Using Industrial Robots to Complete Accurate Manufacturing Applications

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About the Speaker

Richard Pedley

- Technical Consultant for Autodesk Advanced Consulting specialising in Robotics and Automation
- Masters in Mechanical Engineering from the University of Liverpool
- Keen cyclist, climber and salsa dancer.

Agenda

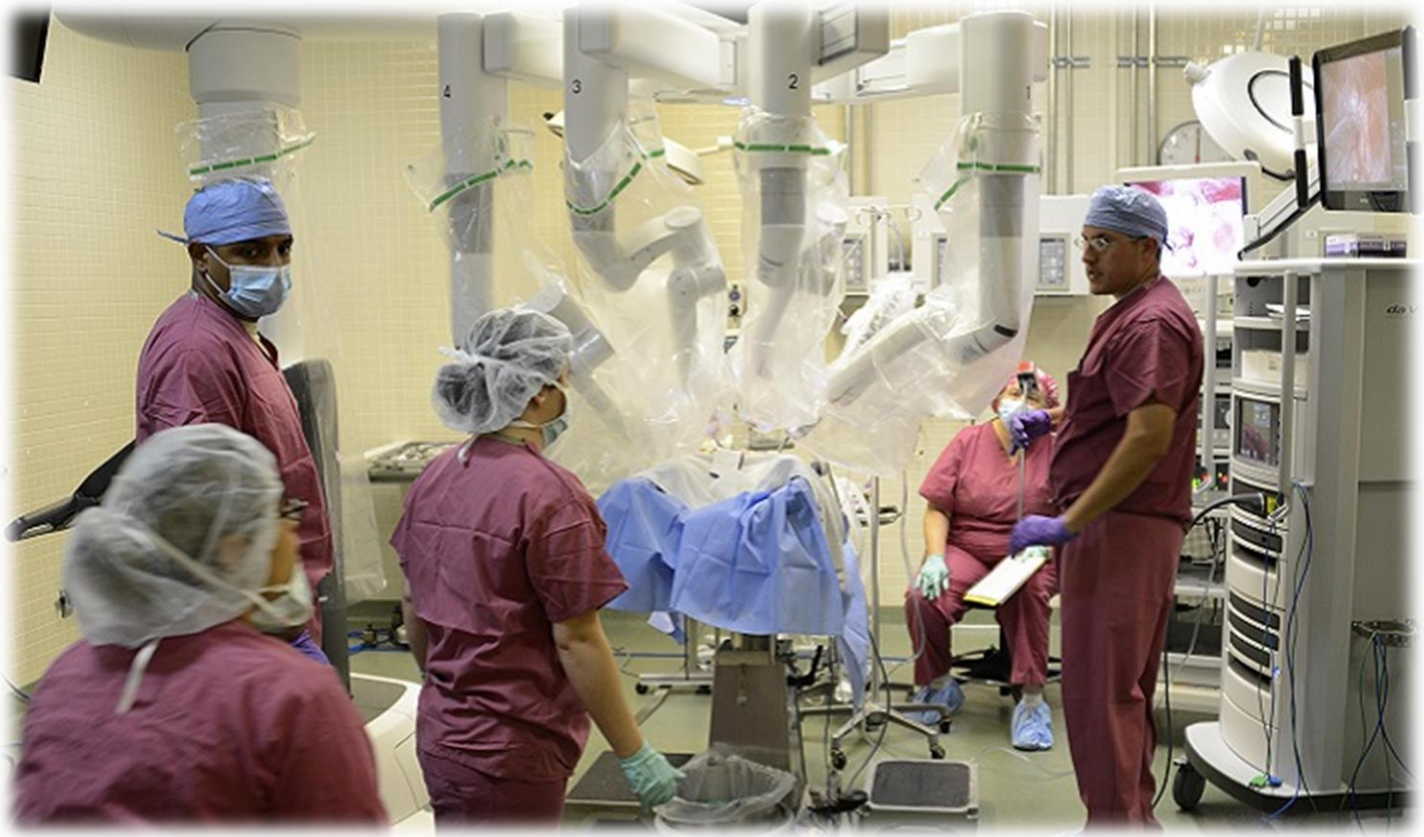
- Introduction
  - Key terms
  - Applications of Industrial Robots
  - Offline Programming
- Sources of inaccuracies
- Solutions
  - Robot based Metrology
  - Robot polishing
  - Robot Milling
- Applications
- Conclusion

Objectives

- To Understand:
  - The causes of inaccuracies
  - Existing solutions
  - Aims and outcomes of the COMET project

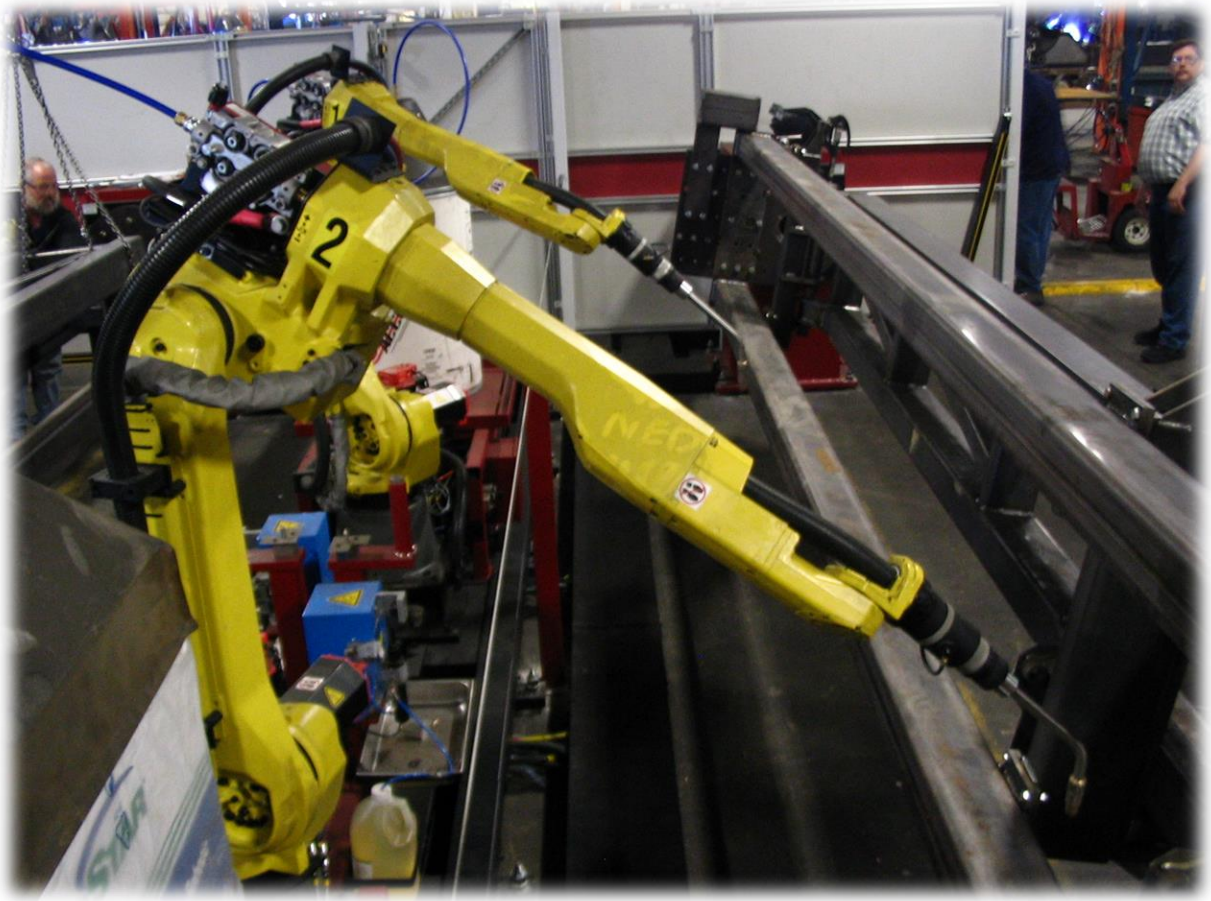
Introduction

Service Robots



Images by: Nohau and Jenay Randc

Industrial Robots



Images by: Phasmatisnox and HumanRobo

Cartesian Machines

- 3 linear axes used to achieve positions
- Can be scaled, for example gantry systems.
- CNC milling machines are examples of cartesian machines.

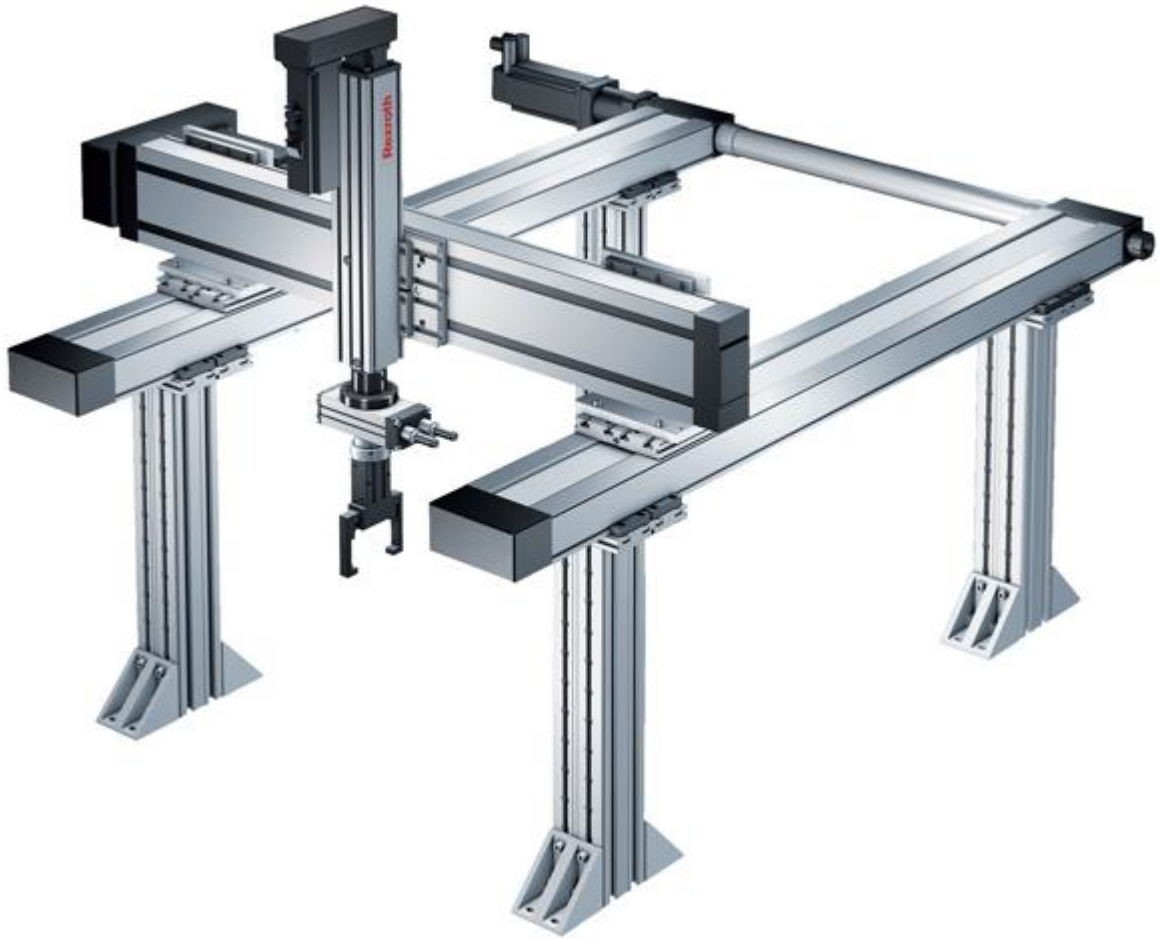


Image by: Richard Vaughn

Accuracy and Precision

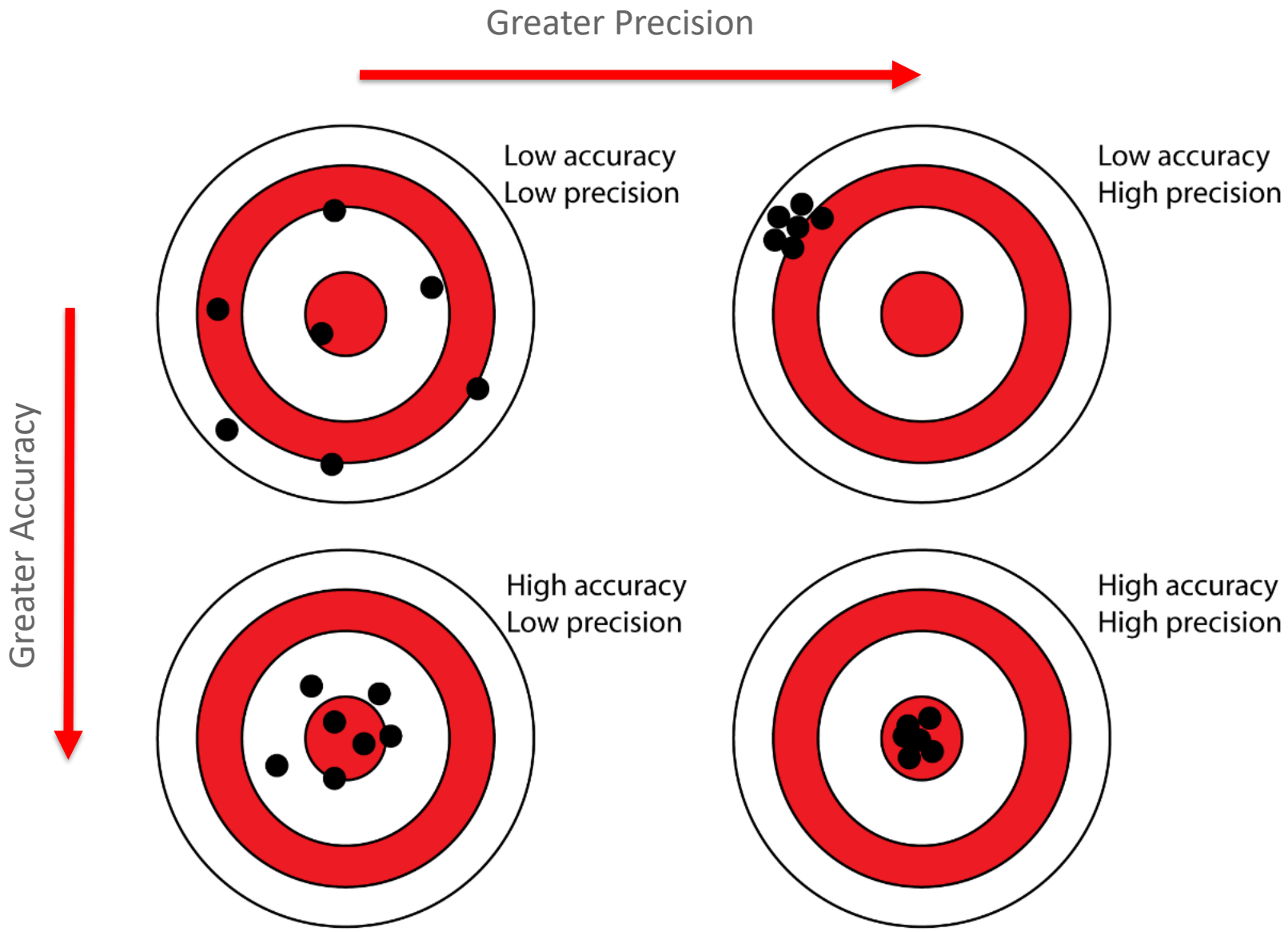
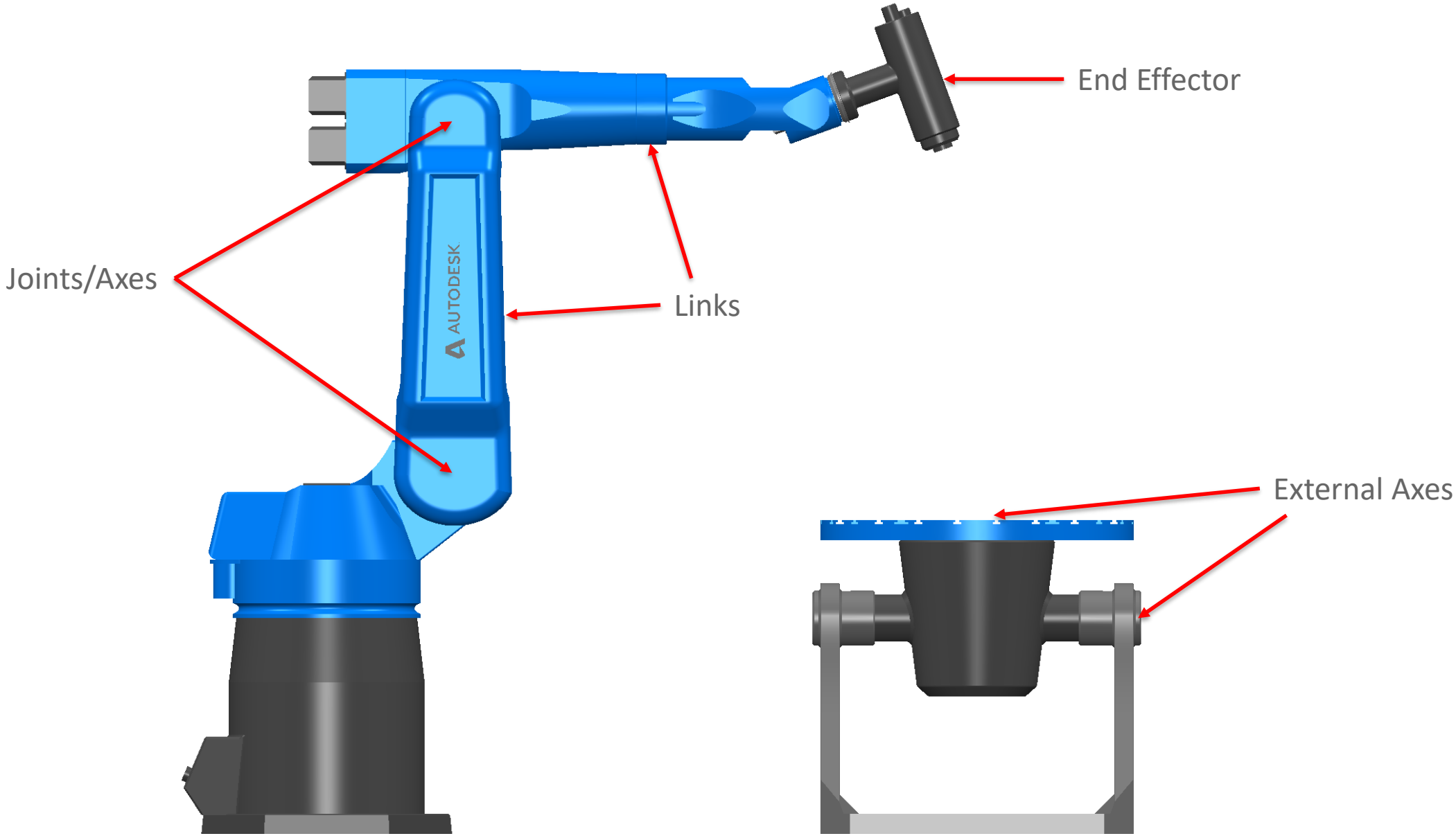
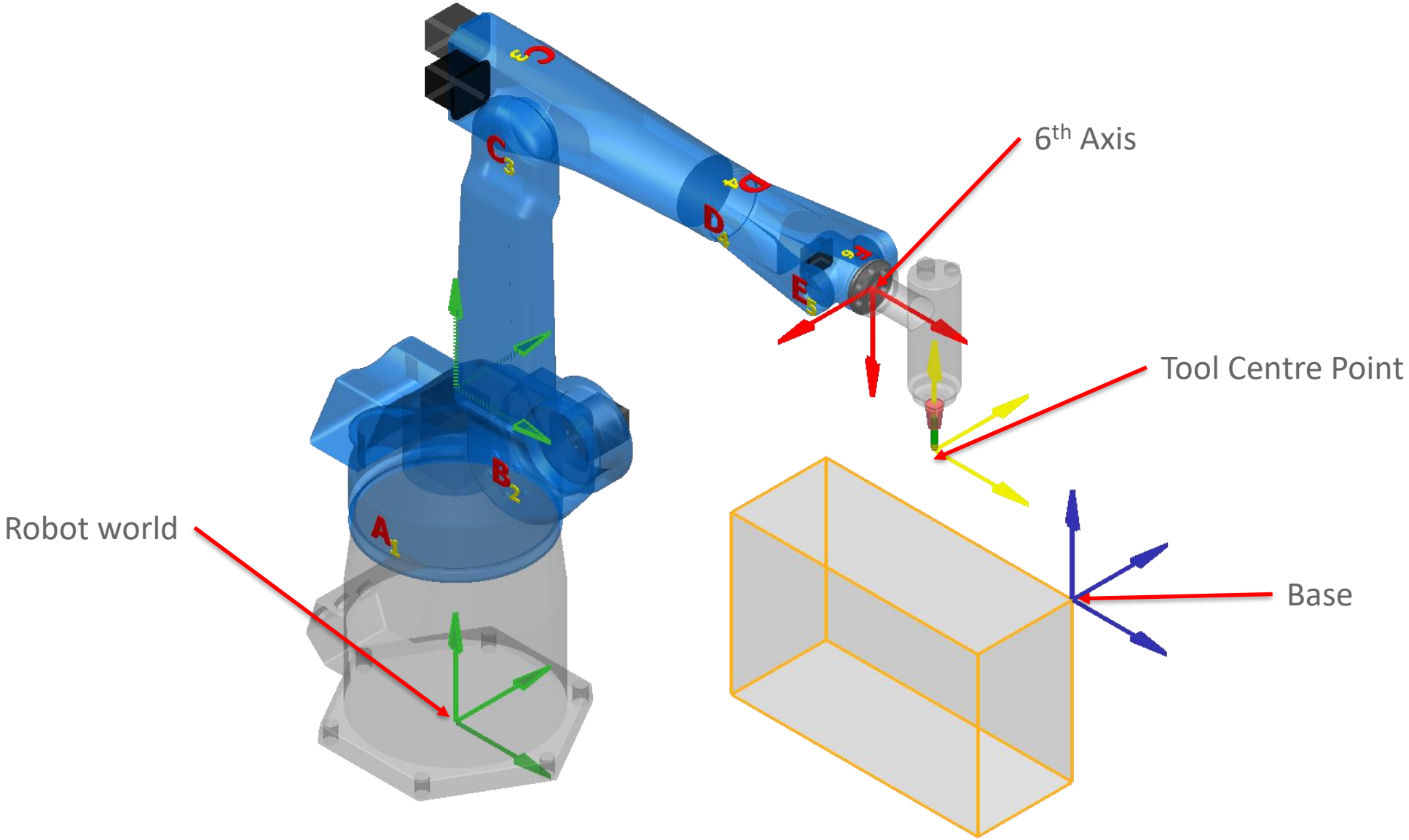


Image by: examspm.com

Robot Components



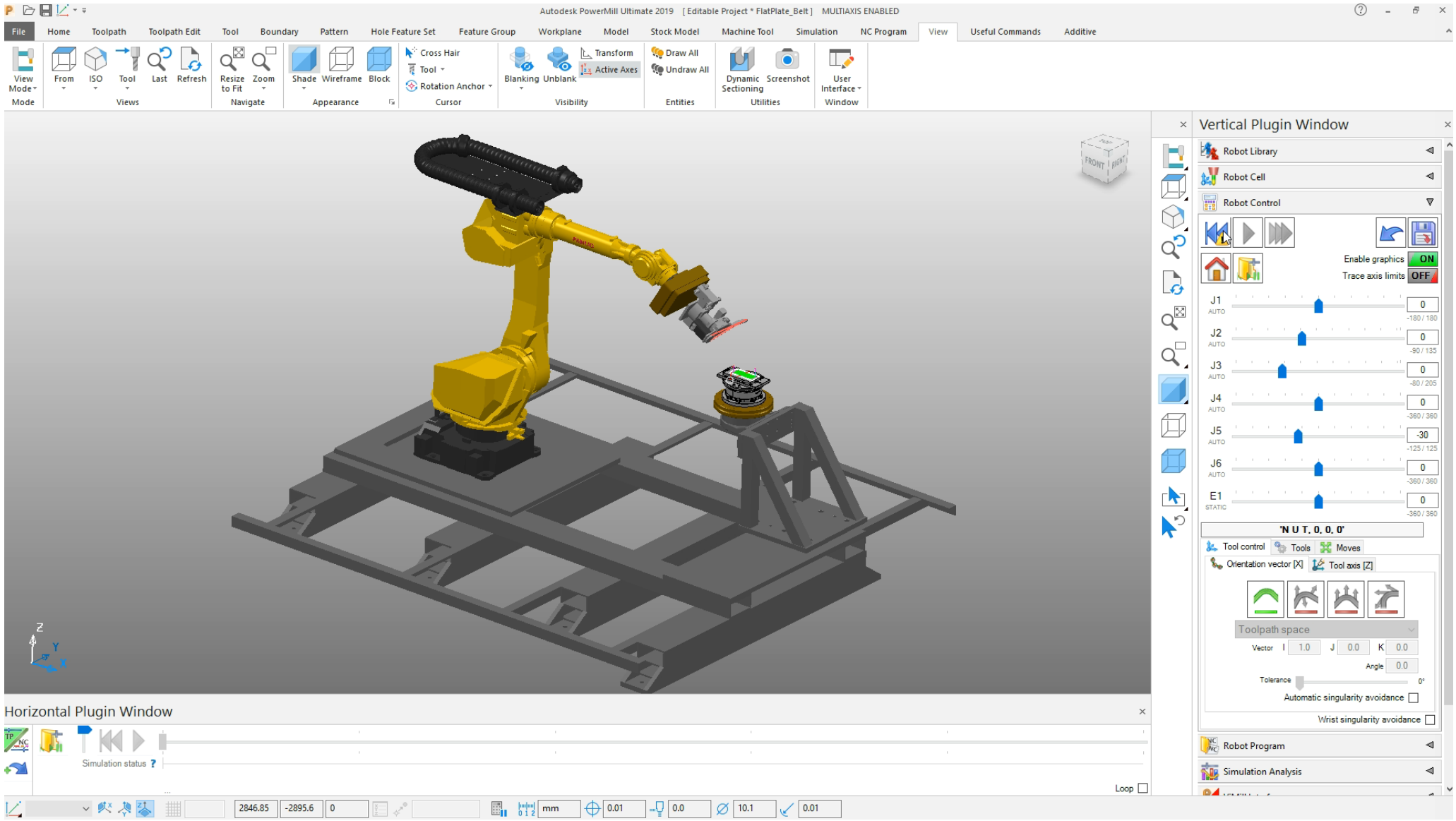
Coordinate Systems



Online Programming

Image by: Sue Sapp

Offline Programming



Applications of Industrial Robots

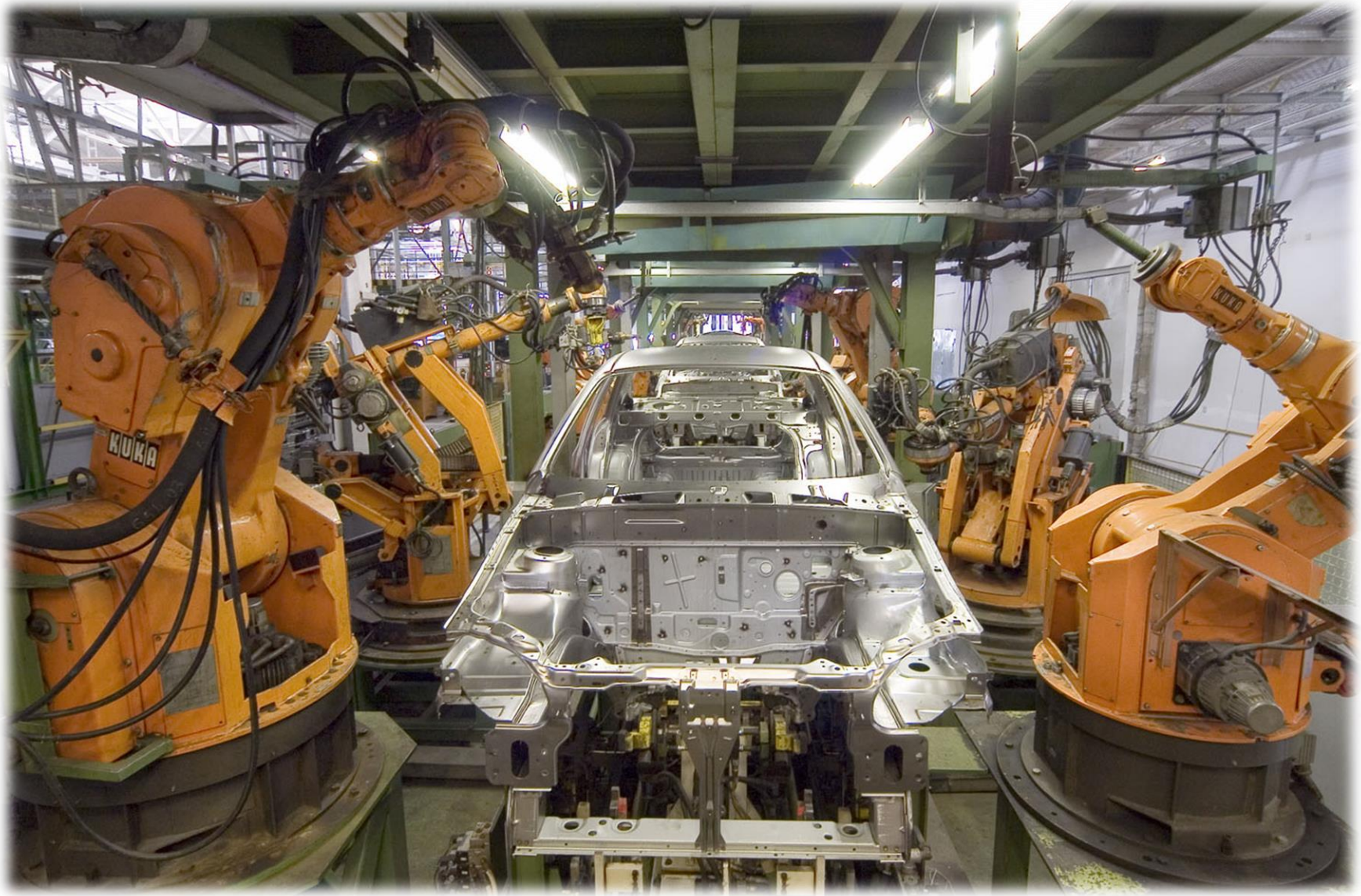


Image by: Mixabest

Applications of Industrial Robots

Image by: Robotics Online Marketing Team

Applications of Industrial Robots

Image by: Waerfelu

Applications of Industrial Robots

Image by: Tim Hornyak

Applications of Industrial Robots

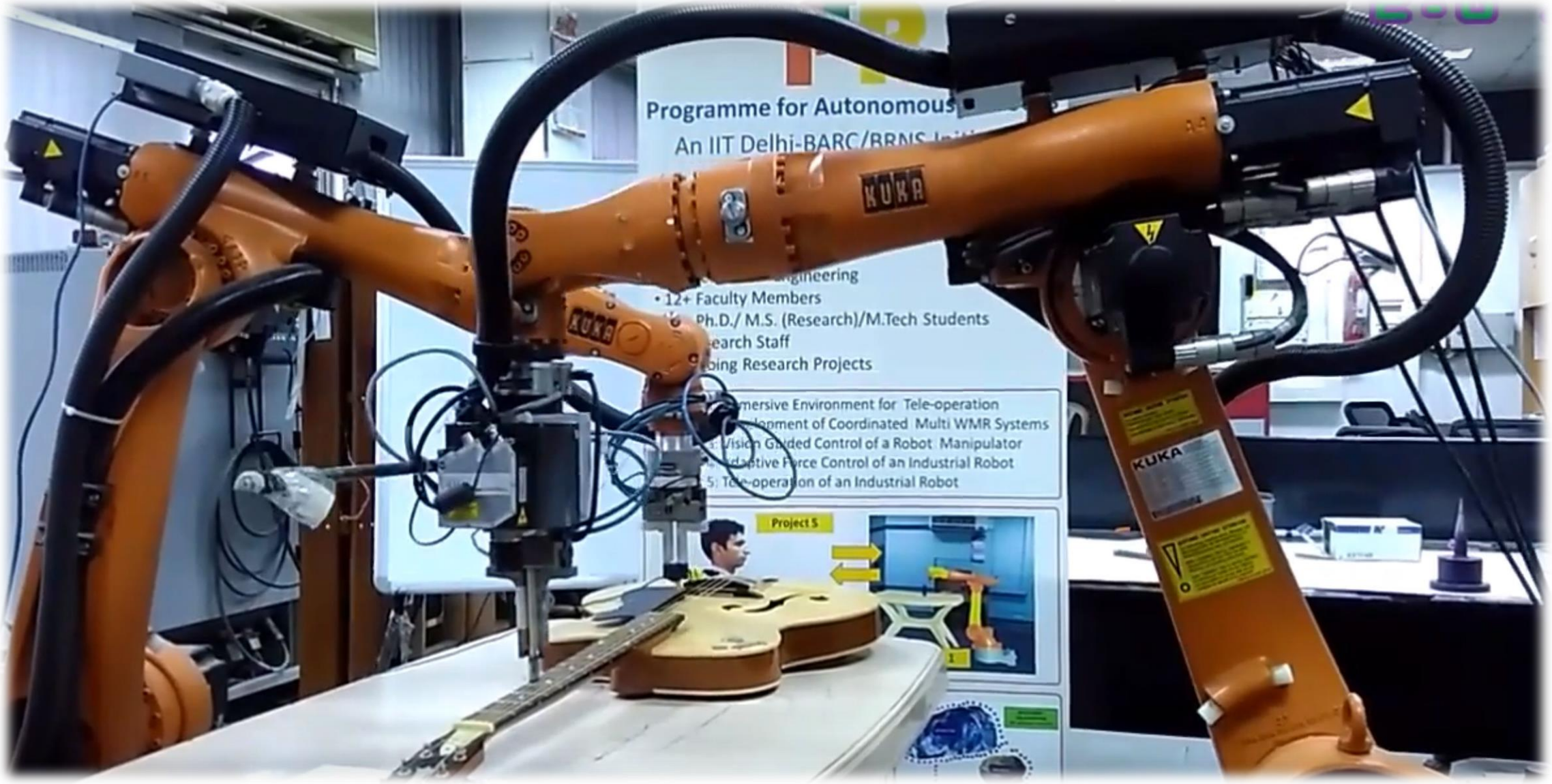
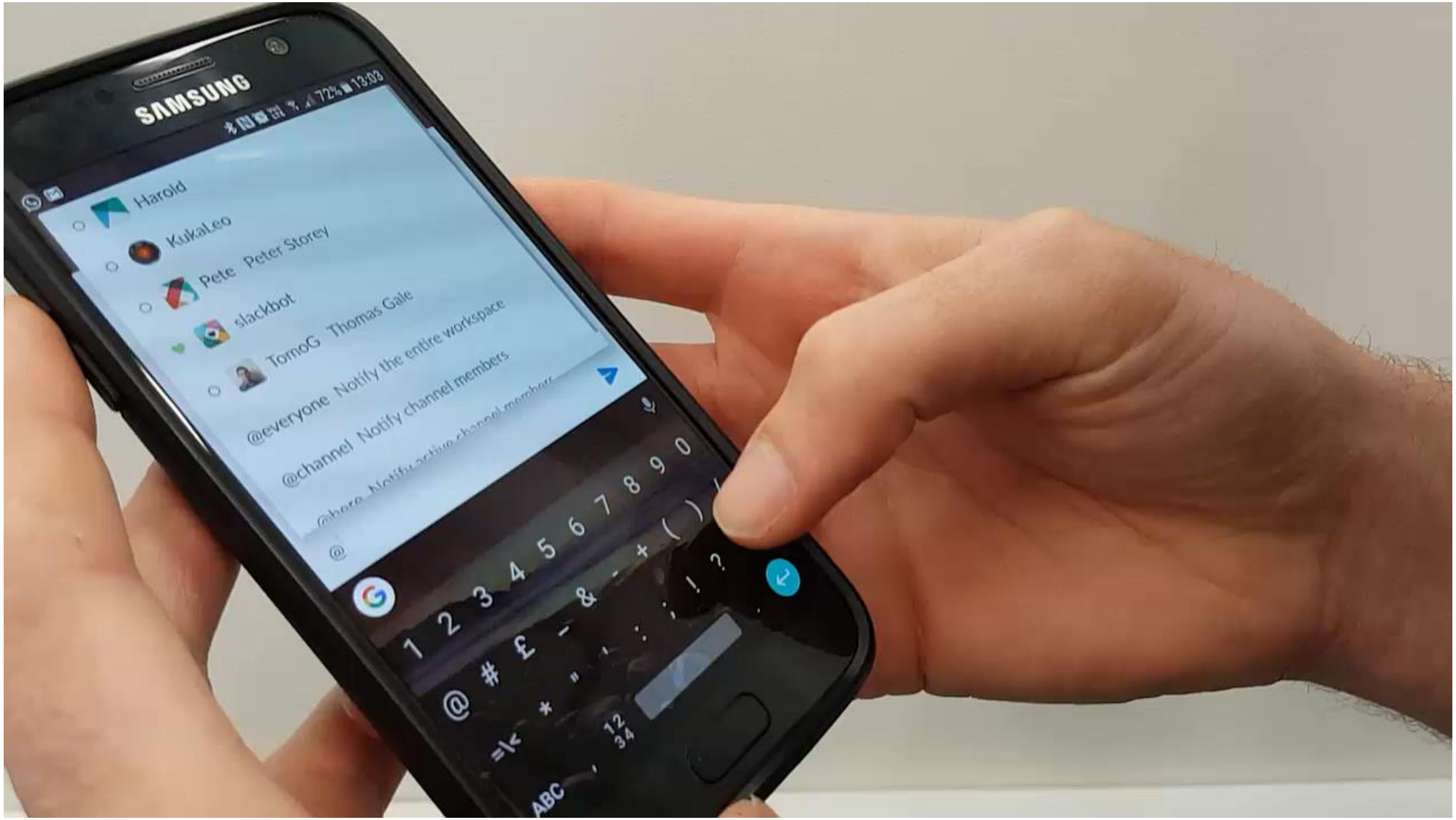


Image by: Keshav Bimbraw

Applications of Industrial Robots



Video by: Thomas Gale

Applications of Industrial Robots

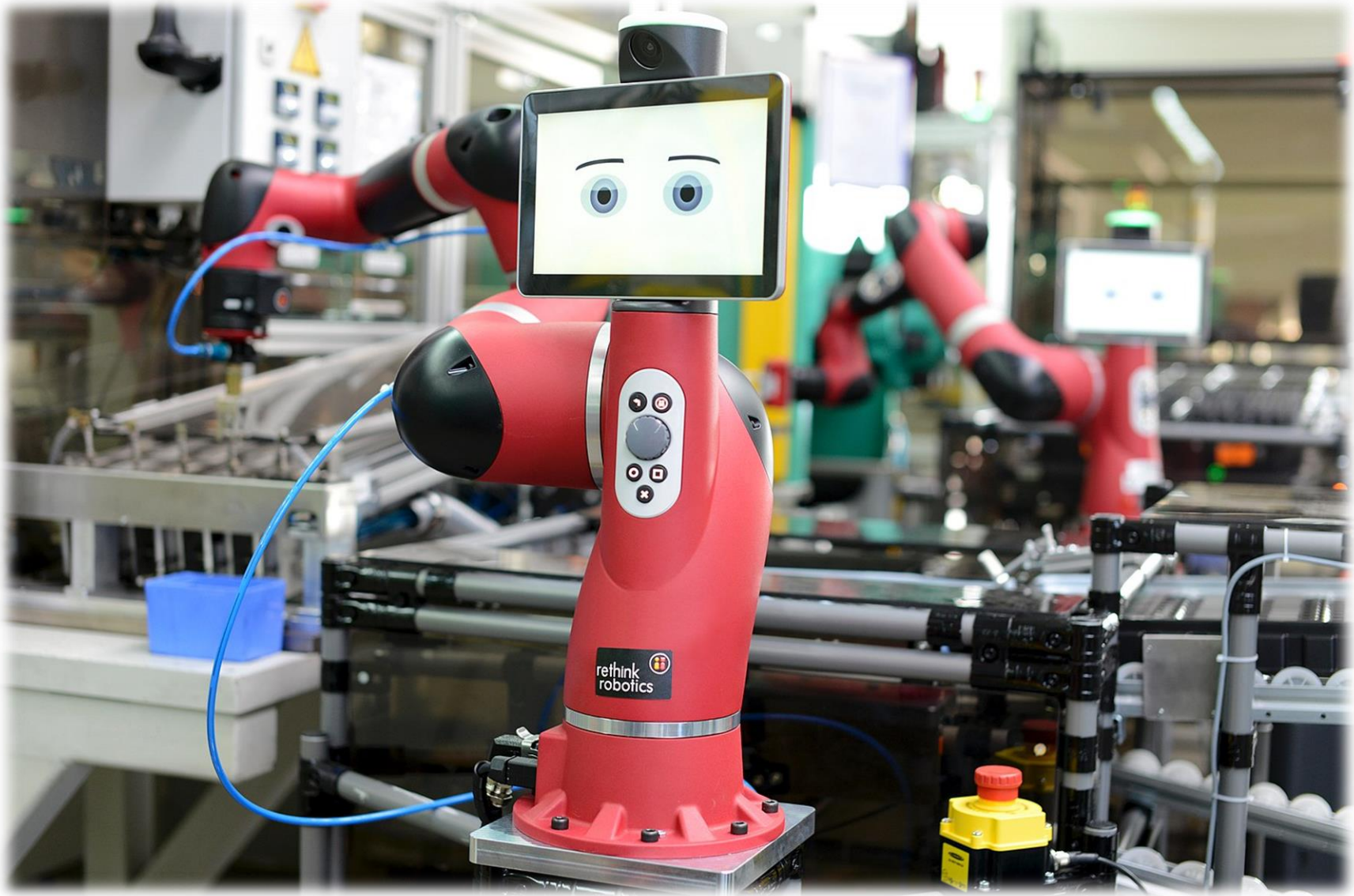


Image by: Rethink Robotics

Applications of Industrial Robots

Image by: Royal Caribbean

Applications of Industrial Robots

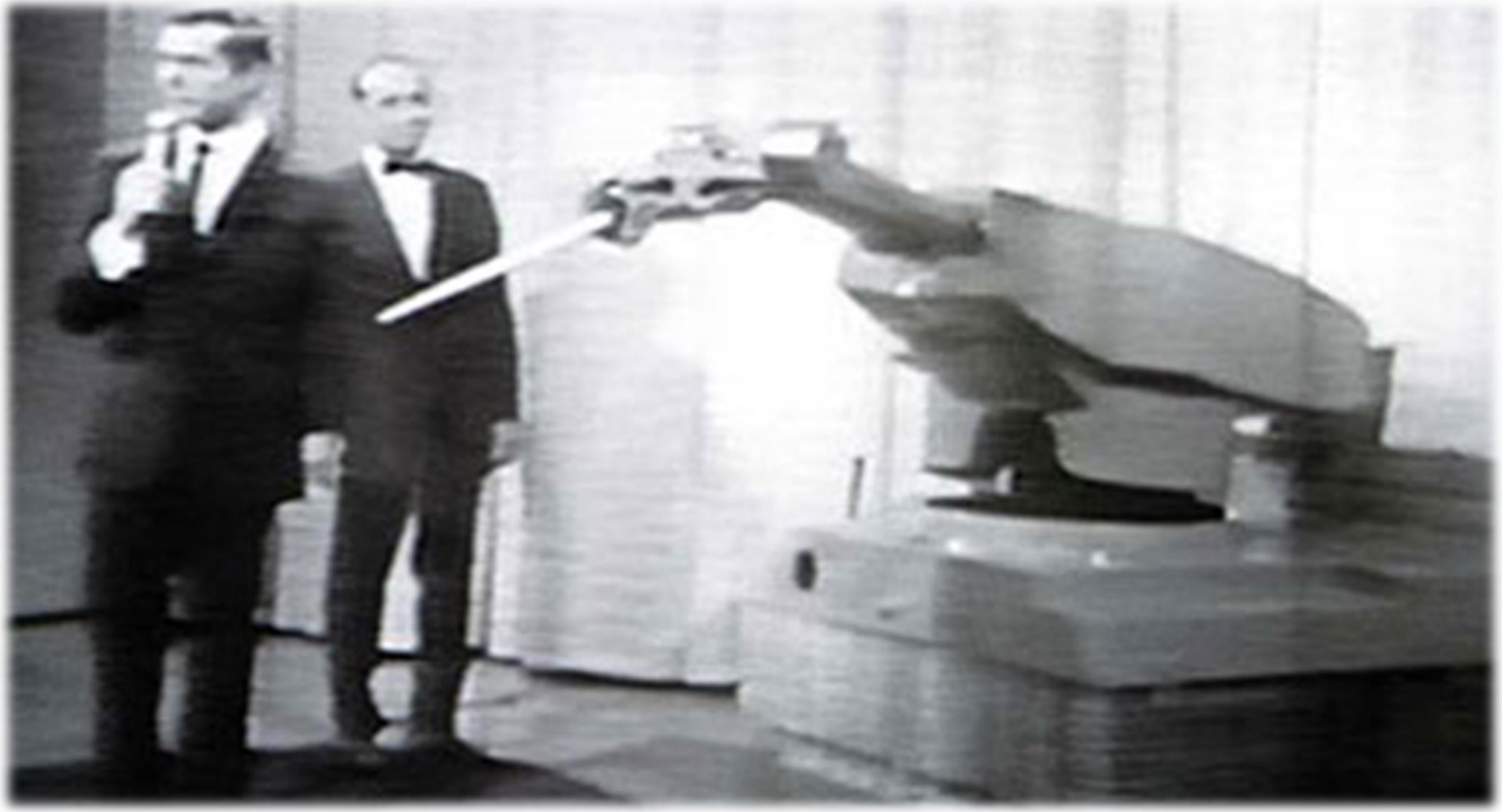


Image by: The Tonight Show

Offline Programming

Offline Programming

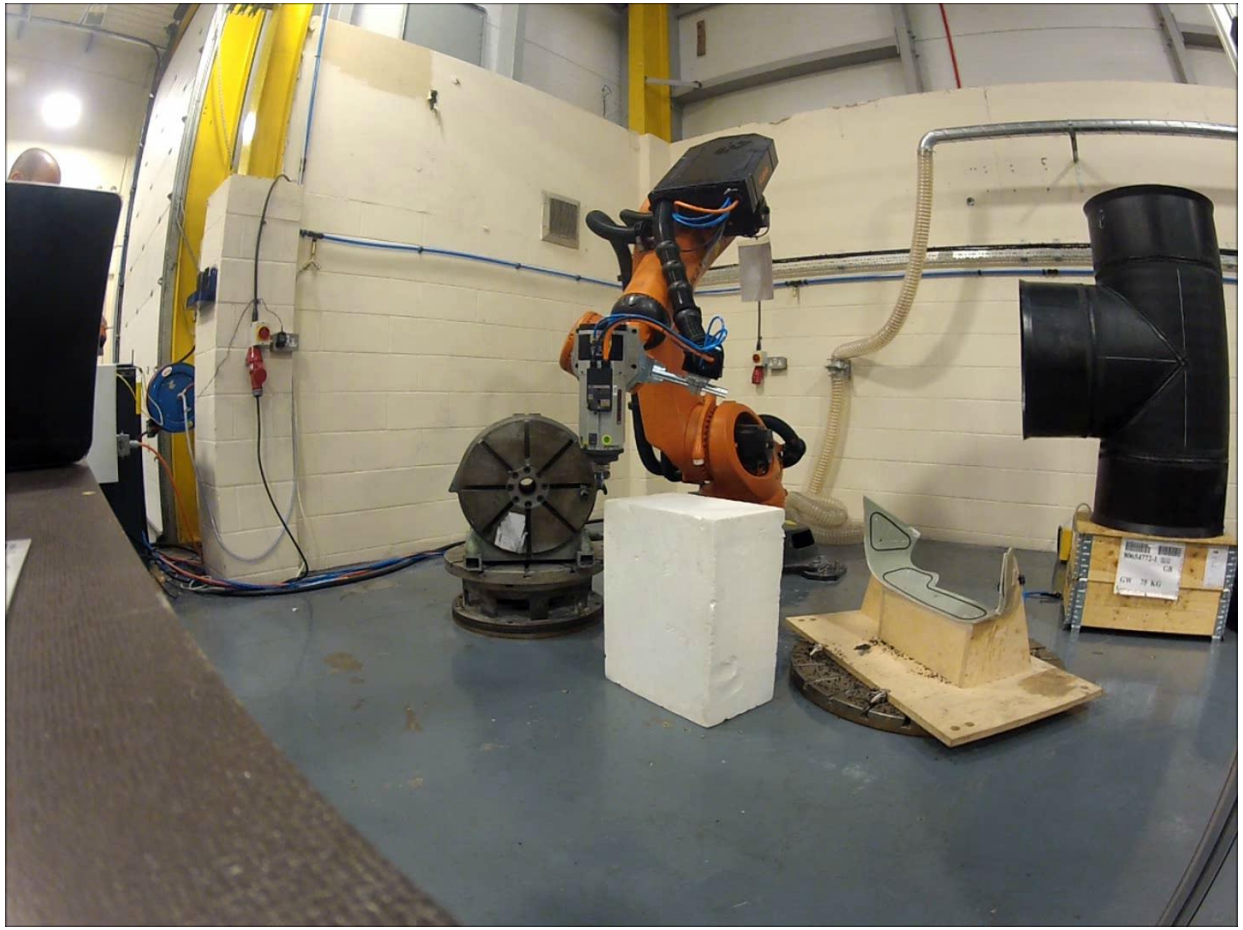
Sources of Inaccuracy

Taught Coordinate Systems

- Reference points have to be taught manually.
- 2 types, tool and base systems.
- Tool position is taught by positioning tool tip over spike 3 times in different orientations.

Taught Coordinate Systems

- Base data is taught by measuring 3 different points to define the axes of the workplane.
- Requires calibrated tool.
- Errors carried forward from inaccuracies in the taught tool position.



Joints

- Motors in each of the joints have inherent errors in them.
- Errors from all joints stack
- Distance from joint exaggerates the error.
- Single large error in the joints results in 12.14mm error in position.
- Error in each joint results in 0.29mm error in position

Global transform

X	-141.210	A1	0.000
Y	-1.990	B2	0.000
Z	834.685	C3	0.000
R1	0.000	D4	0.000
R2	0.000	E5	0.000
R3	0.000	F6	0.000

Global transform

X	-141.183	A1	0.005
Y	-2.160	B2	0.005
Z	834.452	C3	0.005
R1	-0.006	D4	0.005
R2	0.017	E5	0.005
R3	-0.011	F6	0.005

Axis Reversals

- Imperfections in gear interfaces result in small gaps.
- When the axes reverse there is rotation of the gears through this space that does not translate to movement of the arm.
- Permanent angular offset between the same position if approached from opposite directions
- Same effect as the joint inaccuracies and stacks with them.

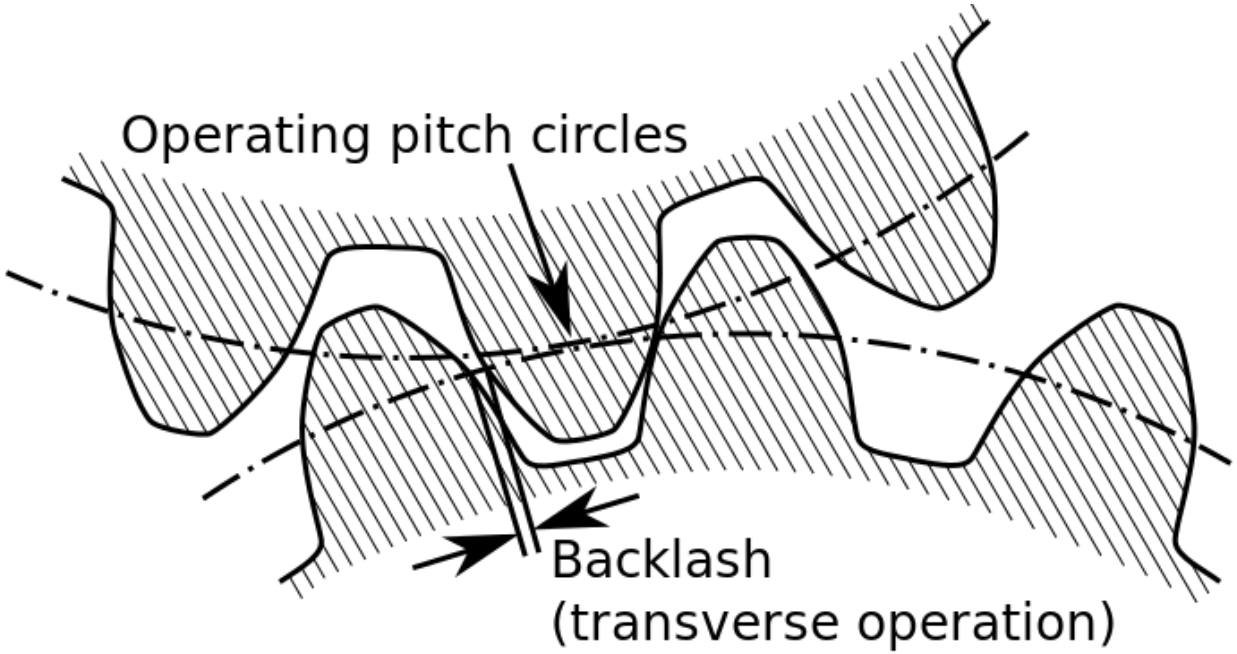
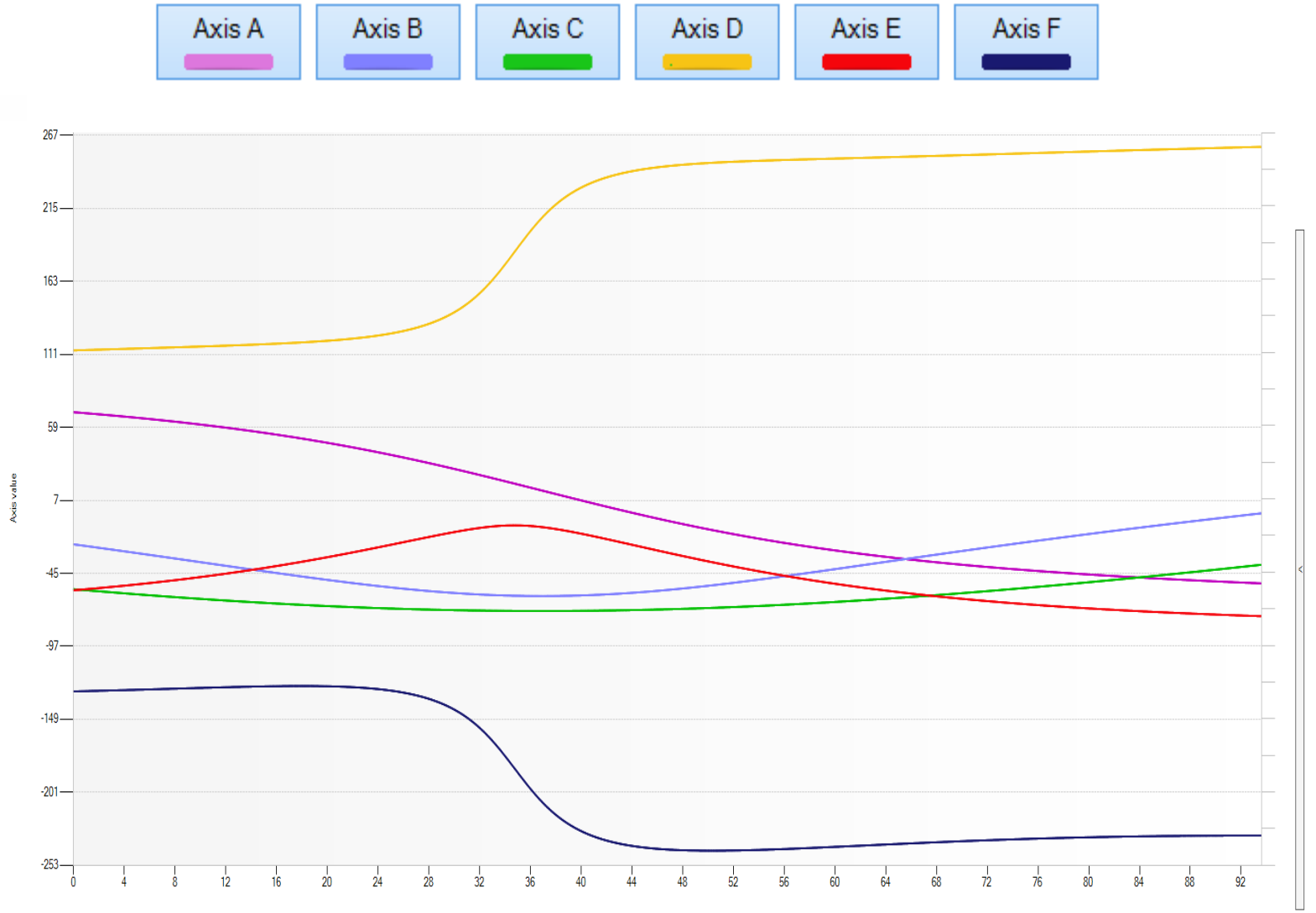


Image by: GearHeads

Axis Reversals



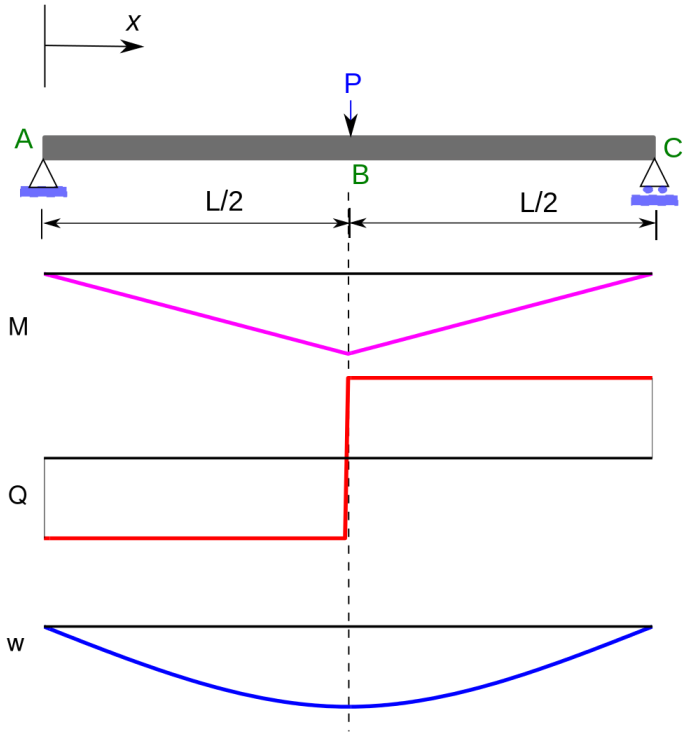
Lack of Rigidity

- Robots deflect under heavy load
- Constant deflection
- Present in online programming

Image by: Fanuc America

Lack of Rigidity

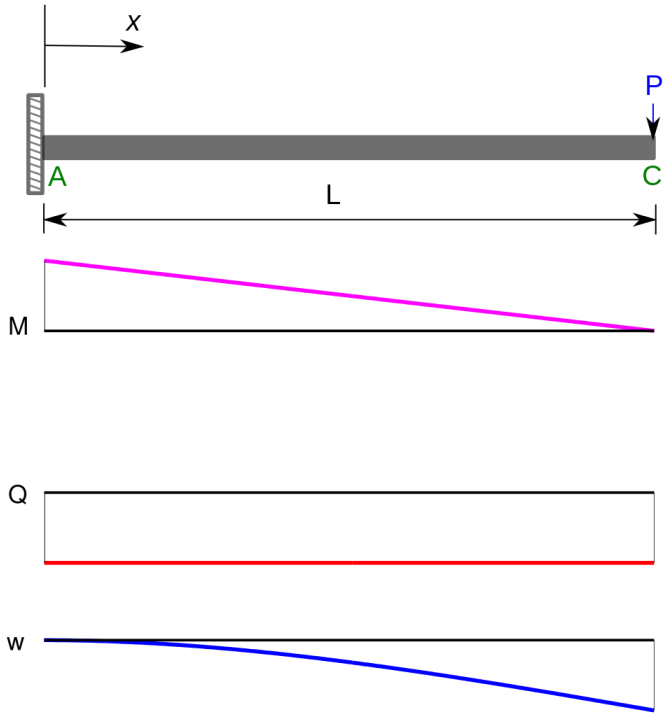
Cartesian Machine



$$w_{max} = \frac{PL_C{}^3}{48EI}$$

$$L_C = 2L$$

Robot



$$w_{max} = \frac{PL^3}{3EI} = \frac{PL_C{}^3}{24EI}$$

Images by: Bbanerje

Lack of Rigidity

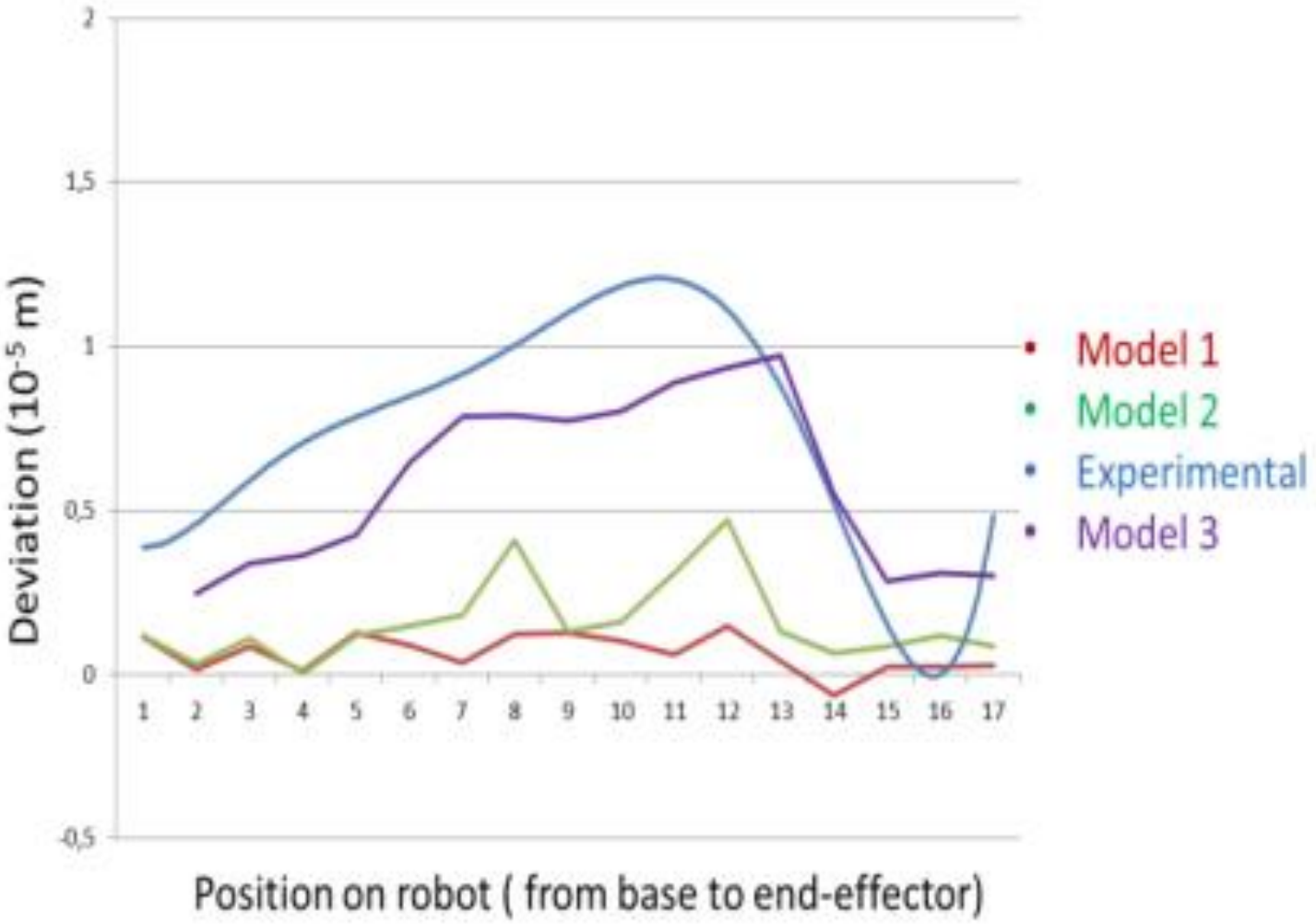


Image by: C. Doukas, J. Pandremenos, P. Stavropoulos, P. Fotinopoulos, G.Chryssolouris

Solutions

Robot-Based Metrology

Robot-Based Metrology

- Non-contact metrology devices can be mounted on robot arms to automate inspection process.

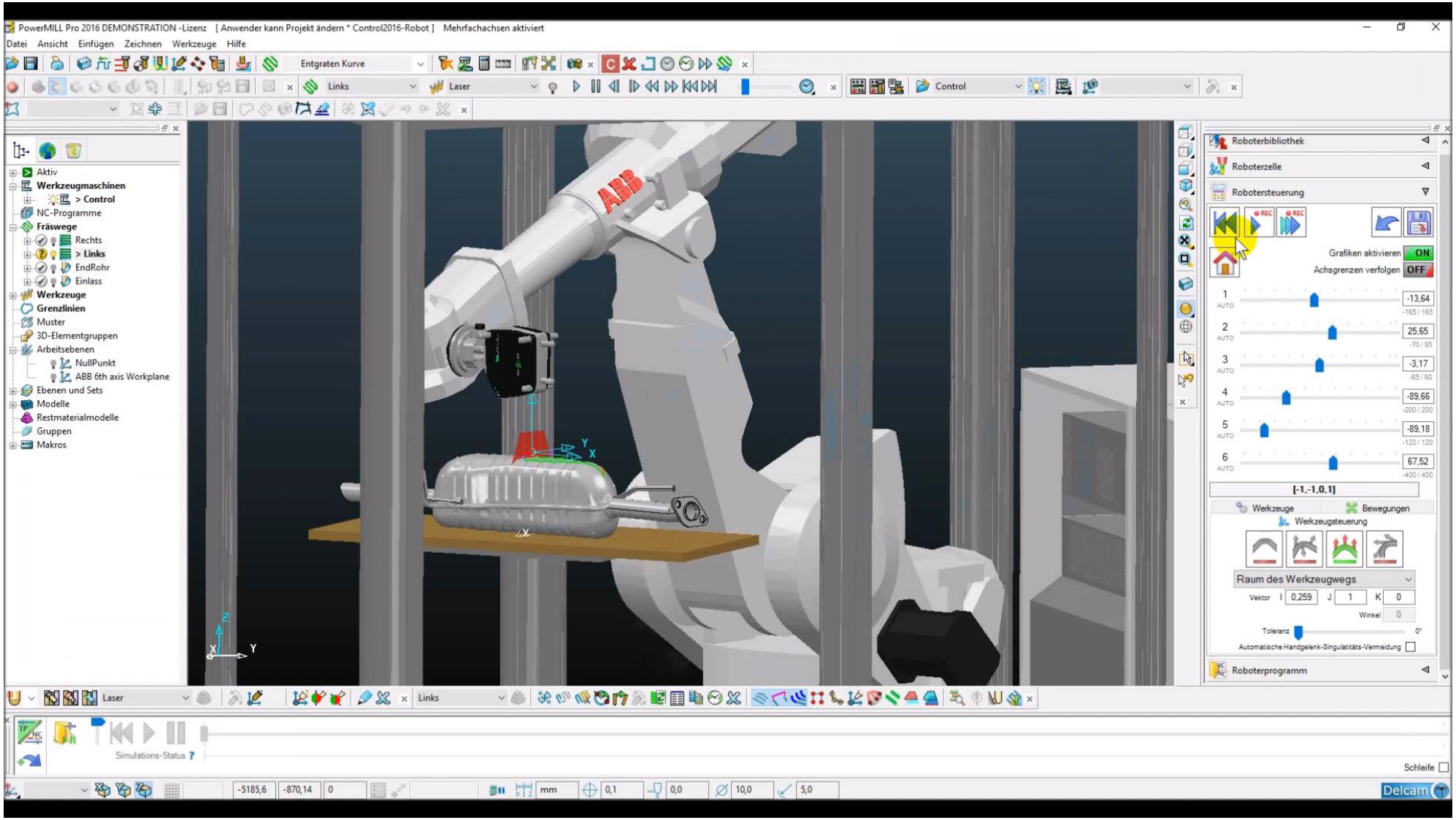
- 2 main technologies that allow this:
  - Tracking systems
  - Part aligned systems

Tracking Systems

- Sensor moves over the part
- 2 cameras constantly monitor the position and orientation of the sensor.
- Collected points are transformed into common reference coordinate system.
- Inspection is built up of these images stitched together.
- Continuous recording of data
- Accurate to ~0.07mm

Image by: Creaform

Tracking Systems



Robot based Metrology

- The robot coordinates are ignored and the data is transformed to an independent coordinate system.
- Accuracy of positioning of the sensor is not vital to the operation.
- Robot is used as a carrier to move the sensor around.

Robot Polishing

Polishing

- Improve the surface finish of parts
- Manual, time consuming process
- Variable quality
- Prevalent across a range of industries

Robot Polishing

- Established solution
- Compliant head
- Process controlled by material removal
- Contact Point determined by tool axis
- Can be programmed offline

Image by: J. H. Benedict Company

Research

- European projects
  - PoliMATIC
  - SYMPLEXITY

- Aims:
  - Improve available hardware
  - Improve available software
  - Determine better workflows

Image by: J. H. Benedict Company

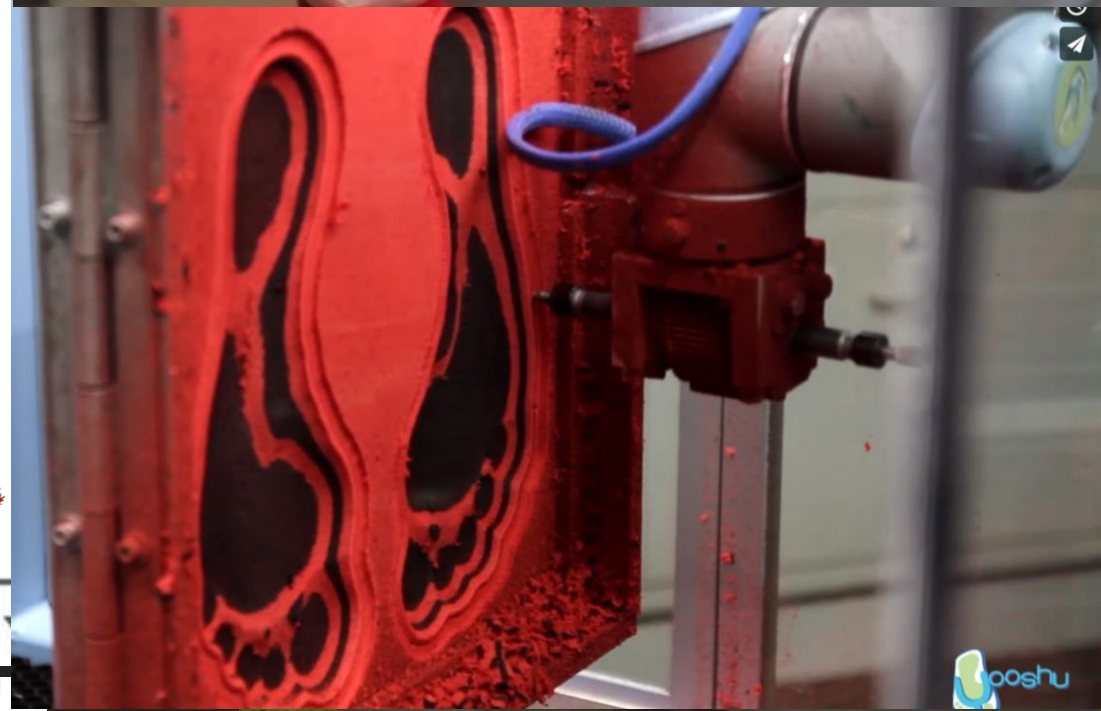
SYMPLEXITY Project

Robot Milling

Robot Milling

- Already used for milling in a range of industries:
  - Architecture
  - Entertainment
  - Marketing
  - Mould making
  - Customisation

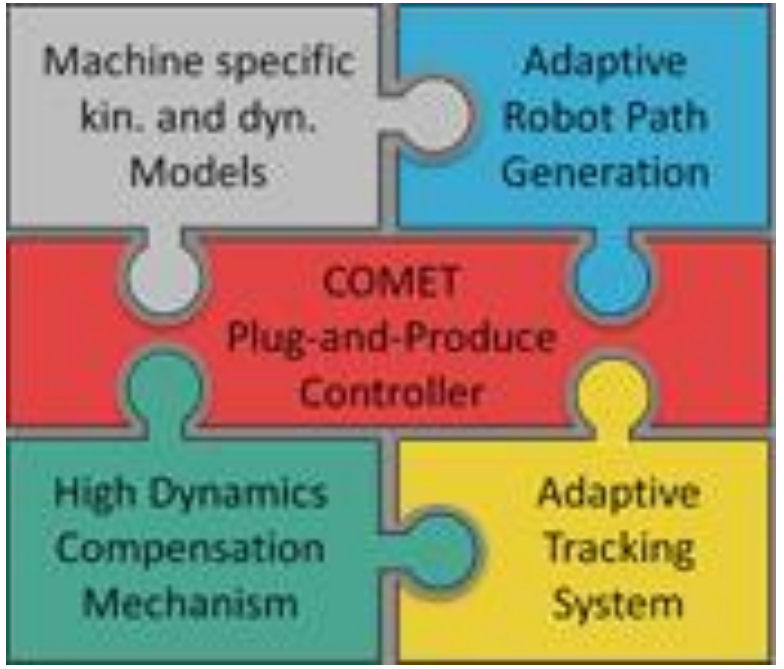
- Primarily soft materials, relaxed tolerance operations, large parts.



COMET Project

COMET Project

- Plug-and-produce **CO**mponents and **MET**hods for adaptive control of industrial robots enabling cost effective, high precision manufacturing in factories of the future.
- 30 month project by 14 technical contributors.
- Universities, research institutes and commercial suppliers.
- Combination of hardware and software resources.



Software Tools

- 2 software resources produced as a result of this:
  - Tool and Spindle calibration
  - Rotary table calculator

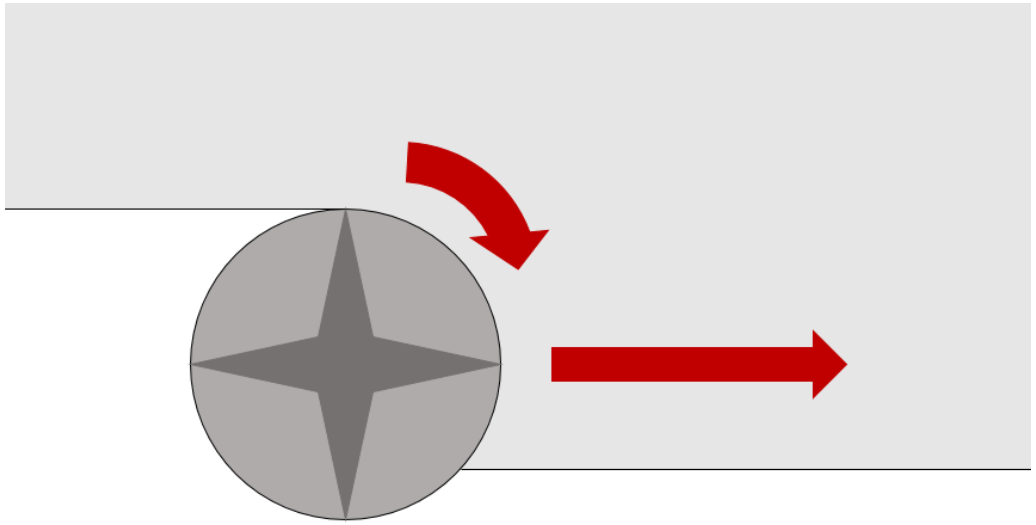
- Reduced errors as a result of taught positions by automating the process.

The Problem

- Focussed on methods to overcome process forces.

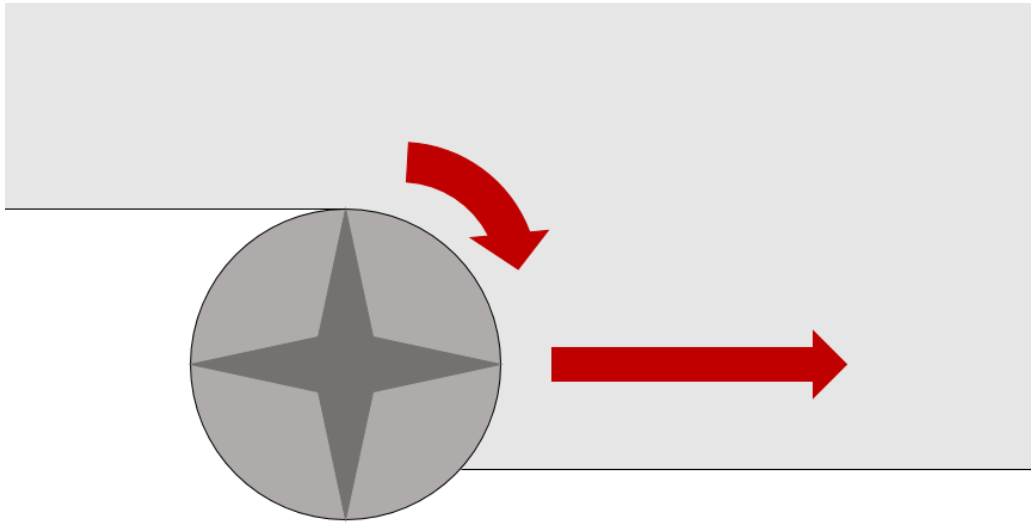
- Process forces for milling has 2 components:
  - Low frequency mean force
  - High frequency cutting force

- Require separate solutions



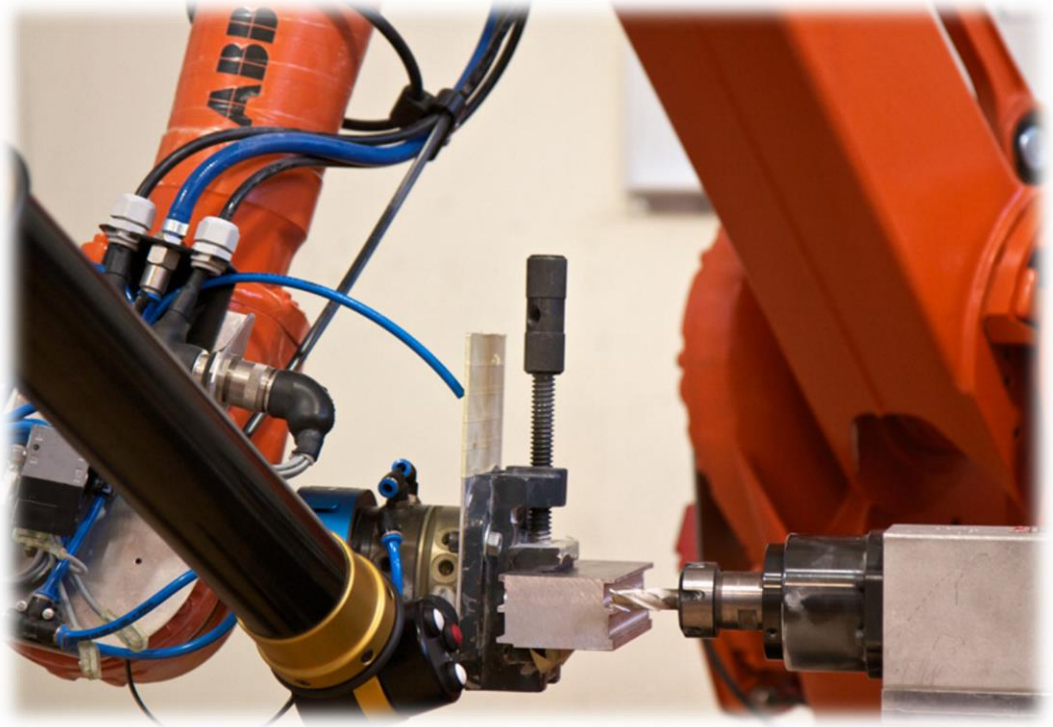
Process Parameters

- Cutting Parameters
  - Cutting feed
  - Control of engagement angle
  - Minimisation of force perpendicular to direction of cut
  - Position of part relative to the robot



Force Modelling

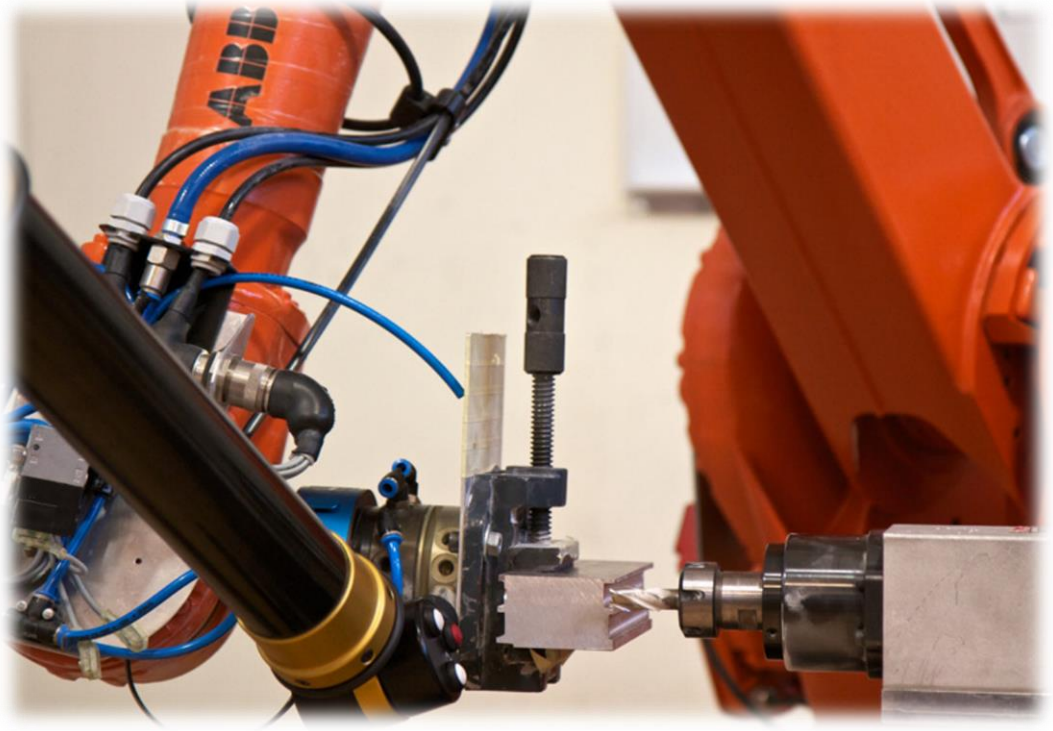
- Calculation of the low frequency process forces that would be experienced.
- Based on machining parameters.
- Process integrated into software.



Information by: Sornmo, Schneider, Robertsson, Puzik and Johansson

Deflection Calculation

- Generate a stiffness model for the individual robot.
- Use stiffness model and force modelling to calculate deflection.
- Apply offsets to the programmed path based on expected deflection.



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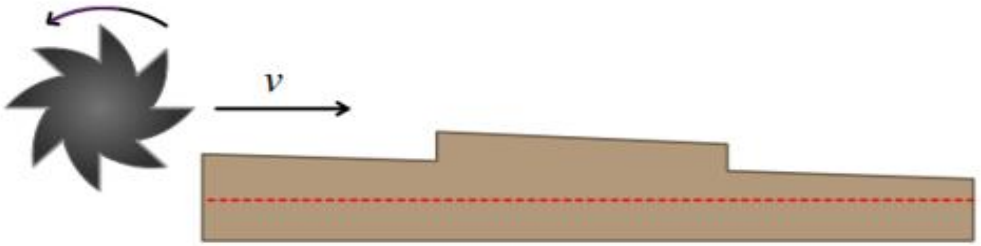
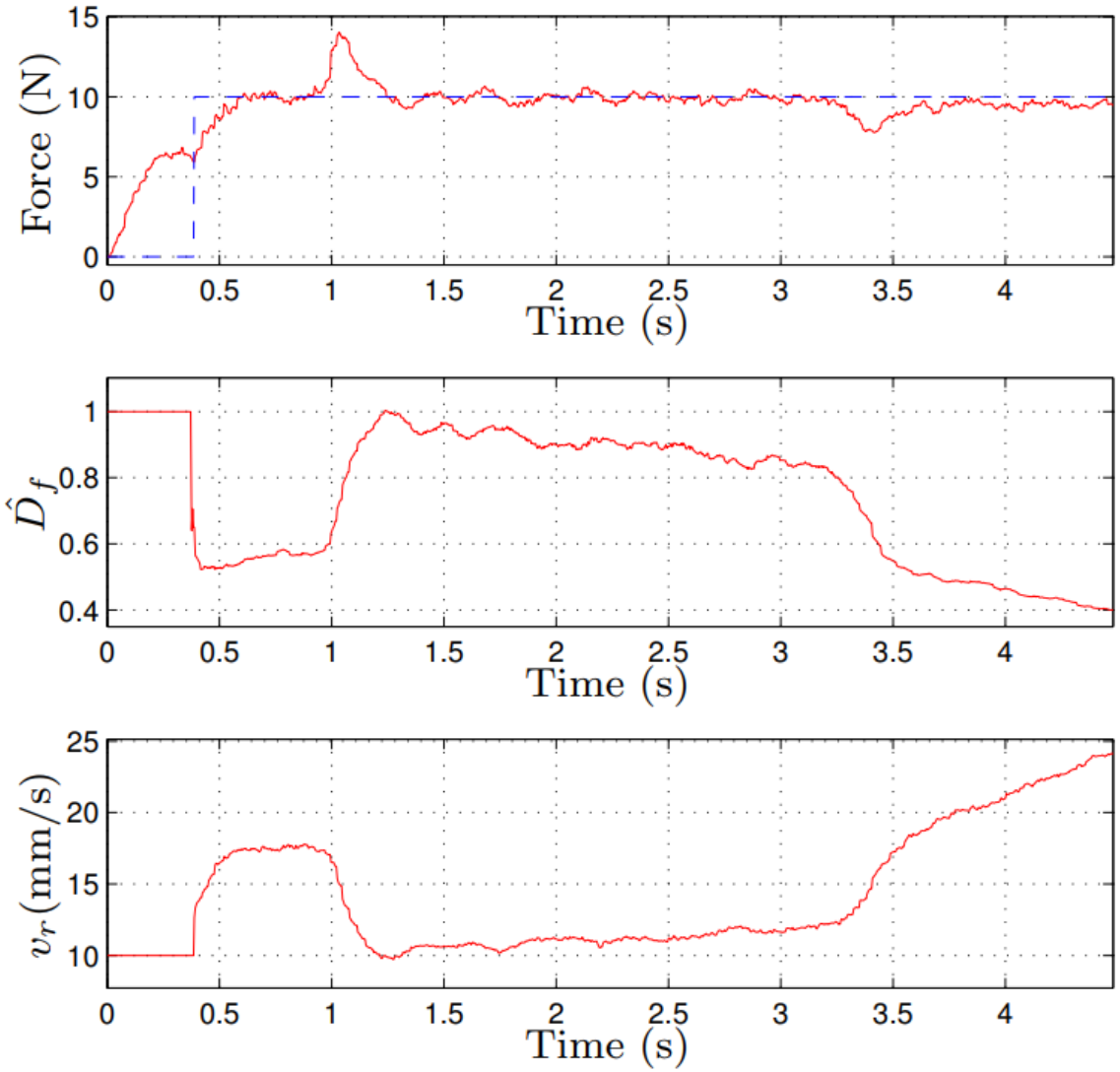
Force Control





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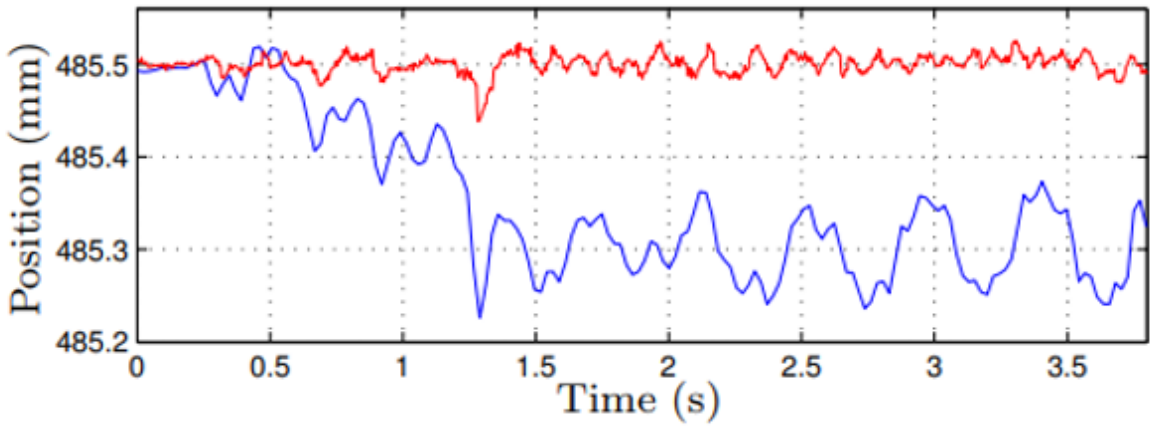
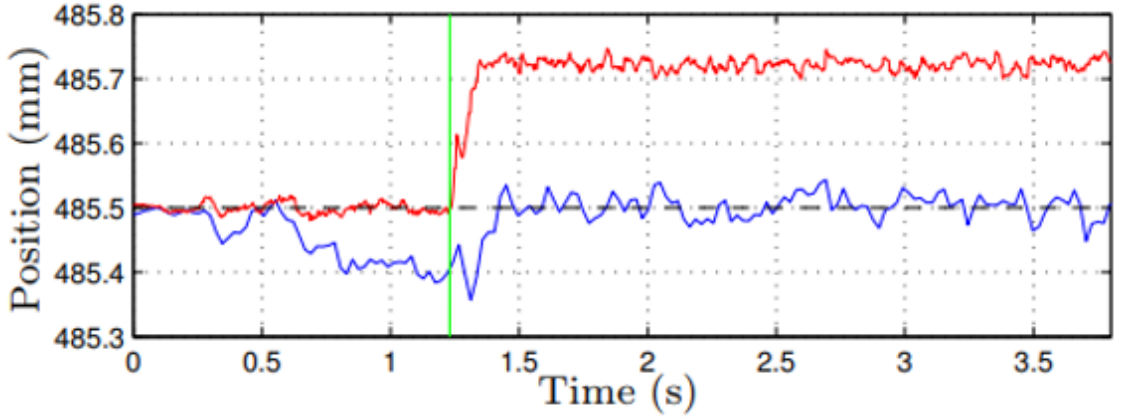
Force Control





Information by: Sornmo, Schneider, Robertsson, Puzik and Johansson

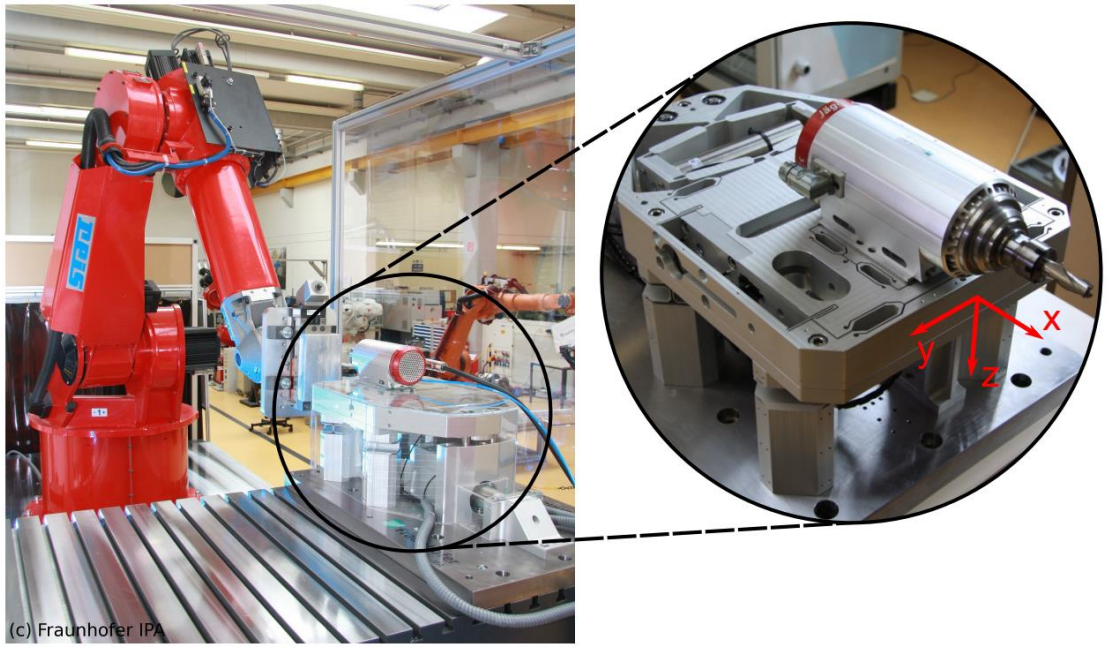
Position Tracking

- Tracking system to monitor actual robot position.
- Alignment of tracking target to base workplane and tool reference point.

Images by: COMET Project

Position Tracking

- Position fed into controller
- Compared to programmed position
- High dynamic compensation mechanism used to adjust relative positions
- Improved accuracy to ~12µm



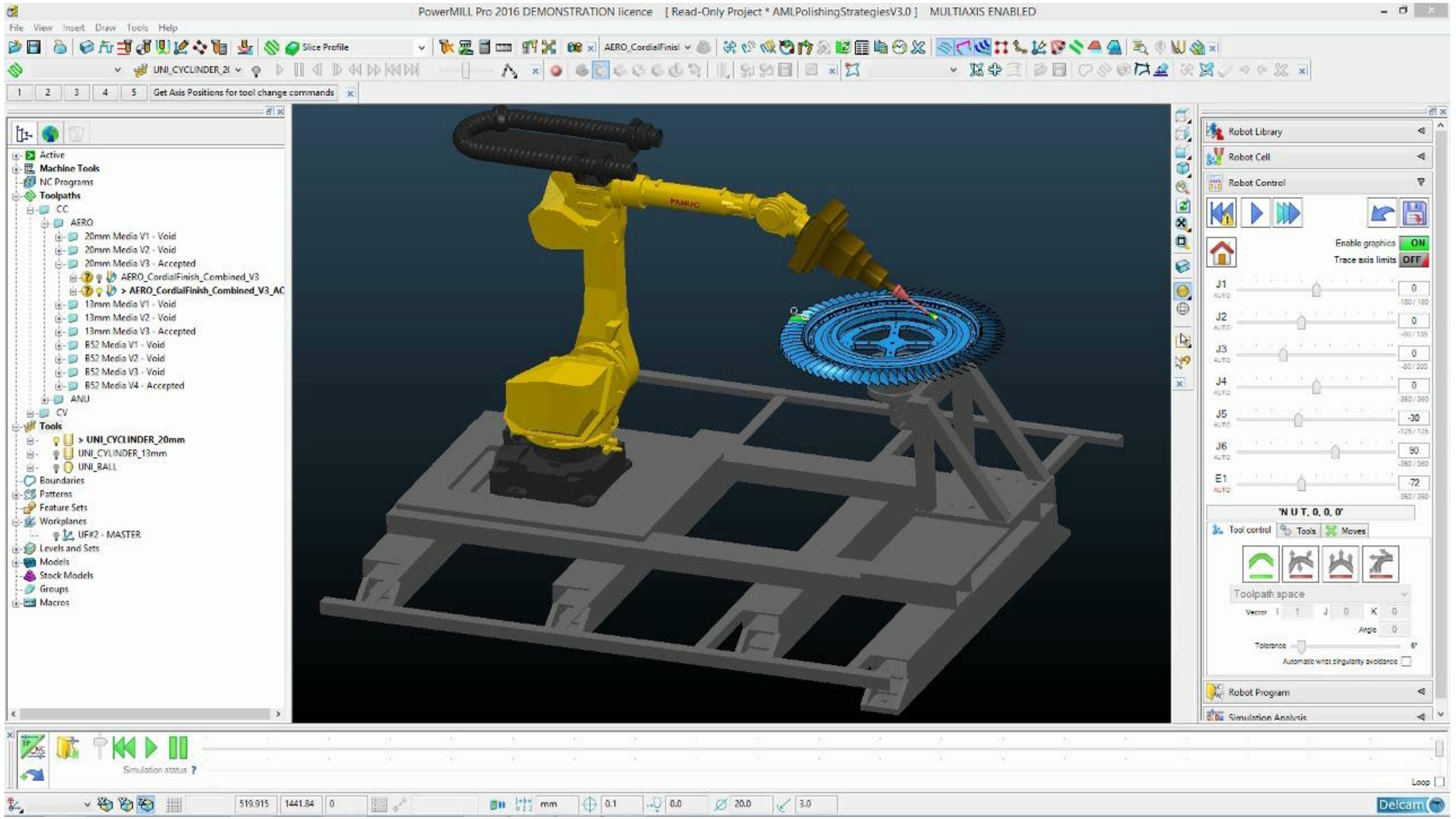
Images by: Fraunhofer IPA

Applications

Nikon Robot Drilling

Video by: Nikon

Polishing of Blisks



Polishing of Blades

Conclusions

Conclusion

- Robots are fundamentally limited in the accuracy they can achieve.
- Can work with additional hardware to achieve good results.
- Consideration of important factors in process.
- Investment into research.
- Technology adopters.

Further Reading

- For more information:
  - http://www.comet-project.eu/results.asp
  - www.symplexity.eu

Questions

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