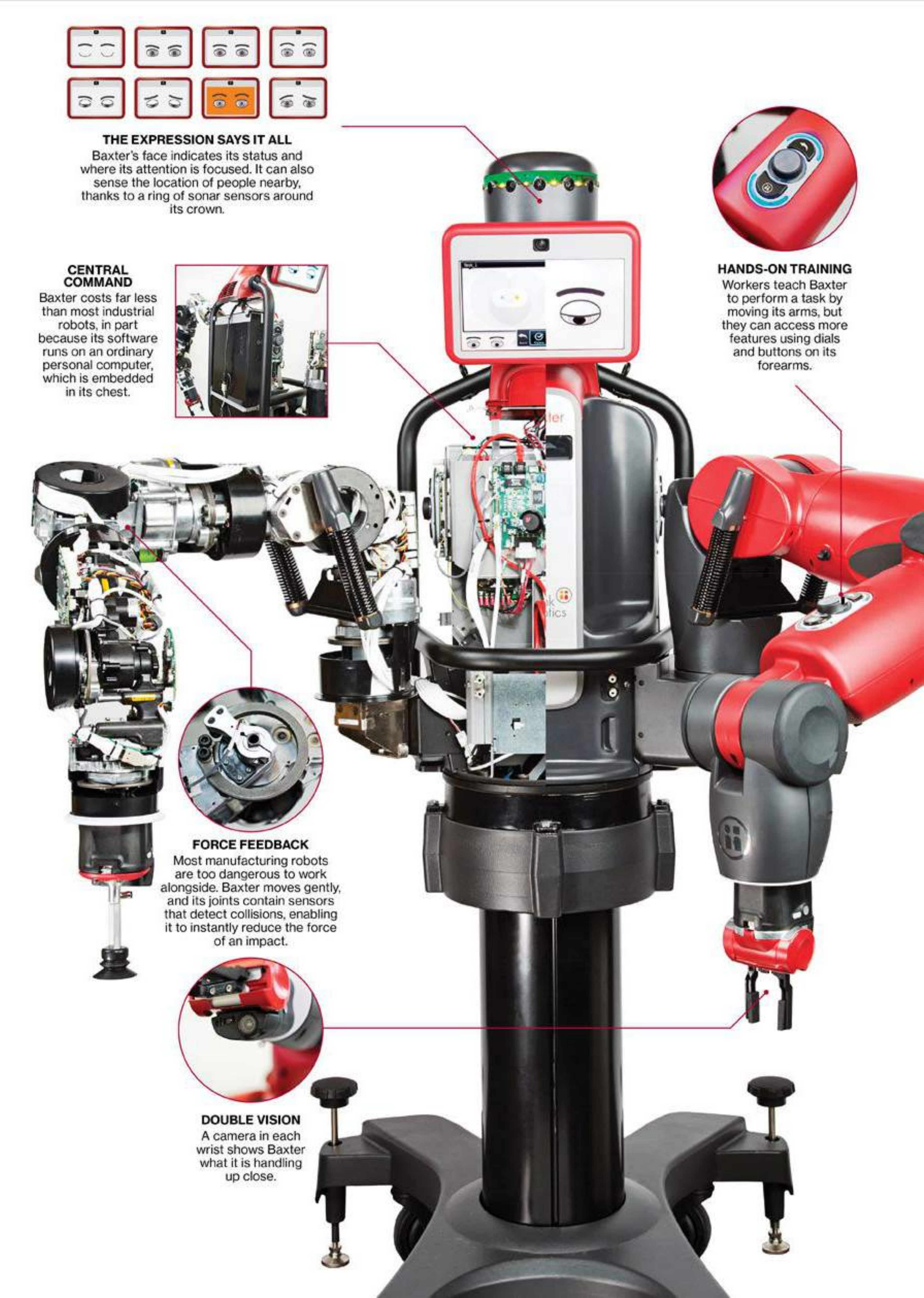
Design by UR supplier Kollmorgen

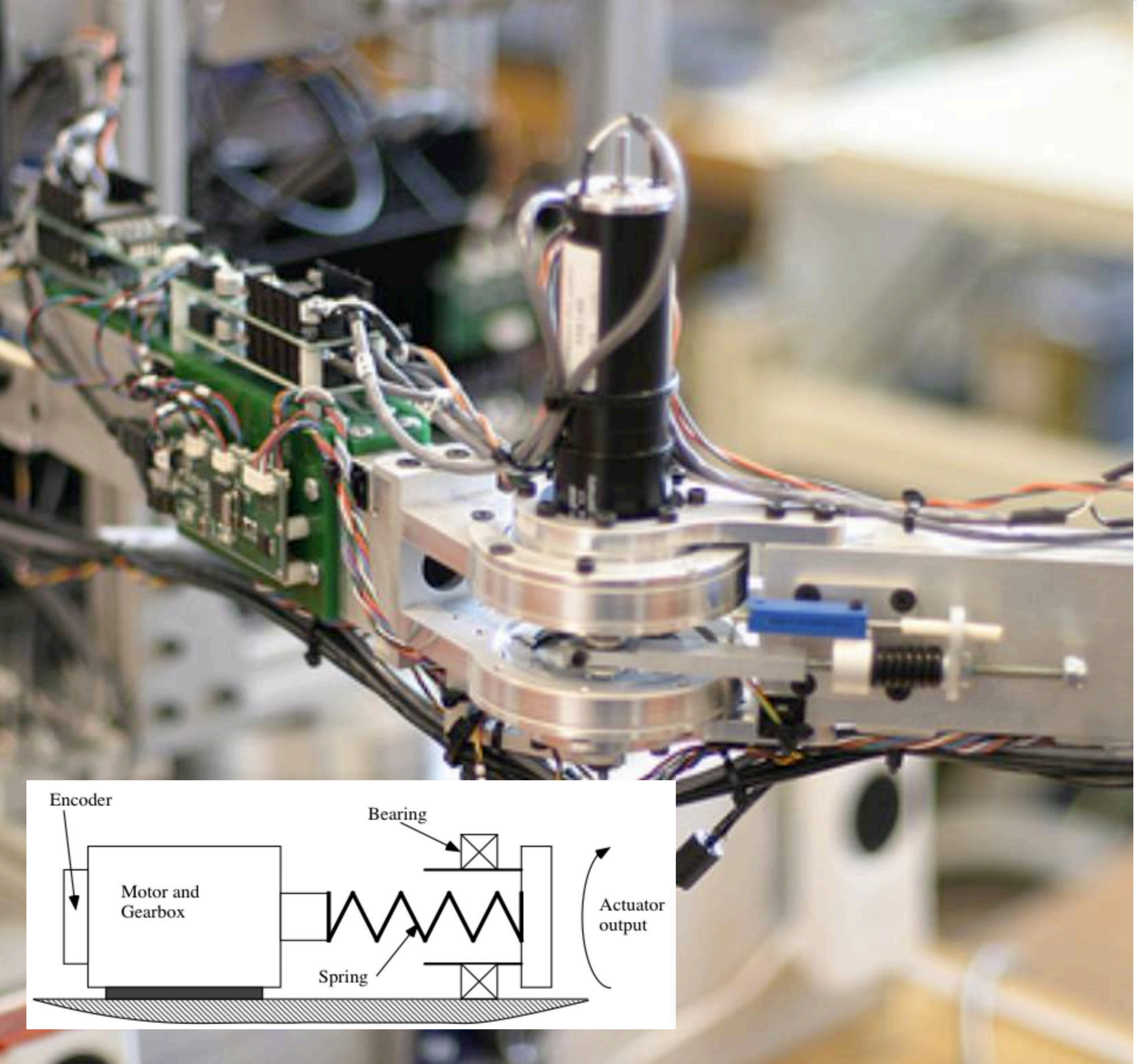


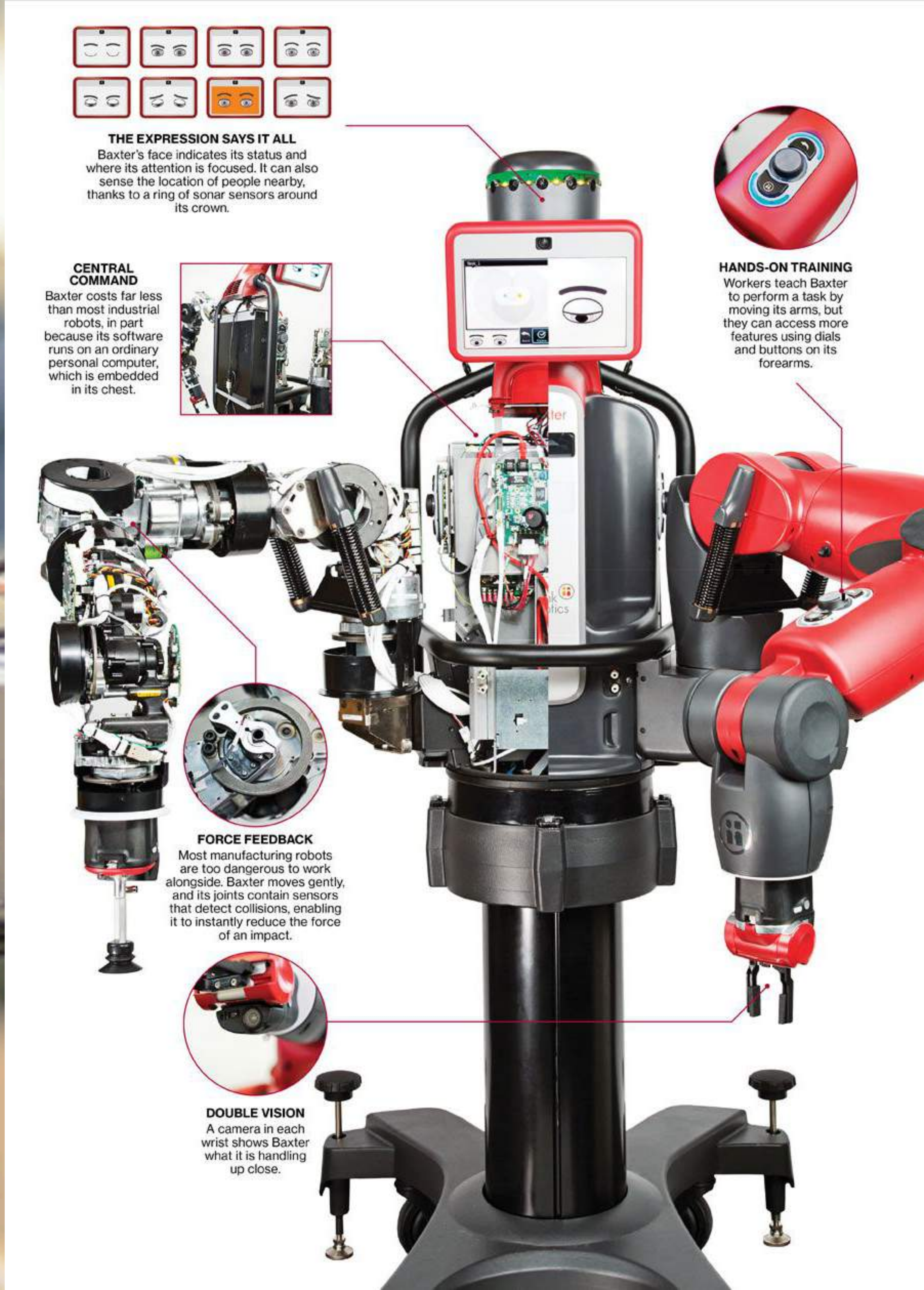
Rethink Robotics

From 2003 to 2013

- Video, dual arm, UX with a cute face
- Series Elastic Actuator with Integrated sensing
    - Patented by MIT in 1993
    - Inexpensive way to get good force control
        - Make robots that are compliant, good at tasks, safer around humans, good in unstructured environments etc.
    - Spring in series with gearbox
    - Turn force control problem into position control
    - Spring filters gearbox nonlinearities, gives smooth output torque
    - Gain in compliance, sacrifice bandwidth




Encoder
Bearing
Motor and
Gearbox
Actuator
output
Spring


THE EXPRESSION SAYS IT ALL
Baxter's face indicates its status and where its attention is focused. It can also sense the location of people nearby, thanks to a ring of sonar sensors around its crown.
CENTRAL COMMAND
Baxter costs far less than most industrial robots, in part because its software runs on an ordinary personal computer, which is embedded in its chest.
HANDS-ON TRAINING
Workers teach Baxter to perform a task by moving its arms, but they can access more features using dials and buttons on its forearms.
FORCE FEEDBACK
Most manufacturing robots are too dangerous to work alongside. Baxter moves gently, and its joints contain sensors that detect collisions, enabling it to instantly reduce the force of an impact.
DOUBLE VISION
A camera in each wrist shows Baxter what it is handling up close.

More and more designs …

Since 2013 …









Examples of Engineering Specifications

Reading the Technical Data Sheet (TDS)

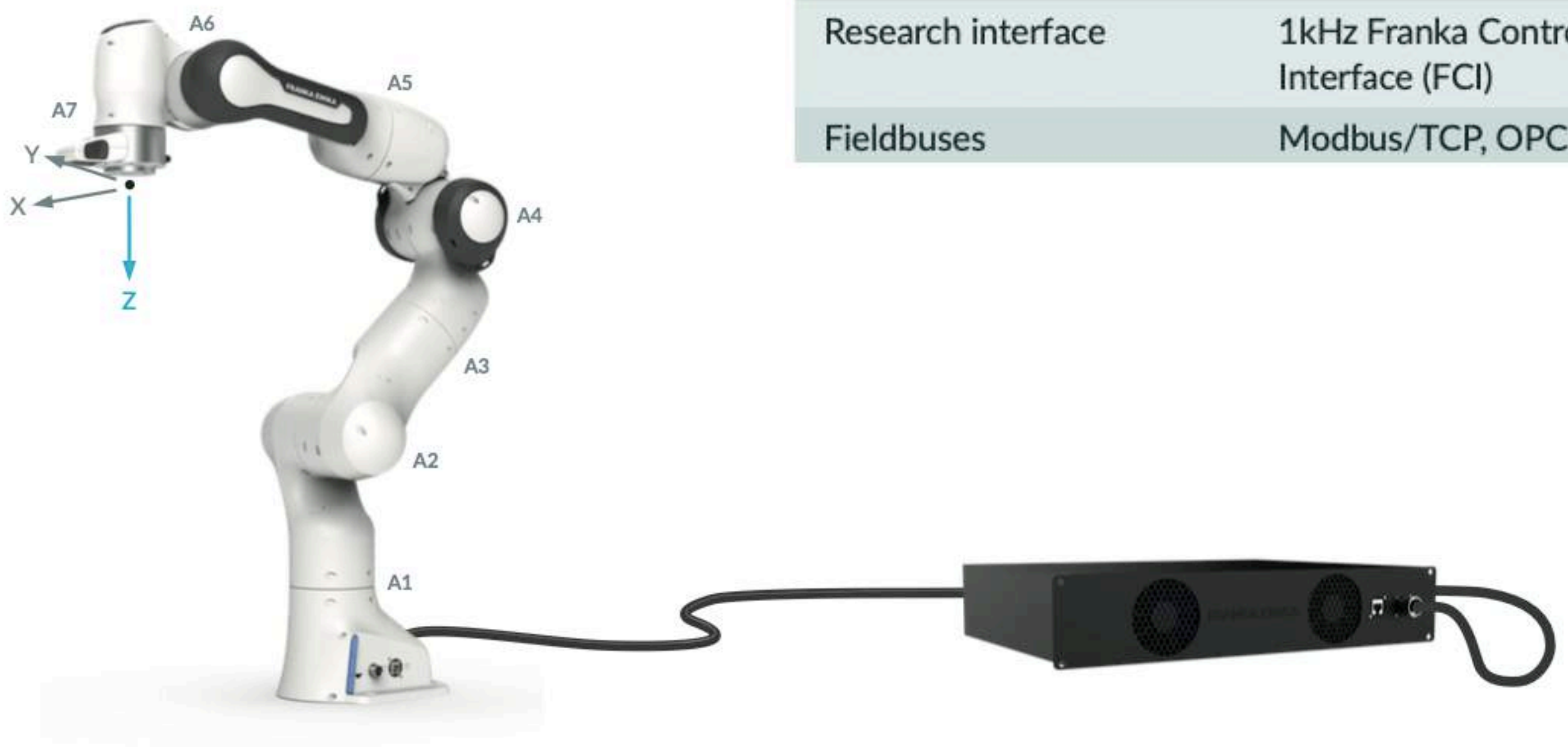
HARDWARE

Arm

Degrees of freedom	7
Payload	3 kg
Workspace	see backside
Maximum reach	855 mm
Force/ Torque sensing	link-side torque sensors in all 7 axes
Expected nominal lifetime [3,4]	20,000 h
Joint position limits	A1, A3, A5, A7: -166°/166° A2: -101°/101° A4: -176°/-4° A6: -1°/215°
Mounting flange	DIN ISO 9409-1-A50
Installation position	upright
Weight	~ 17.8 kg
Moving mass	~ 12.8 kg
Protection rating	IP30
Ambient temperature [2]	15 – 25 °C (typical) 5 – 45 °C (extended)
Air humidity	20 – 80 % non-condensing
Power consumption	• max. ~ 350 W • typical application ~ 60 W
Interfaces	• ethernet (TCP/IP) for visual intuitive programming with Desk • input for external enabling device • input for external activation device or safeguard • Control connector • Connector for end effector

Control

Controller size (19")	355 x 483 x 89 mm (D x W x H)
Supply voltage	100 – 240 VAC
Mains frequency	47 – 63 Hz
Power consumption	~ 80 W
Active power factor correction (PFC)	yes
Weight	~ 7 kg
Protection rating	IP20
Ambient temperature	15 – 25 °C (typical) 5 – 45 °C (extended)
Air humidity	20 – 80 % non-condensing
Interfaces	• ethernet (TCP/IP) for internet and/or shop-floor connection • power connector IEC 60320-C14 (V-Lock) • Arm connector



Interaction

Guiding force	~ 2 N
Collision detection time	<2 ms
Nominal collision reaction time [3,4]	<50 ms
Worst case collision reaction time [3]	<100 ms
Adjustable translational stiffness	0 – 3000 N/m
Adjustable rotational stiffness	0 – 300 Nm/rad
Monitored signals	joint position, velocity, torque cartesian position, velocity, force

ADD-ONS

Safety retrofit option with safety-rated PLC	PLd Cat. 3 • Safe torque off (STO) • Safe OSSD inputs
Fully integrated end effectors	• 2-finger gripper • Vacuum gripper
Fast mounting	Clamping Adapter
Demonstration	Pop-up Box
Research interface	1kHz Franka Control Interface (FCI)
Fieldbuses	Modbus/TCP, OPC UA

SOFT-ROBOT PERFORMANCE

Motion

Joint velocity limits	A1, A2, A3, A4: 150°/s A5, A6, A7: 180°/s
Cartesian velocity limits	up to 2 m/s end effector speed
Pose repeatabillity	<+/- 0.1 mm (ISO 9283)
Path deviation [3]	<+/- 1.25 mm

Force

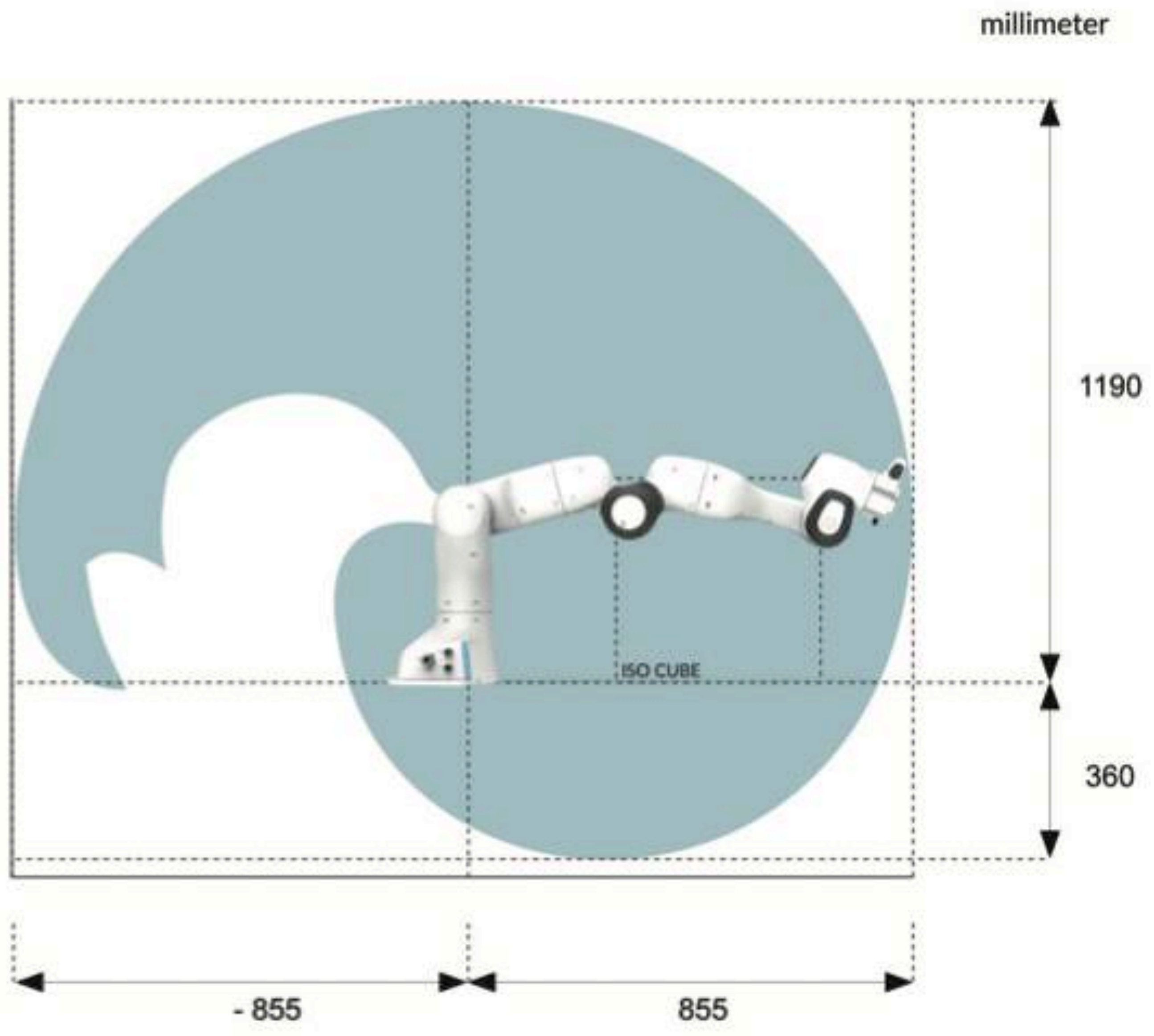
Sensing [3]

Force resolution	<0.05 N
Relative force accuracy	0.8 N
Force repeatability	0.15 N
Force noise (RMS)	0.035 N
Torque resolution	0.02 Nm
Relative torque accuracy	0.15 Nm
Torque repeatability	0.05 Nm
Torque noise (RMS)	0.005 Nm

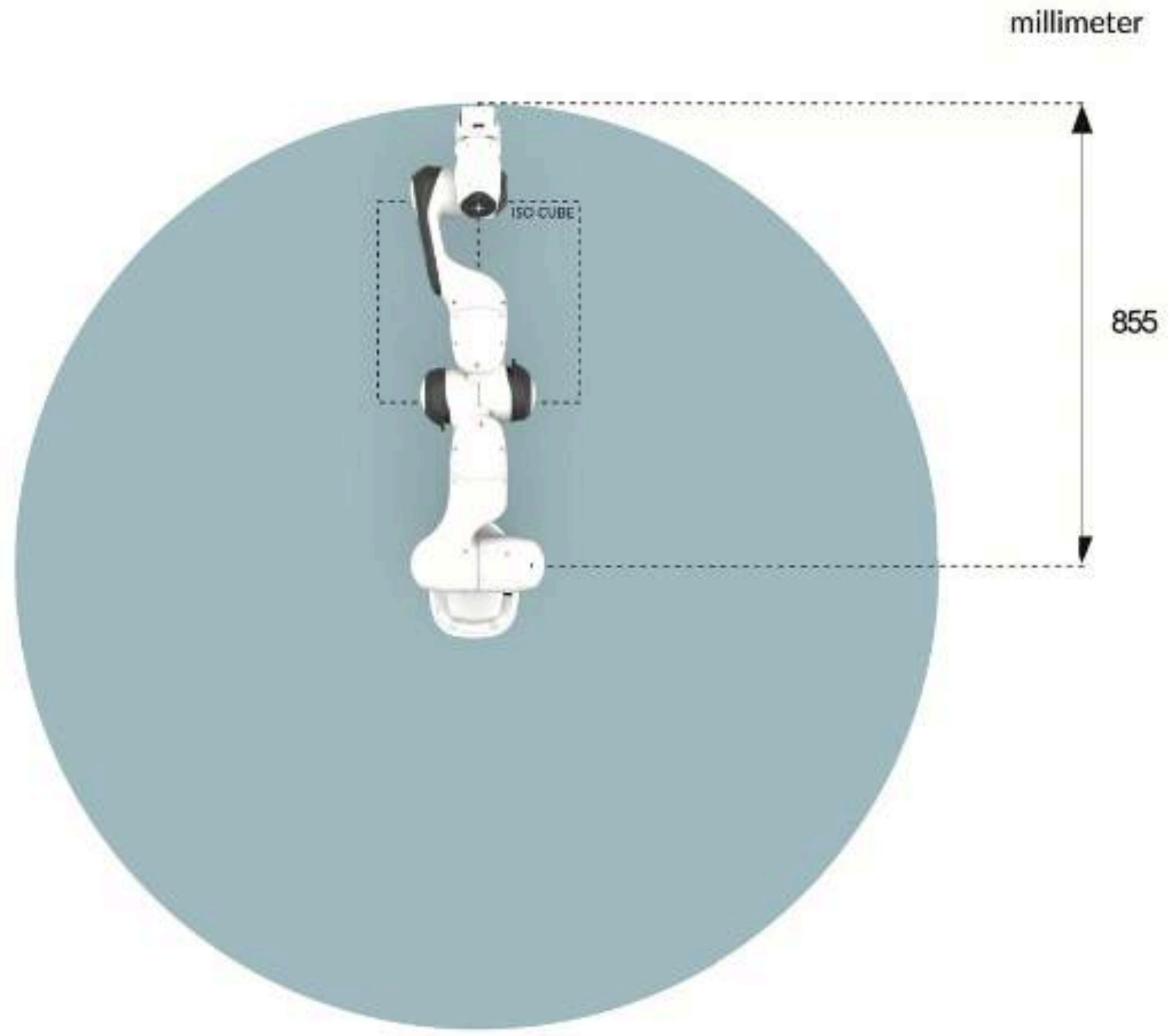
1 kHz Control [3]

Minimum controllable force (Fz)		0.05 N
Force controller bandwidth (-3 dB)		10 Hz
Force range [N]	Nominal case	Local best case
Fx	-125 – 95	-150 – 115
Fy	-100 – 100	-275 – 275
Fz	-50 – 150	-115 – 155
Torque range [Nm]	Nominal case	Local best case
Mx	-10 – 10	-70 – 70
My	-10 – 10	-16 – 12
Mz	-10 – 10	-12 – 12

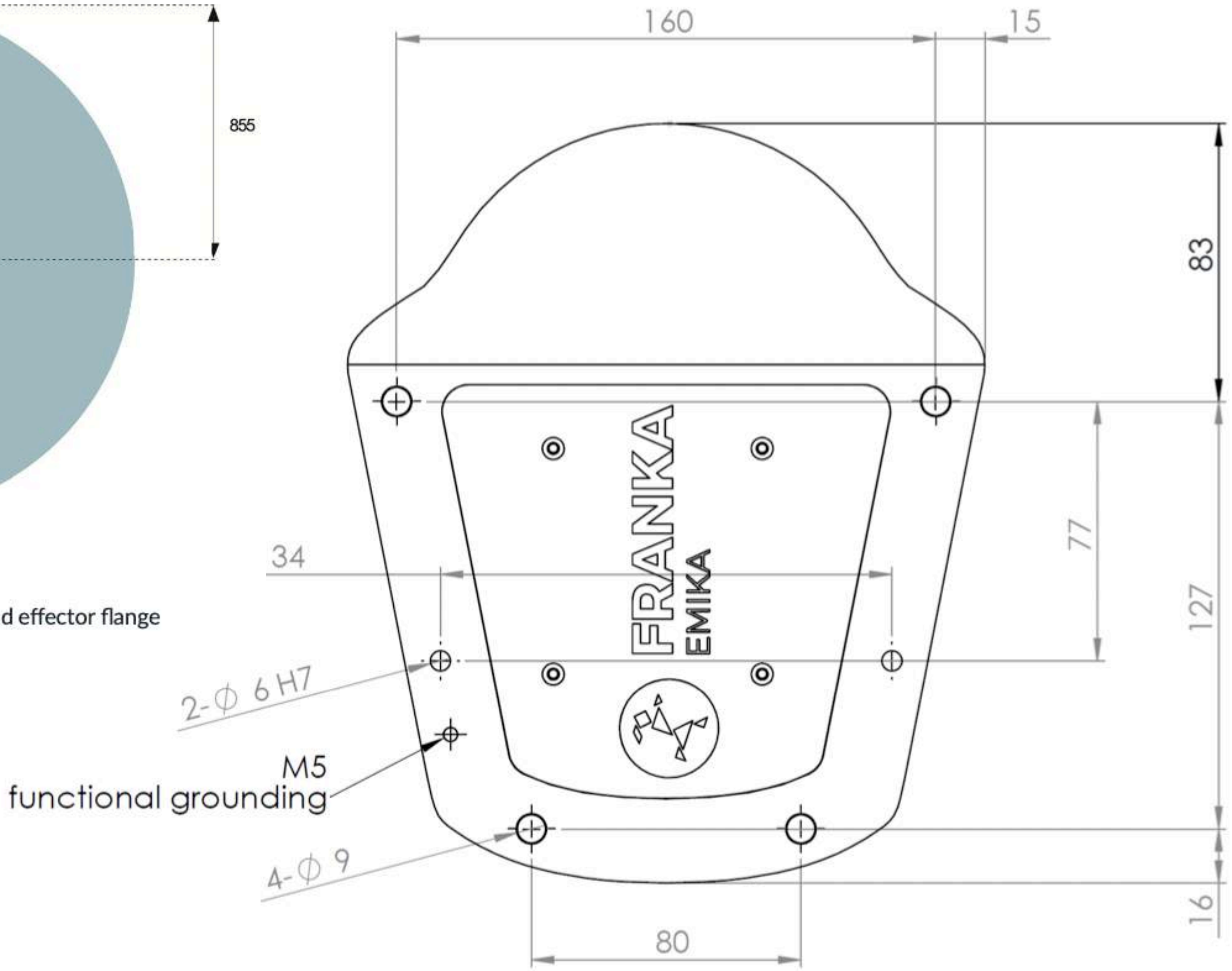
Reading the Technical Data Sheet (TDS)

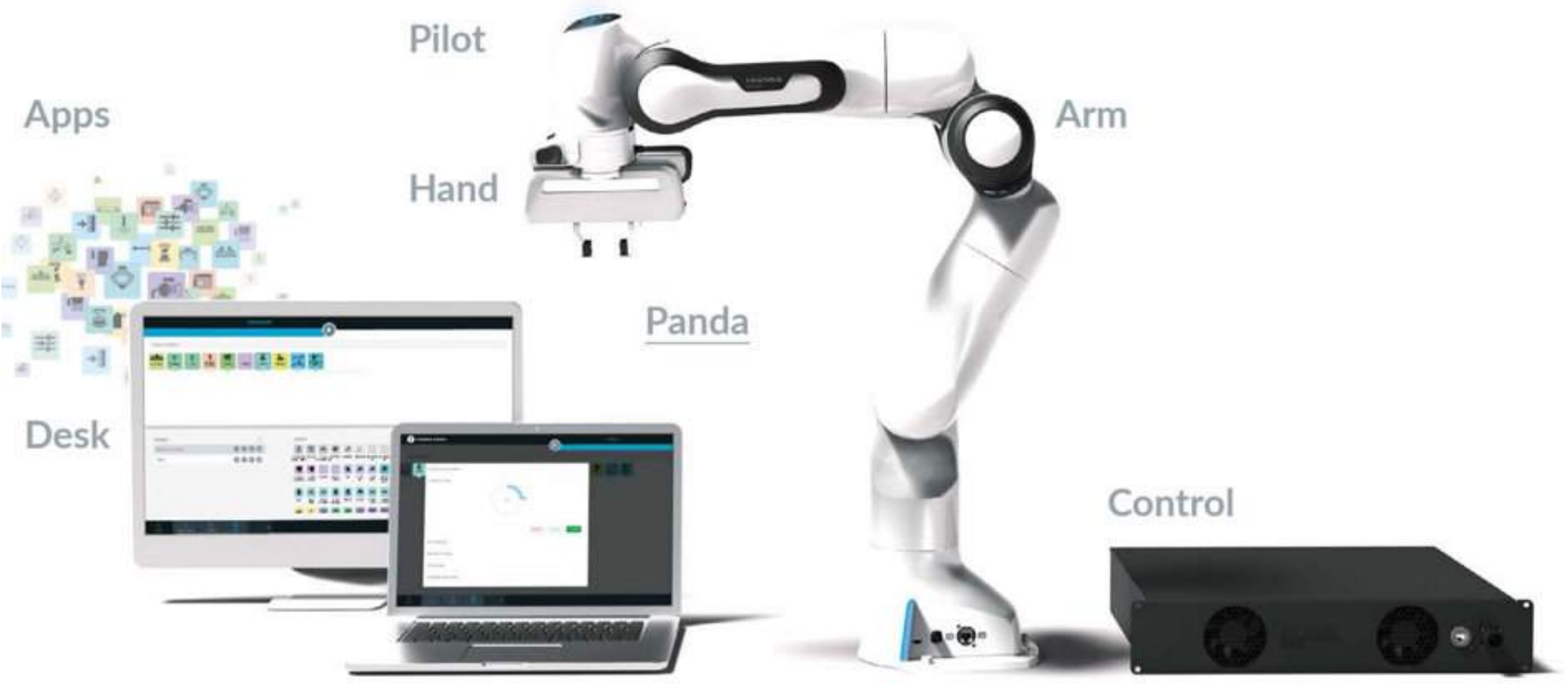


Side-view: reachable space for the end effector flange



Top-view: reachable space for the end effector flange

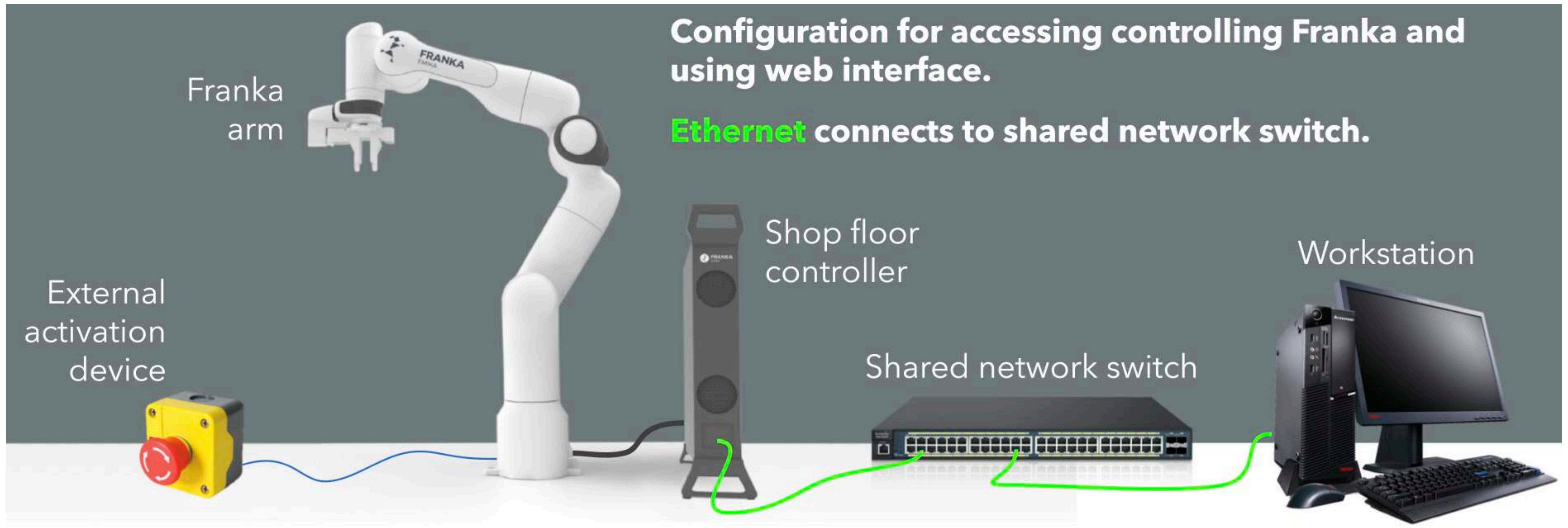


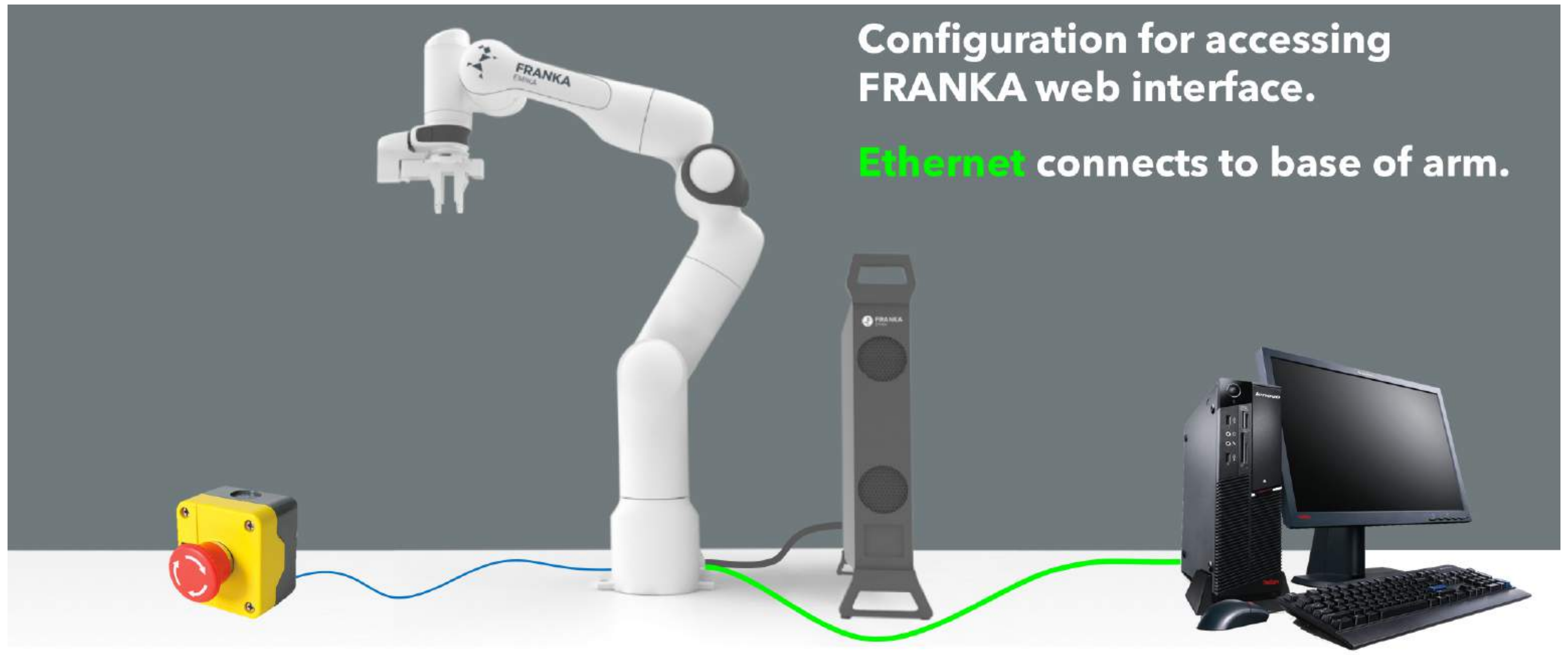


Reading the Technical Data Sheet (TDS)

Other helpful resources

- https://support.franka.de/
- https://github.com/bionicdl-sustech/DeepClaw
- https://de3-rob1-chess.readthedocs.io/en/latest/franka.html
- https://visp-doc.inria.fr/doxygen/visp-daily/tutorial-franka-pbvs.html
- https://github.com/ARISE-Initiative/robosuite
- https://github.com/stepjam/RLBench





Reading the Technical Data Sheet (TDS)

TECHNICAL SPECIFICATIONS:

Robot Type	AUBO-i5 Articulated Type / Modular
Controlled Axes DoF	6 axes (J1, J2, J3, J4, J5, J6) J7max
Reach	924 mm, 880 mm (working range)
Payload	5Kg
Weight	24 Kg
Footprint	172 mm diameter
Collaborative Operation	Safety monitored stop, speed and separation monitoring, hand guide operation, power and force limiting design
Certifications	ISO 10218-1:2011, EN 60204-1:2006 + A1:2009, ISO 12100: 2010, ISO 13849-1:2008, CE
Repeatability	(+/- 0.05 mm)
Linear Velocity	2.8 m/s adjustable
Power Consumption	200 watts typical application
Materials	Aluminum, Steel, Plastic
Ambient Humidity	Normal 75% RH or less without frost or dew, 85% RH short term
Ambient Temperature	0 to 45 degrees Celsius
IP Classification of Robot	IP54
Programing	Teach pendant with user interface, guide to teach, ROS compatibility through an API, Lua or Python
Communication	CAN bus
Motor Type	Harmonic drive 48 Volt
Installation Orientation	Any Ceiling, Floor, Wall

AXIS MOVEMENT	WORKING RANGE	MAXIMUM SPEED	MAX. JOINT MOMENTS
J1 axis rotation base	(+/-) 175°	150°/sec	207 Nm
J2 axis rotation shoulder	(+/-) 175°	150°/sec	207 Nm
J3 axis rotation elbow	(+/-) 175°	150°/sec	207 Nm
J4 axis wrist rotation	(+/-) 175°	180°/sec	34 Nm
J5 axis wrist swing	(+/-) 175°	180°/sec	34 Nm
J6 axis wrist rotation	(+/-) 175°	180°/sec	34 Nm

I/O PORT ON WRIST

Voltage	Current	Digital In	Digital out	Analog In	Analog Out
0/12/24 V	800 mA	4	4	2	0

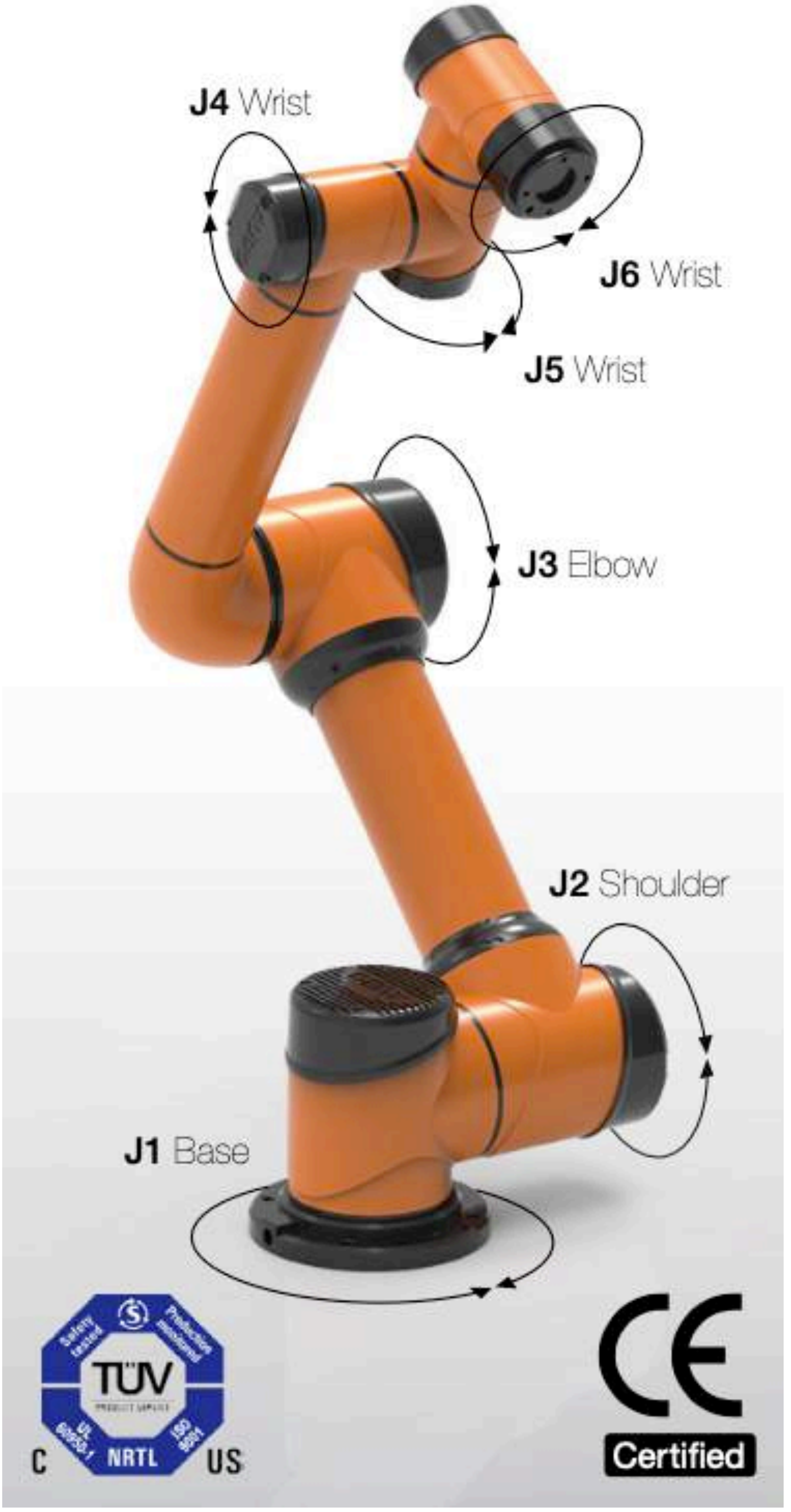
CONTROL BOX

Dimensions (LxWxH)	683x220x622 mm
Weight	20Kg
Cabling	5mm
Color	Black
Communication	TCP/IP, Modbus RTU/TCP
Power supply	100 - 240 VAC, 50 - 60 Hz
IP Classification	IP54

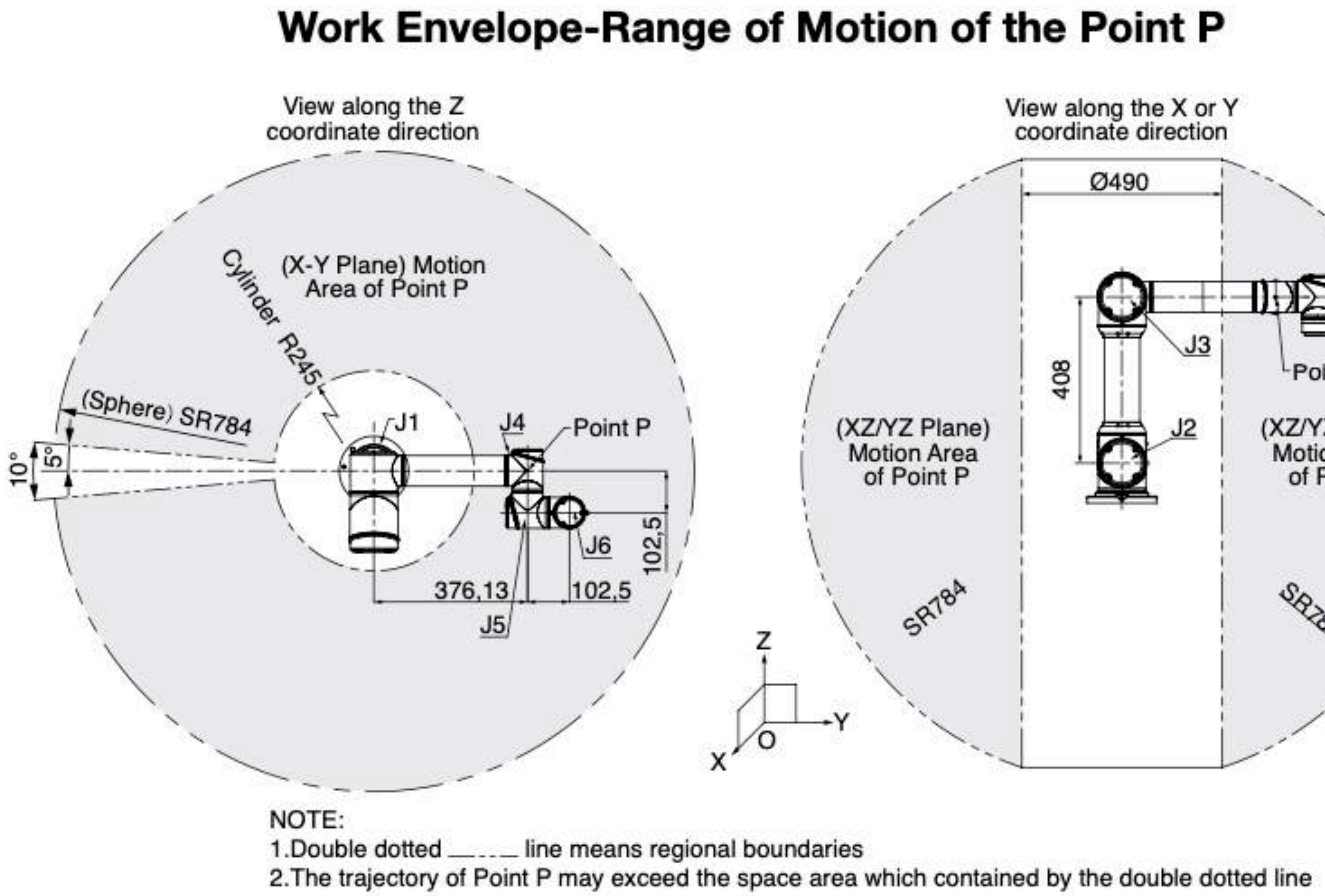
I/O PORTS	User I/O	Safety I/O
Digital in	16	16
Digital out	16	16
Analog In	4	-
Analog out	4	-
Power input	24 Volts	
Power output	3A	

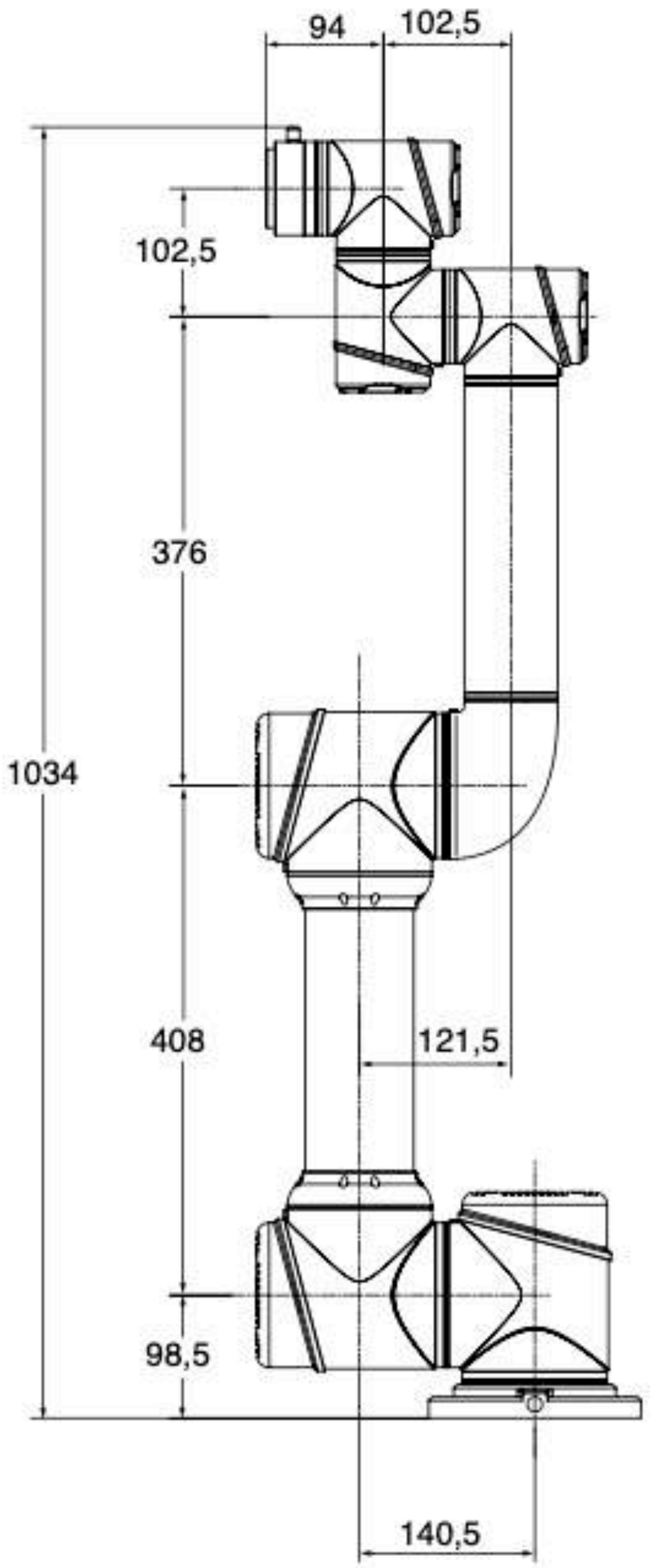
TEACH PENDANT

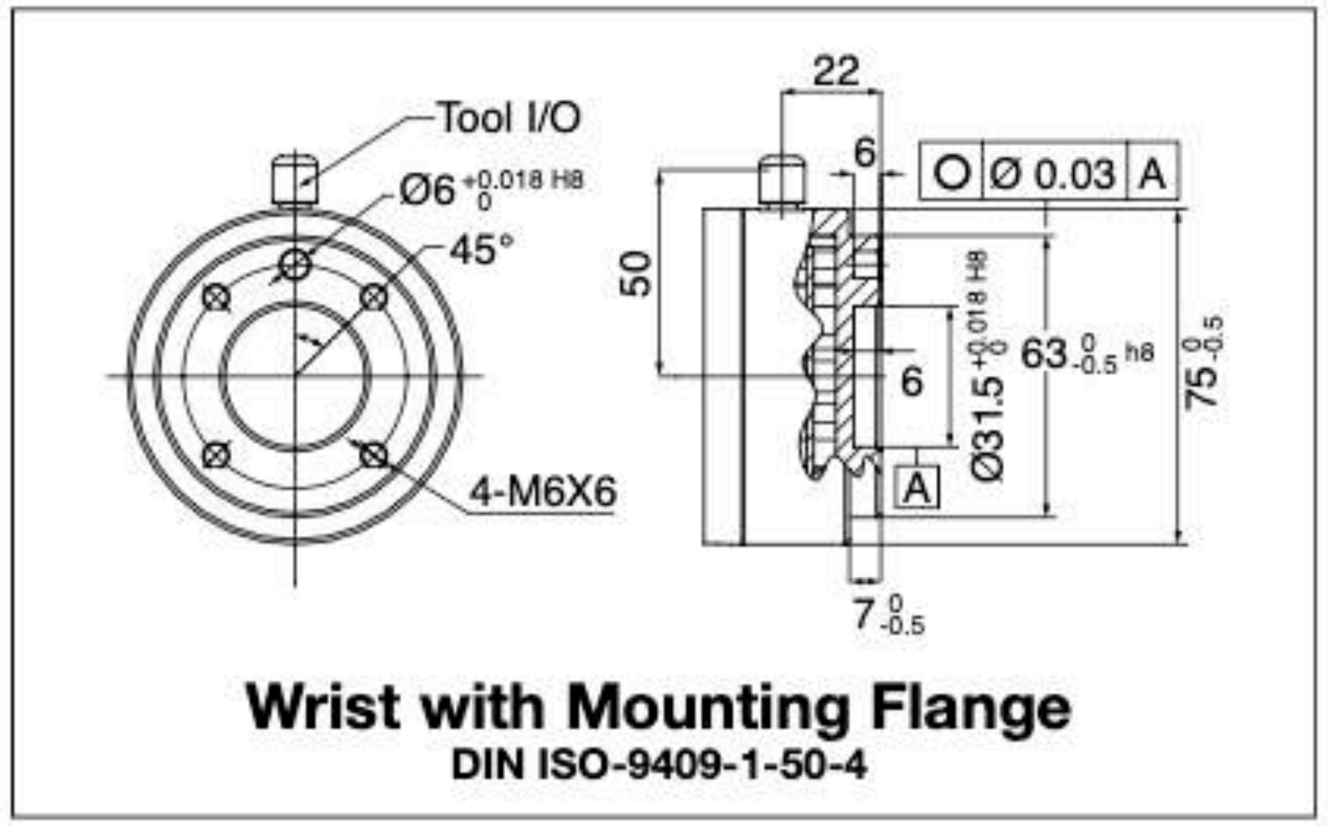
Dimensions (LxWxH)	355x235x54 mm
Weight	1.8 Kg
Display Screen	30 cm Touch LCD Screen
Cabling	4.5 mm
IP Classification	IP54
Color	Orange

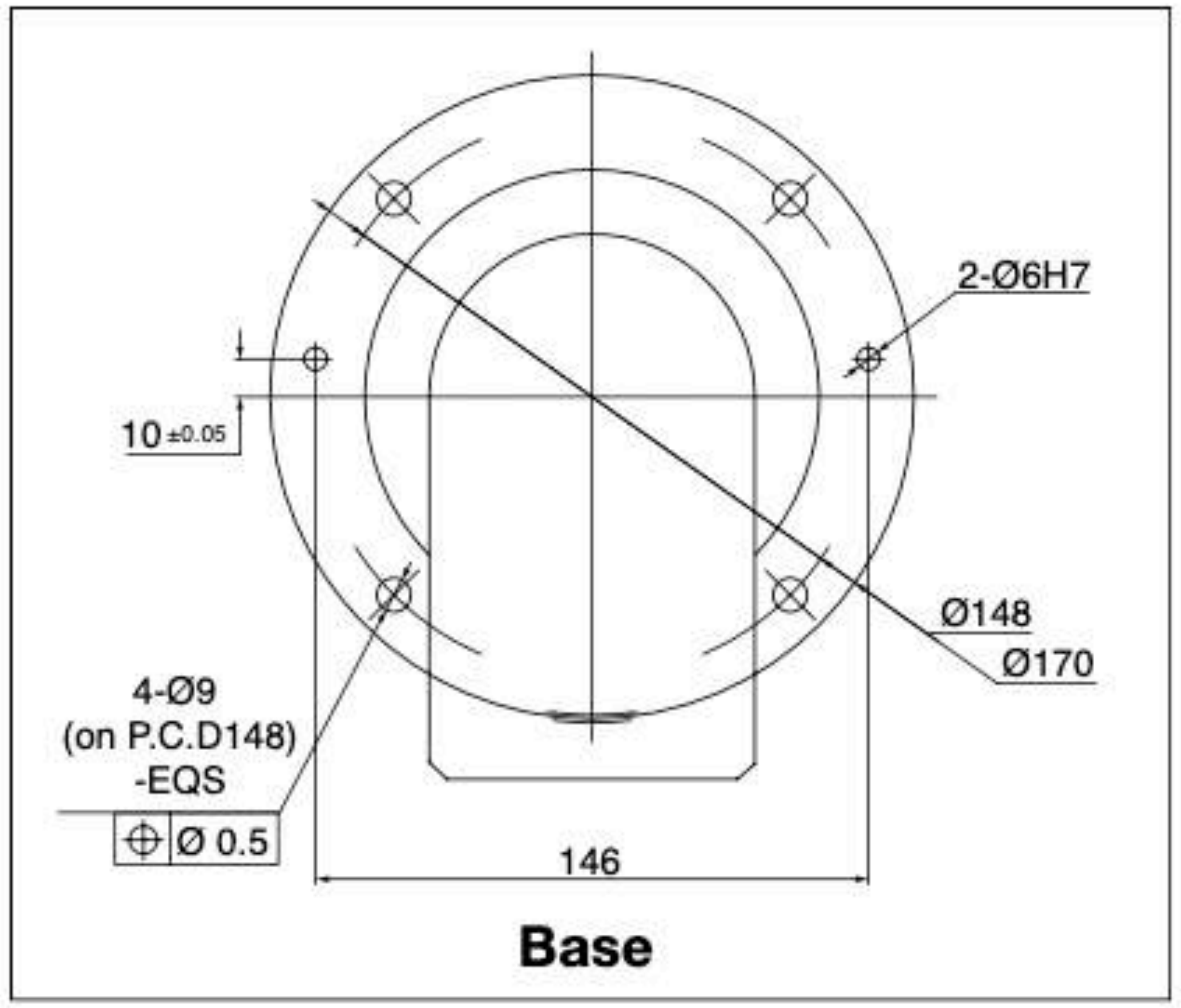


Reading the Technical Data Sheet (TDS)





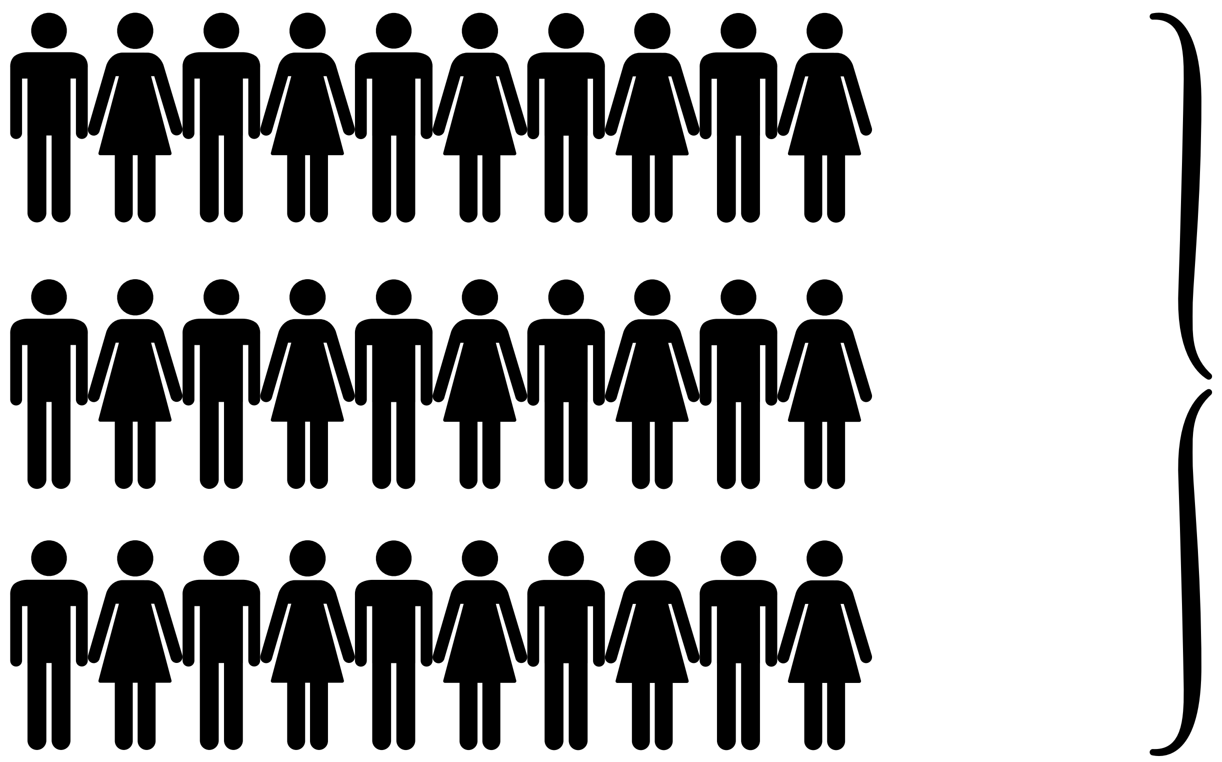




- https://aubo-robotics.com/products/aubo-i5/
- https://github.com/lg609/aubo_robot
- https://github.com/bionicdl-sustech/DeepClaw

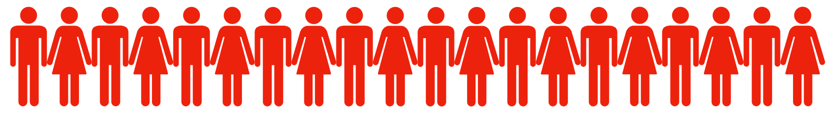
Tell us about yourself

All Students of the Class
(~30 per class)

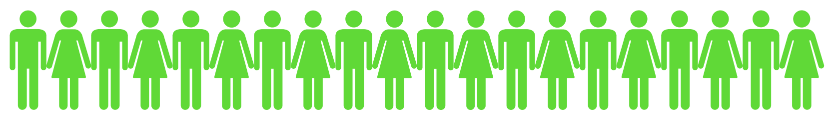


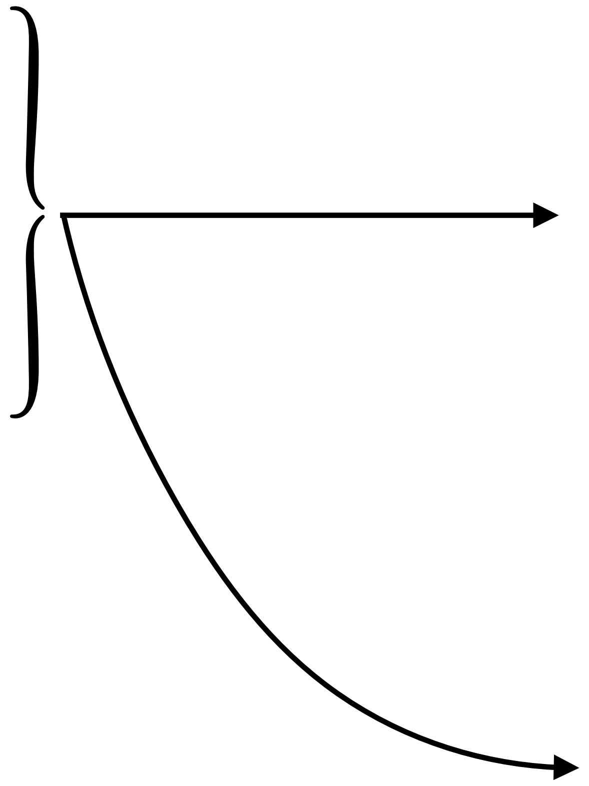
2 Teams of Student Designer
(~15 per team)

Team Red



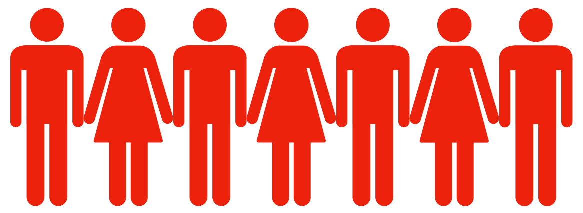
Team Green



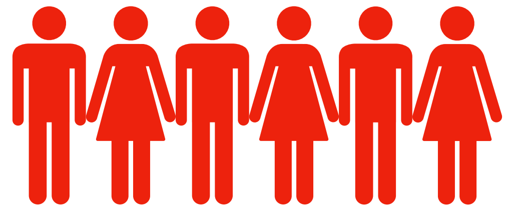


3 Task Forces of Student Designers
(7~8 per task force)

Task Force [Arnold]



Task Force [Bernard]



8 Team Roles per team

- System Integrator
- Financial Officer
- Tool Officer
- Information Officer
- Team Site Master
- Safety Officer
- Yoda Officer
- Video Log Officer

5 Task Roles per task force

- Design Engineer
- Algorithm Engineer
- System Engineer
- Software Engineer
- Data Engineer

ME336

Teams & Task Forces

Thank you

For more information, please visit mainDL.ancoraSIR.com

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