Robotics: Mechanics & Control

Chapter 1: Introduction

In this chapter we review the history and specification of robotics, different robotics classification schemes. Furthermore, from a wide range of robotics application a number of them is illustrated, and ARAS developed robots are introduced. Finally, the course contents will be presented.

K. N. Toosi University of Technology, Faculty of Electrical Engineering,
Department of Systems and Control, Advanced Robotics and Automated Systems

Welcome

To Your Prospect Skills

On Robotics :

Mechanics and Control

01

About ARAS

ARAS Research group originated in 1997 and is proud of its 22+ years of brilliant background, and its contributions to the advancement of academic education and research in the field of Dynamical System Analysis and Control in the robotics application. ***ARAS*** are well represented by the industrial engineers, researchers, and scientific figures graduated from this group, and numerous industrial and R&D projects being conducted in this group. The main asset of our research group is its human resources devoted all their time and effort to the advancement of science and technology. One of our main objectives is to use these potentials to extend our educational and industrial collaborations at both national and international levels. In order to accomplish that, our mission is to enhance the breadth and enrich the quality of our education and research in a dynamic environment.

Contents

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Human Dream: Build a human clone

1. **Human Arm** — Robot Manipulator
2. **Human Leg** — Legged Robots
3. **Human Motion** — Mobile Robot
4. **Human Eye** — Machine Vision
5. **Listen and Talk** — Sound Recognition
6. **Think and Decide** — Artificial Intelligence

Introduction

- What is a robot?!!

  ✓ A robot is a re-programmable multi-functional manipulator designed to move materials, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks. (According to RIA)

  ✓ A robot is a mechanical or virtual artificial agent, usually an electro-mechanical system, which, by its appearance or movements, conveys a sense that it has intent or agency of its own. While there is still controversies about which machines qualify as robots, a typical robot will have several, though not necessarily all of the following properties:

A typical robot will have: several, though not necessarily all of the following properties:

1 Artificial

Is not natural, and it has been artificially created.

2 Measurements

Can sense its environment.

3 Manipulate

Can manipulate things in its environment.

Intent and Agency

4 Intelligence

Has some degree of intelligence.

5 Programmable

It is programmed to do flexible tasks.

6 Motion

Can move with one or more axes of motion.

Robotic History

The word **robot** entered English vocabulary as early as 1923. This word was first used by **Karel Capek** in his book, Rossam's Universal Robots. Capek visualized a situation where bioprocess could create human-like machines, devoid of emotions and souls. However, they are very strong and obeyed, and could be produced quickly and cheaply. Soon all major countries wanted to equip their armies with hundreds of thousands of slave robotic soldiers, who can ght with dedication, but whose loss have no pain. Eventually, the robots decided to become superior to the humans and tried to take over the world. In this story the word robota or worker was coined.

However, the emergence of industrial robots did not occur until after 1940's. In 1946, **George Devol** patents a general purpose playback device for controlling machines using magnetic recording, and in 1954, he designs the first programmable robot, and coins the **term Universal Automation**, planting the seed for the name of his future company - Unimation.

In early eighties, several robot producer companies are emerged and jointed, and the number of industrial robots used in the industries were increased significantly. In the second millennium, robotics research was focused more on the technology to build humanoid robots and robotic pets.

- **1975-1997**

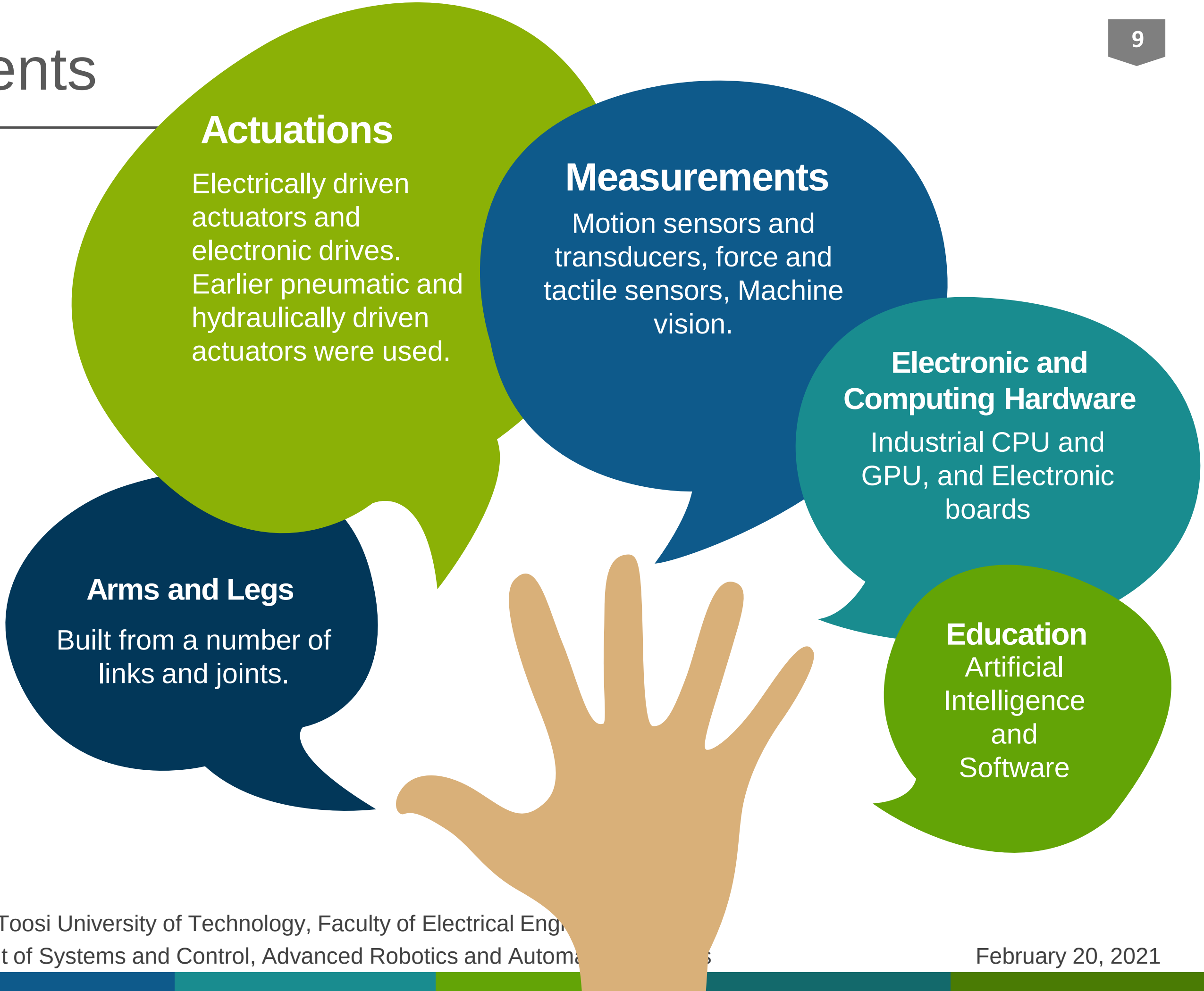
  Era of rapid development of programmable robots working in a structured environment, mostly servo-controlled with industrial PLC's.

- **1990-current**

  3rd Generation Robots, Intelligent robot in an unstructured environment, development of Artificial intelligence, and special architecture for robots.

Robot Components

A mechanism or a robotic manipulator is usually built from a number of links, connected to each other and to the ground or a movable base, by different types of joints. The number of degrees of freedom of a robot depends on the number of links and the type of joints used for the construction of the robot. In this section, the definitions for links, joints, kinematic chains, mechanisms and machines are given, and then the concept of degrees of freedom is described



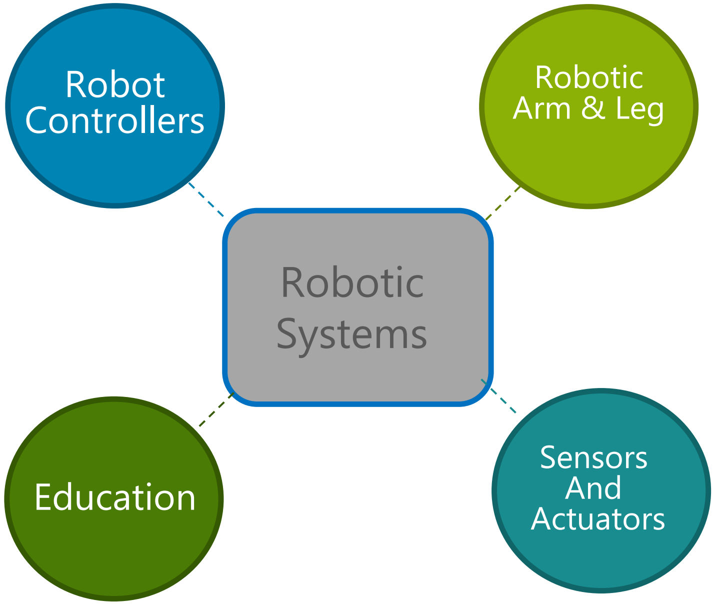
Physical Components in Robot Subsystems

Computer
Communication links, Sensor interface, controller design

Teaching Box
Task Planning, Trajectory Generation

Software
Motion control, path control, impedance control

Artificial Intelligence
Detection and Tracking



Joints and Links
Mechanics, Sensors, transducers

Endeffector
Wrist, Grippers, Tactile

Measurements
Encoders, Vision, Tactile Sensors

Actucators
Motors, Gearbox, Drive

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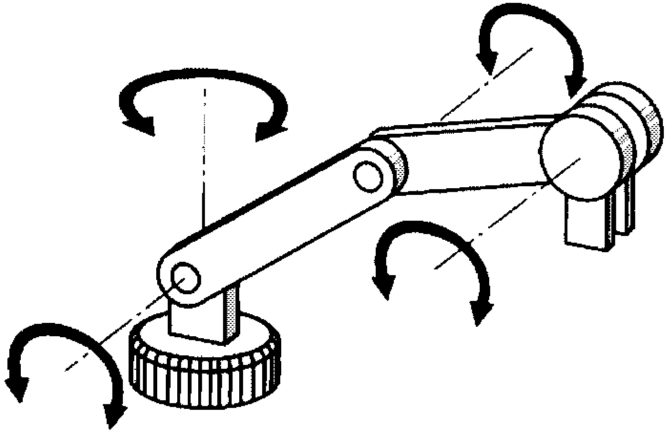
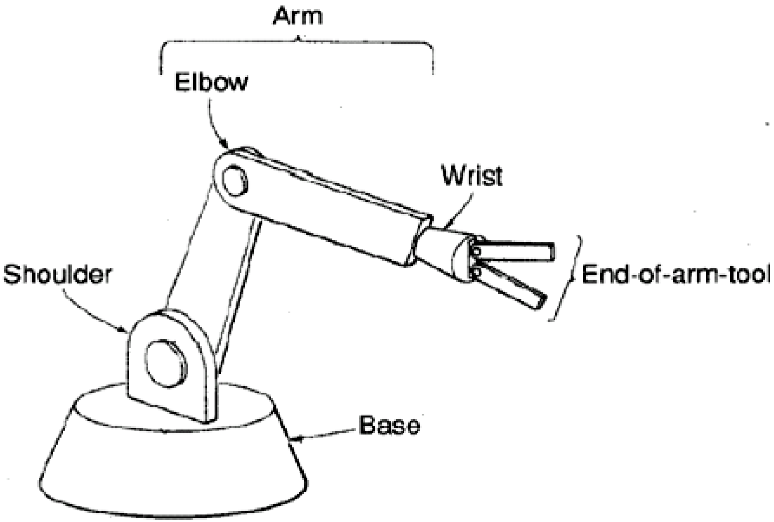
Robot Classification



Articulated



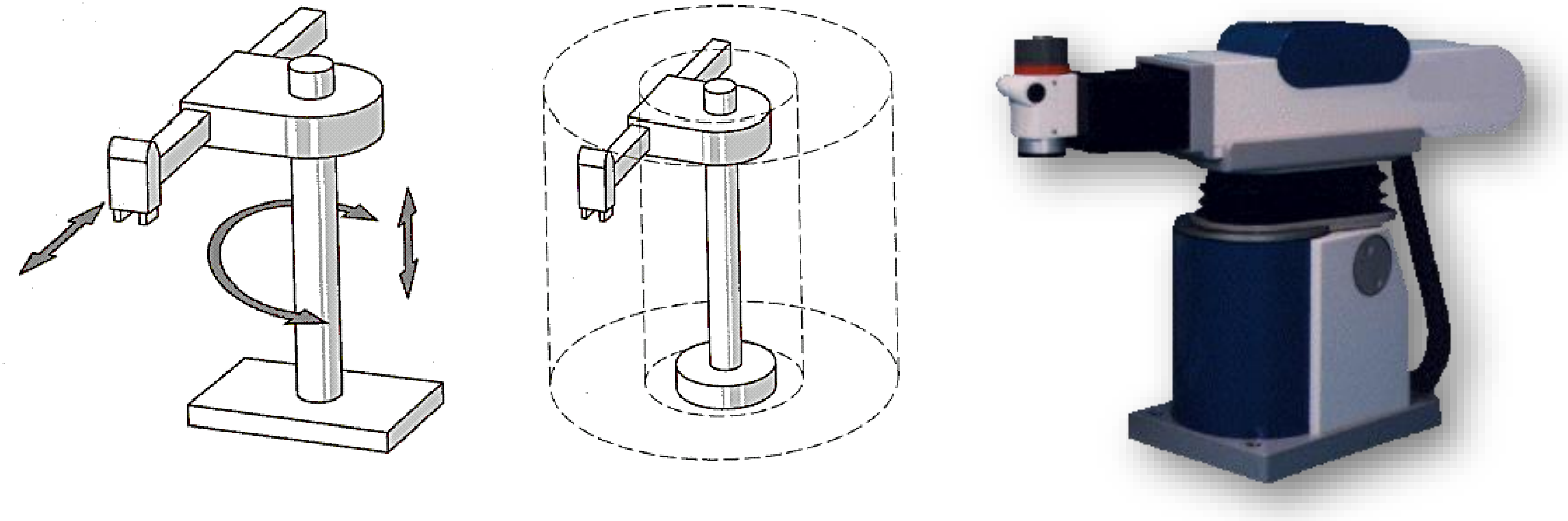
Serial links

Robot Classification

Articulated

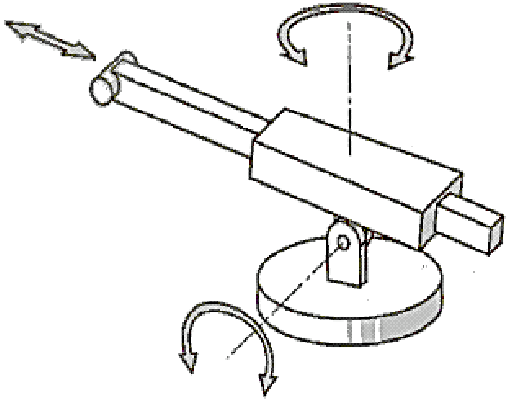
Serial links

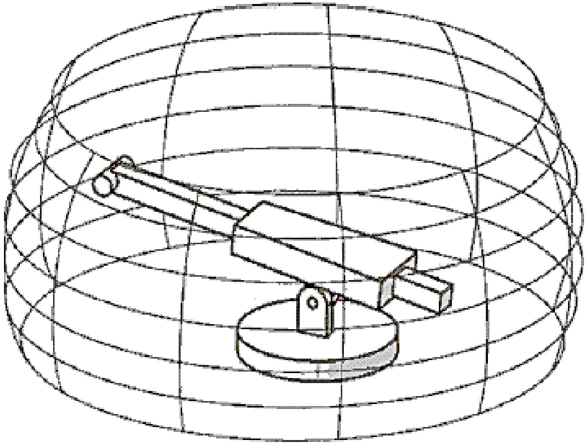
Robot Classification



Cylindrical Robot

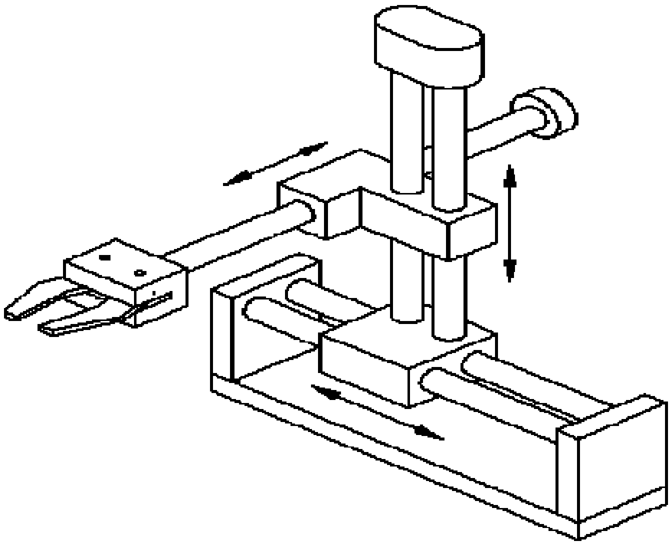
Robot Classification





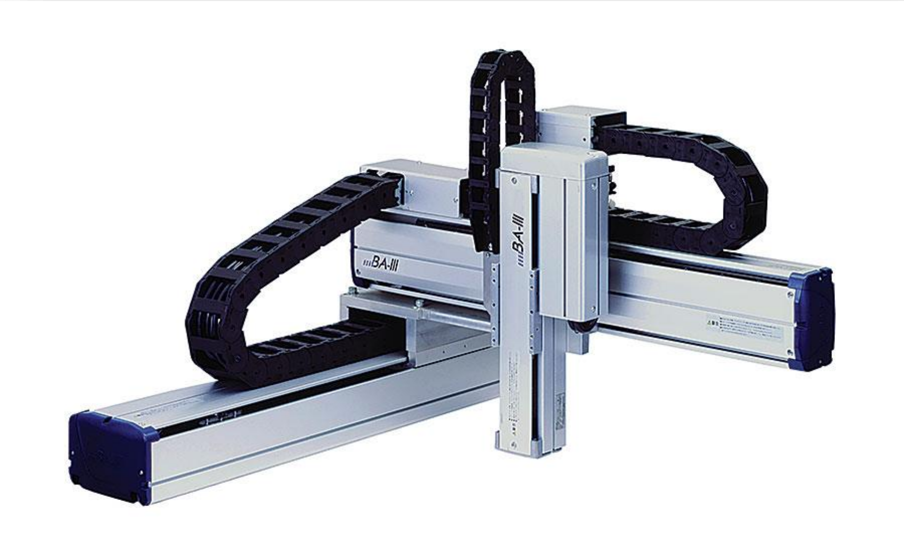
Spherical Robot

Robot Classification



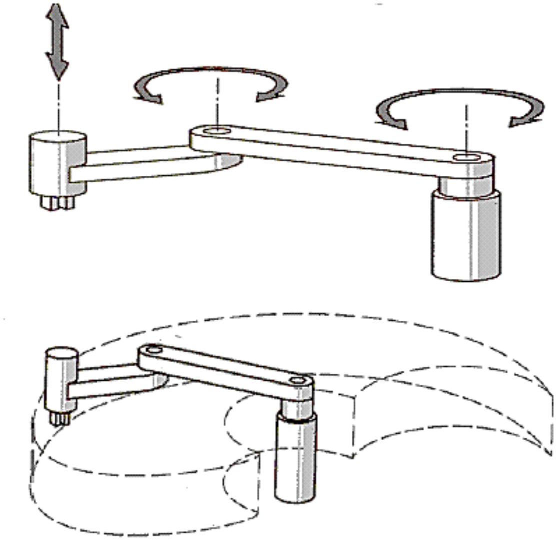
Cartesian Robot

Robot Classification



Cartesian Robot

Robot Classification

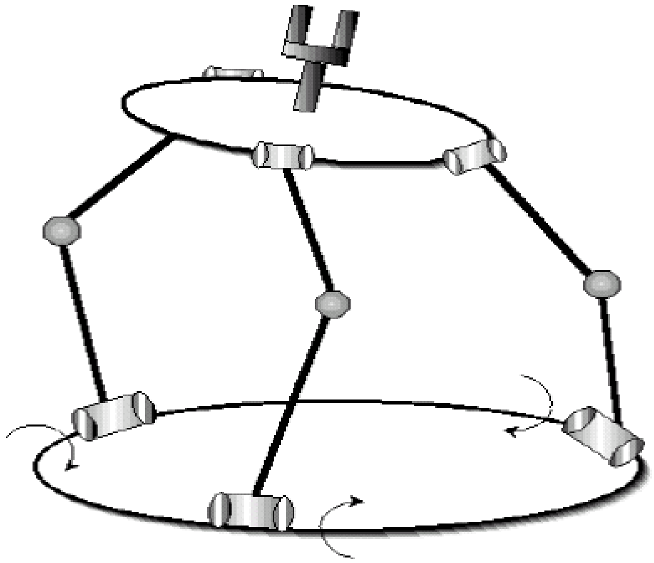


SCARA (Selective Compliance Assembly Robot Arm) Robot

Robot Classification

SCARA Robot

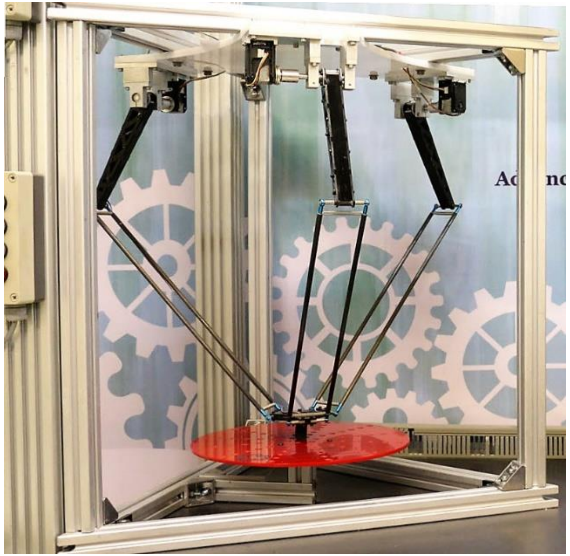
Robot Classification



Parallel Robot

Robot Classification

Stewart-Gough Platform (SGP)



Delta Robot

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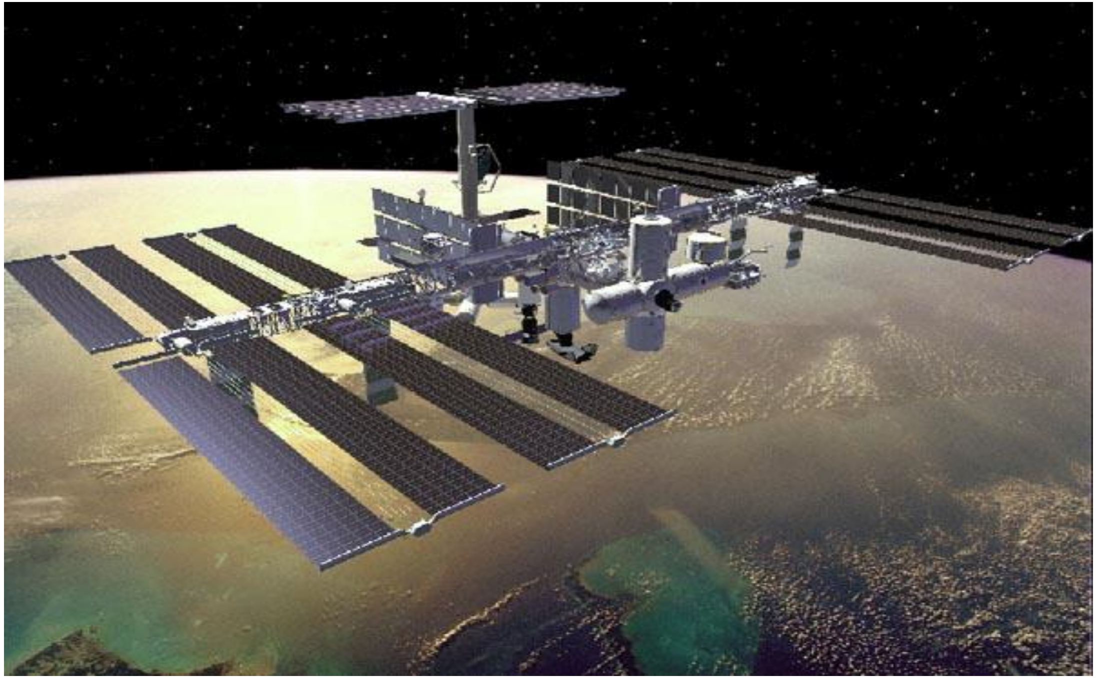
Robotics Applications

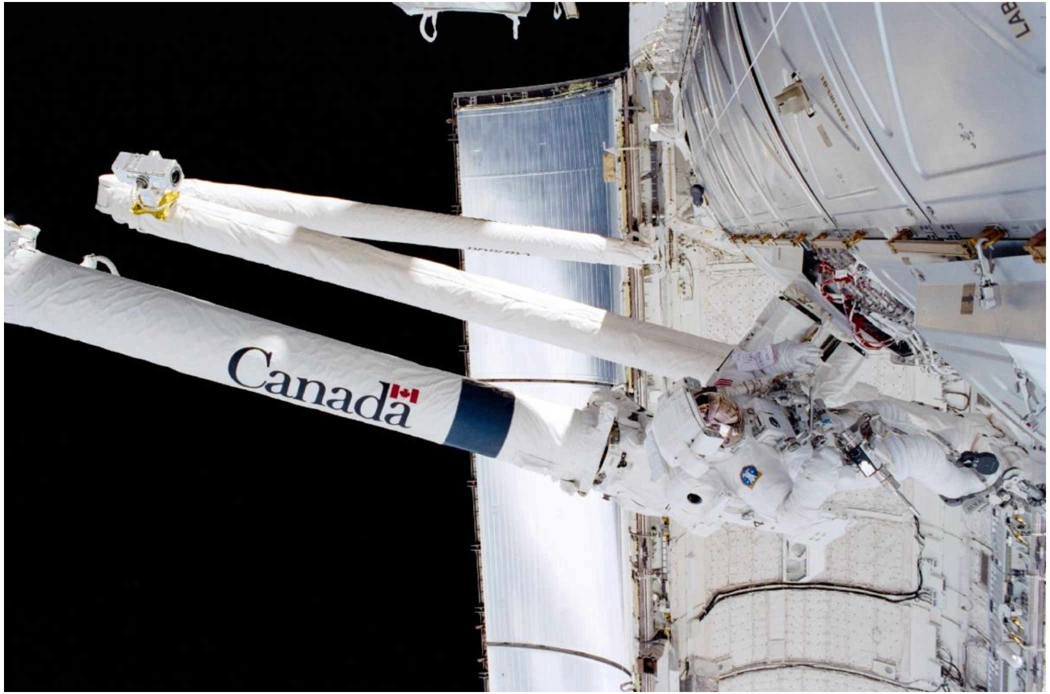


Space Robotics: International Space Station

Robotics Applications

Space Robotics: International Space Station

Robotics Applications



Space Robotics: Space Station Remote Manipulator System (SSRMS)

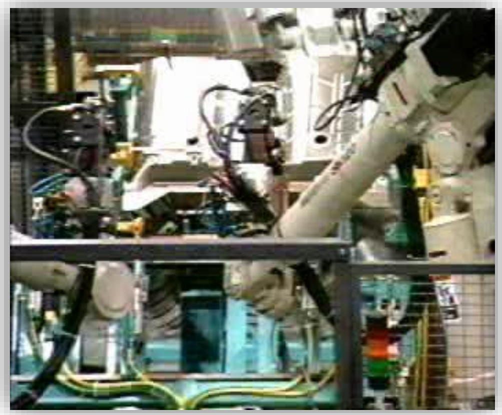
Robotics Applications

Space Robotics: Special Purpose Dexterous Manipulator (SPDM)

Robotics Applications

Industrial Applications: General Purpose Manipulators

Robotics Applications

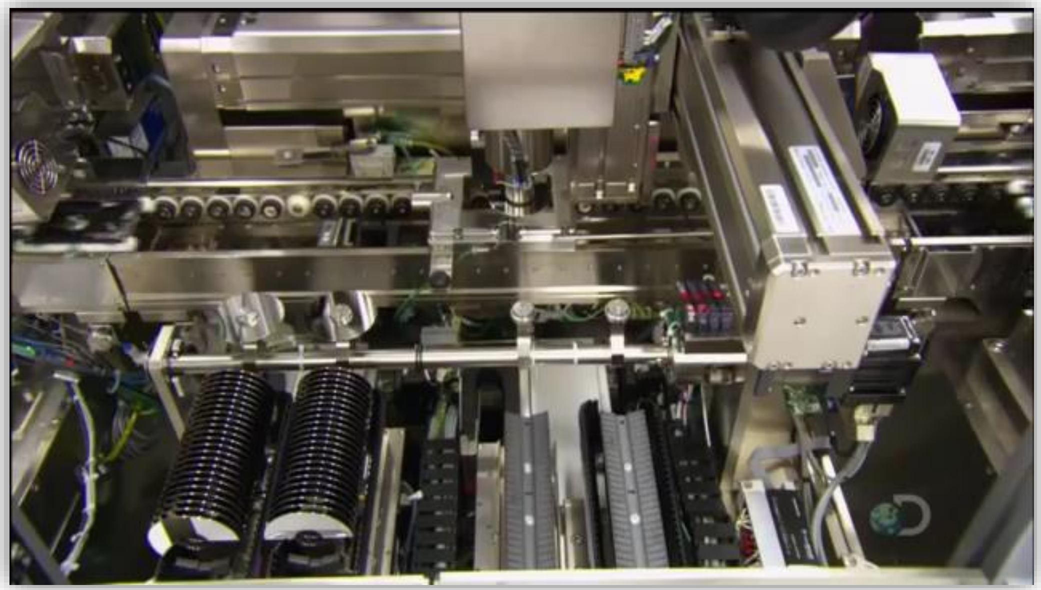


Industrial Applications: Spot , Seam and TIG Welding

Robotics Applications

Industrial Applications: Body Car Painting Robots

Robotics Applications

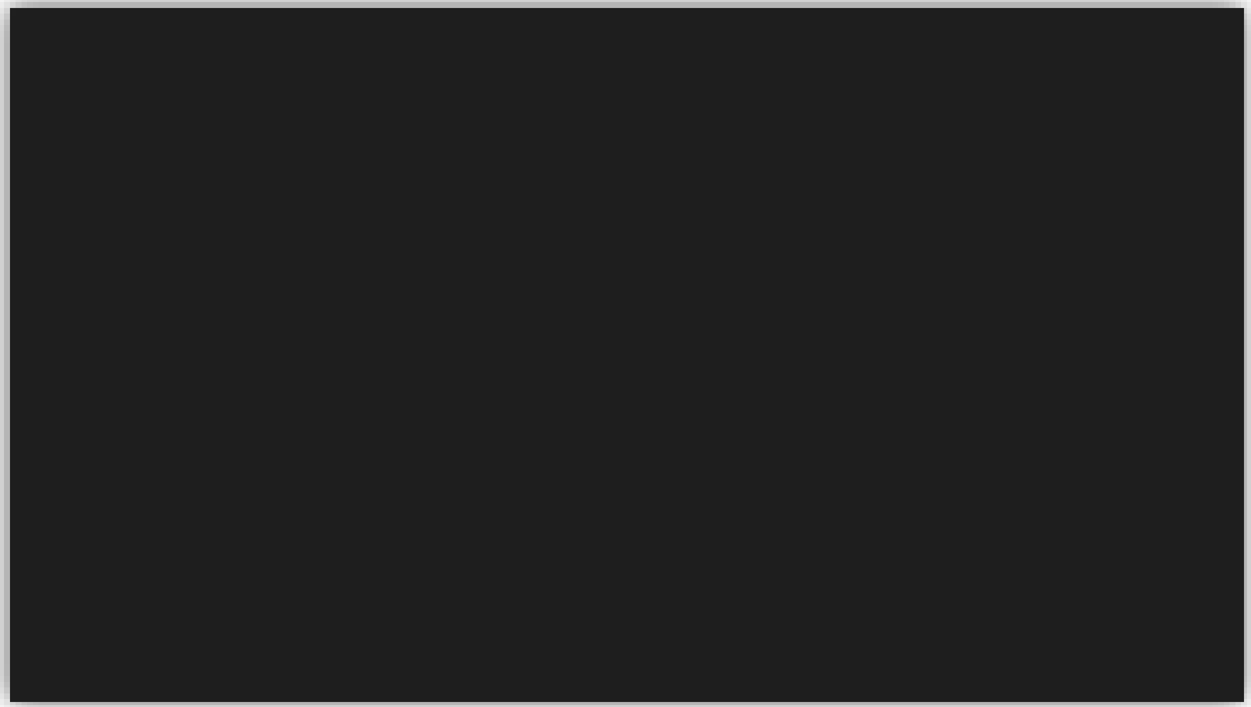


Industrial Applications: Assembly

Robotics Applications

Industrial Applications: Entertainment

Robotics Applications



Surgical Robotics: Da Vinci Surgical Robot

Robotics Applications

Surgical Robotics: KU Lueven Eye Surgery Robotics

Robotics Applications

Autonomous Robotics: Tesla Full Autonomous Car

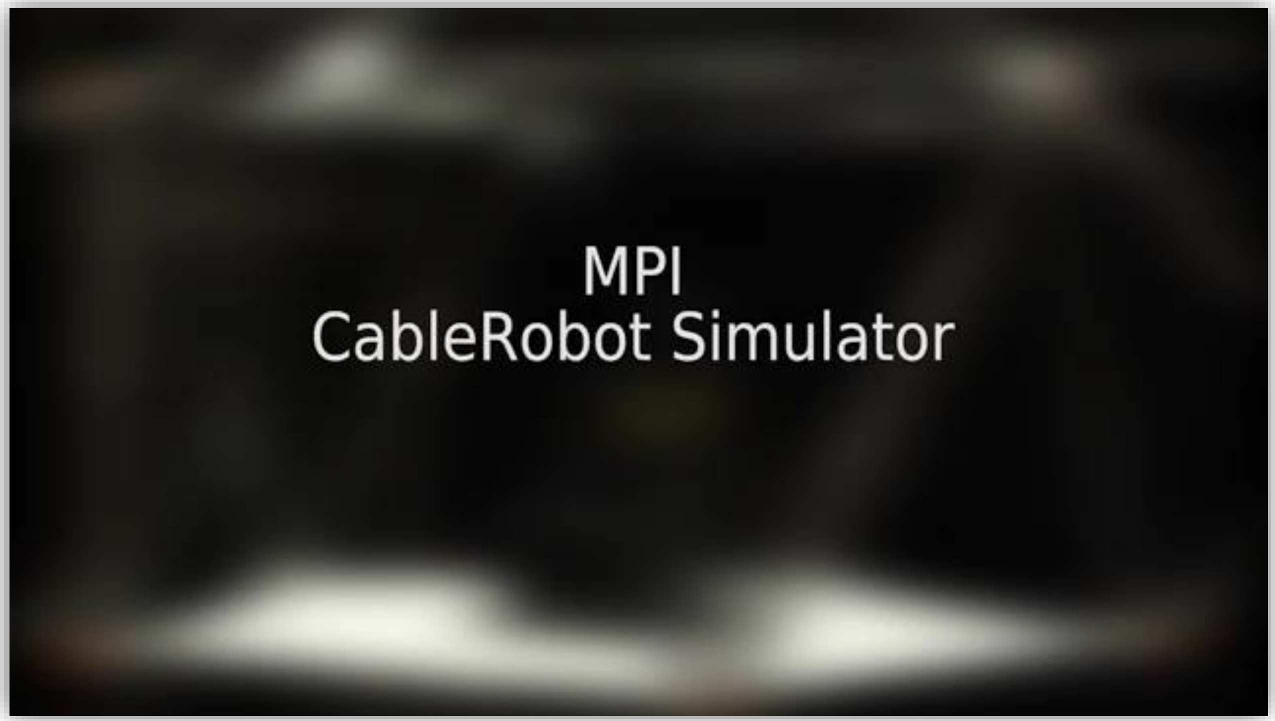
Robotics Applications

Autonomous Robotics: Autonomous Flying Drones (Skydio 2)

Robotics Applications

Parallel Robotics: ABB Flexpicker Delta Robots

Robotics Applications



Cable Robotics: MPI CableRobot Simulator

Robotics Applications

Humanoid Robots: 10 Top and Fun Robots

Robotics Applications

Humanoid Robots: Boston Dynamics Tribute to 2021

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ARAS Developed Robots

Industrial Robots: D&A 101 Casting Robot

ARAS Developed Robots

Industrial Robots: D&A 101 Casting Robot

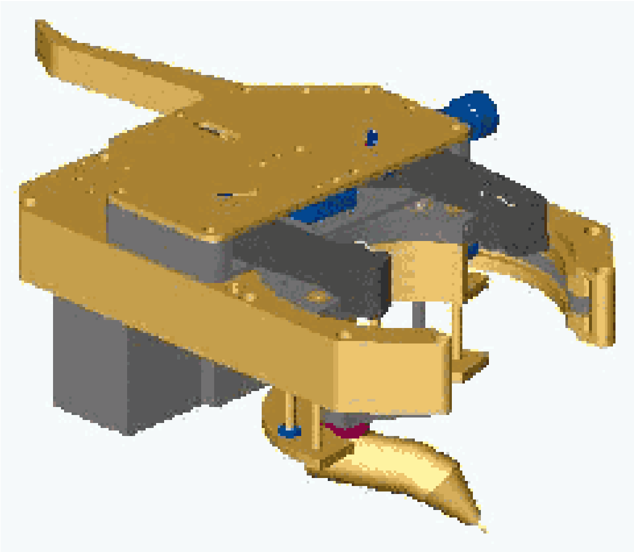
ARAS Developed Robots

Technical Specification	
Robot Type	Articulated
Actuators	DC Motors
Number of axis	4
Payload	5 Kg
Max. Reach	2100 mm
Accuracy	5 mm
Repeatability	±2.5 mm
weight	1000 Kg
Mounting Position	Floor

Industrial Robots: D&A 101 Casting Robot

ARAS Developed Robots

Automatic Pipe welding robot is designed for automated welding of nozzles to headers used in power plant boilers. The radial welding of these pipes with different radii necessitates saddle curves tracking with adjustable dimensions. The mechanical subsystems controlled by individual micro-controllers being supervised by a central controller, provide a fully automated solution to this application, despite the geometrical limitations.



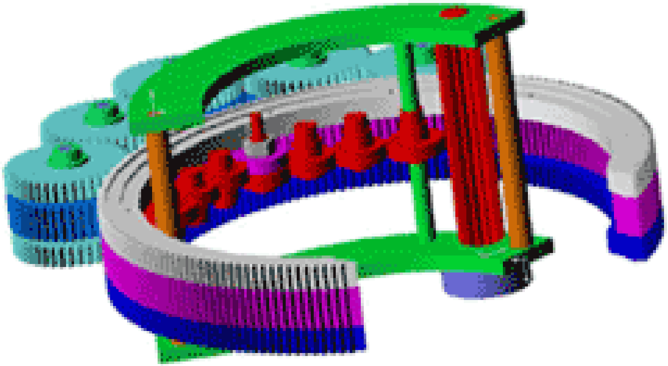
Industrial Robots: D&A 110 Pipe Welding Robot

ARAS Developed Robots

A saddle curve is formed at the intersection of nozzle to the header. The welding torch needs three degrees of freedom to go through this curve:

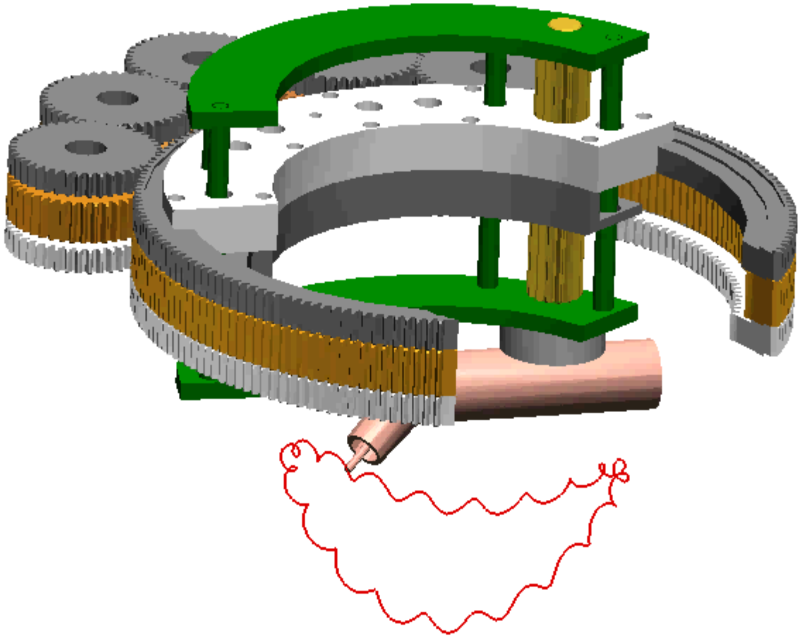
- A revolute movement around the nozzle (φ movement).
- A prismatic movement along the nozzle axis (Z movement).
- In addition, since the nozzles have variable diameters, a third degree of freedom is used to compensate this movement which moves the torch along the nozzle radius (r movement).

These three movements are supported by 3 gear groups. A general view of this mechanism is shown in the figure.



Industrial Robots: D&A 110 Pipe Welding Robot

ARAS Developed Robots



Industrial Robots: D&A 110 Pipe Welding Robot

ARAS Developed Robots

D&A 401 is a robotic cell designed to illustrate the integration of five different automatic components of a production line working together. The integrity of robotic handling system, flexible conveying system, Quality control unit and grading system is controlled with an IPC, and a user friendly software developed for the system. This robotic cell consists of :

- A 4 DOF robot
- A 5 DOF robot
- A quality control arm
- An indexing table
- A flexible conveyer
- A grading station

Industrial Robots: D&A 401 Robotic Cell

ARAS Developed Robots

Technical Specification	
Robot Type	Articulated
Actuators	Stepper Motors
Number of axis	5
Payload	0.7 Kg
Max. Reach	630 mm
Accuracy	0.5 mm
Repeatability	±0.5 mm
weight	50 Kg
Mounting Position	Floor, Ceiling, Wall

Industrial Robots: D&A 401 Robotic Cell -5DoF Robot

ARAS Developed Robots

Technical Specification	
Robot Type	Articulated
Actuators	DC Motors
Number of axis	4
Payload	1.5 Kg
Max. Reach	1750 mm
Accuracy	3 mm
Repeatability	±3 mm
weight	185 Kg
Mounting Position	Floor

Industrial Robots: D&A 401 Robotic Cell – 4DoF Robot

ARAS Developed Robots

Industrial Robots: D&A 401 Robotic Cell

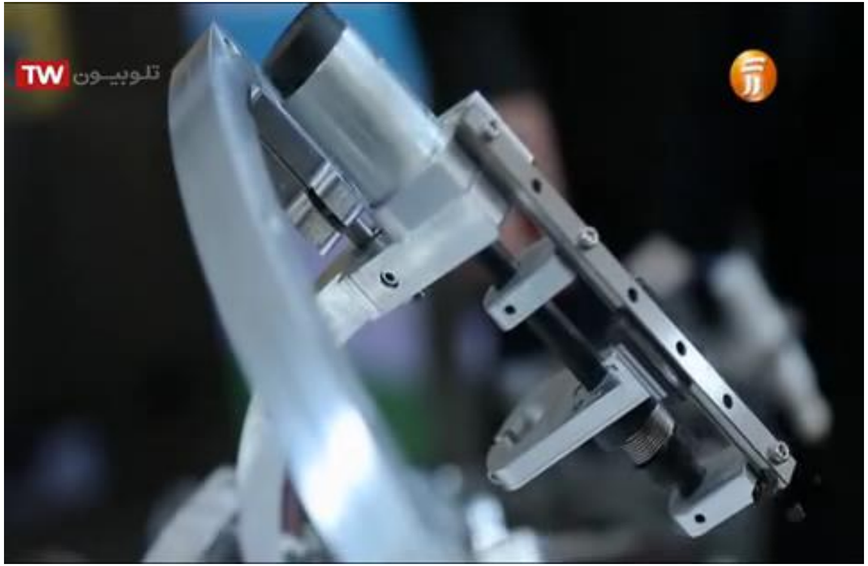
ARAS Developed Robots

Spherical Parallel Robot

ARAS Diamond

Vitreoretinal Eye Surgery Robot

The Diamond robot is designed to perform as the slave robot in a robotic-assisted eye tele-surgery system. A parallel spherical mechanism is proposed to provide the Remote Center of Motion (RCM) by the mechanical solutions. The proposed parallel mechanism has several advantages over the serial ones owing to the higher structural stiffness and improved position accuracy.



Surgical Robots: ARAS Diamond Robot

ARAS Developed Robots

Haptic Device

ARASH-ASiST

Vitreoretinal Eye Surgical Training Robot

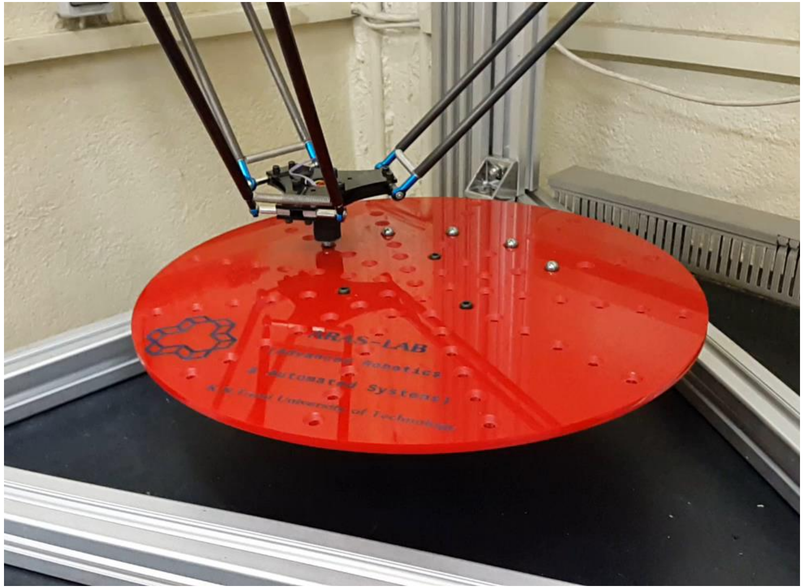
ARASH:ASiST takes advantage of parallelogram structure to produce a remote center of motion mechanism designed especially for minimally invasive vitreoretinal eye surgery. ARASH:ASiST is a dual surgery-haptic device specially designed for vitrectomy eye surgery training.

Surcigal Robots: ARASH-ASiST

ARAS Developed Robots

Surgical Robots: ARASH-ASiST

ARAS Developed Robots



Delta Robot

KNTU Delta Robot

Pick and Place Delta Robot

In this research project, the optimal design and implementation of a Delta robot are investigated. The optimum design of KNTU Delta robot was investigated considering all the design criteria such as kinematic, dynamic, configuration and trajectory planning. The desired configuration for installation of Delta robot is formulated as an optimization problem and has been solved to reach to the highest rate of pick and place operation.

Parallel Robots: Delta Robot

ARAS Developed Robots

ARAS Painter Robot

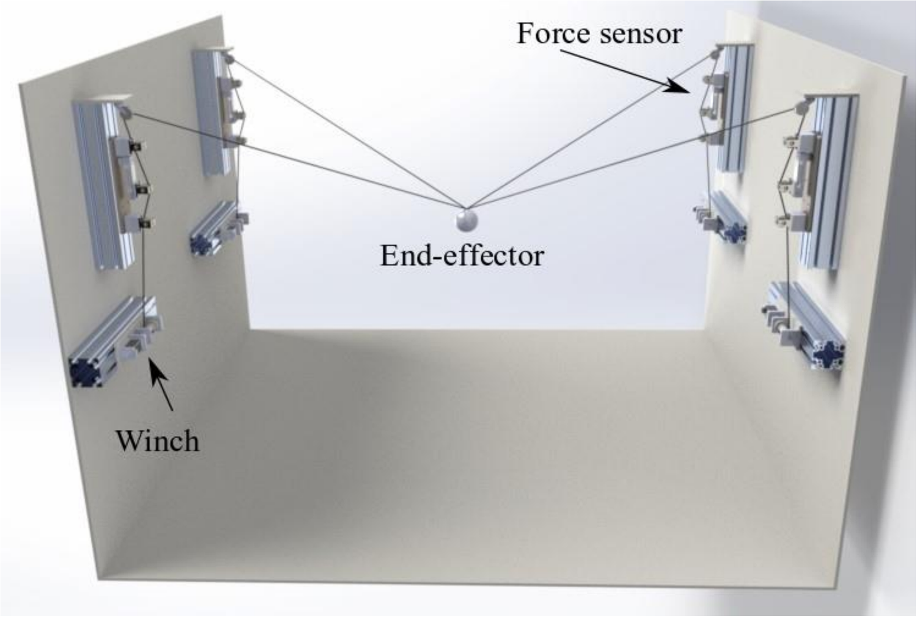
Kamal-ol Molk Robot

Kamal-ol Molk is the first example of a painter CDPR that has been done in the ARAS robotics group. This robot is able to draw portraits and calligraphy with various Persian fonts.

Kamal-ol Molk I is a suspended CDPR, consisting of two actuators for two degrees of freedom on XY plane, and a servo actuator on the moving platform to move the drawing tool.

Cable Robots: Painter Robot - Kamal-ol-molk I

ARAS Developed Robots



Cable Robotics: ARAS CAM

Large Scale CDM

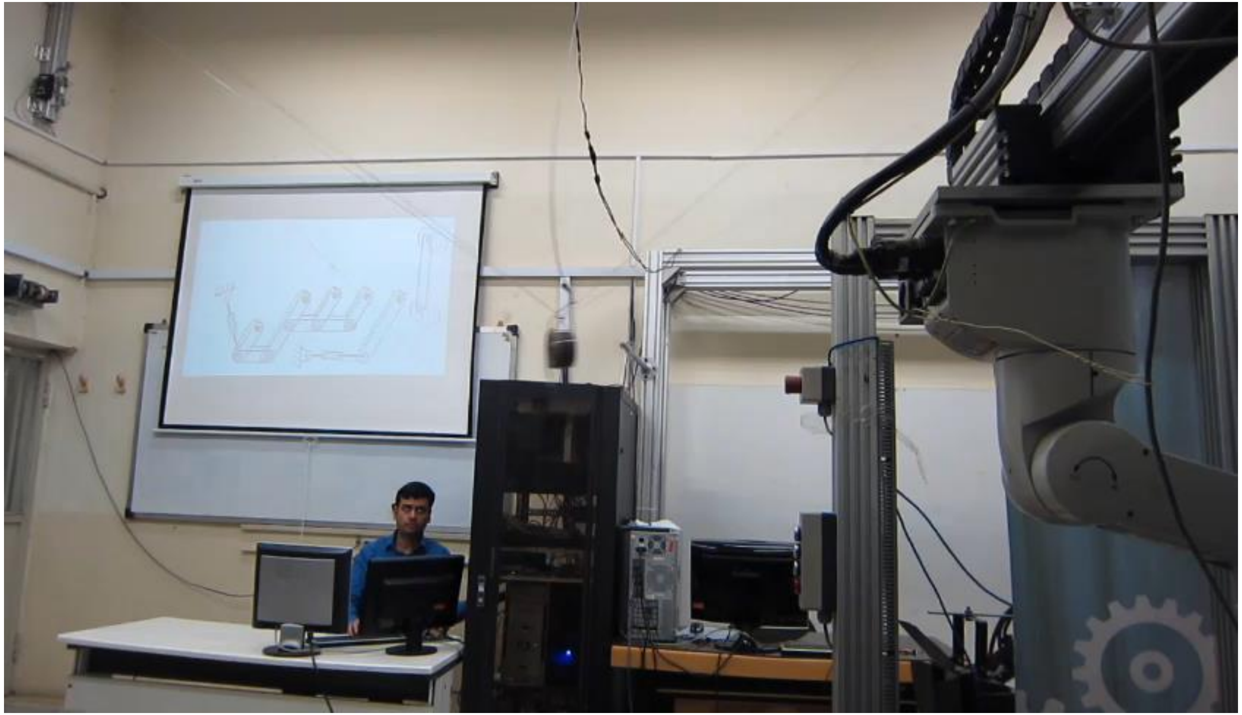
ARAS Spider Cam

The main components of the system are:

- Tower Units
- Smart End-Effector
- Central DAQ System
- Central Computing System
- IR-Tracker System

The DAQ and embedded computing are designed as a distributed signal conditioning and computing systems to facilitate reliability and modularity. The robot is comprised of four tower units. The smart end-effector carries a gimbal camera kit and is equipped with two vision sensors and an IMU for estimating the position, and an Nvidia Jetson SBC through CAN and UDP interfaces.

ARAS Developed Robots



Cable Robots: ARAS CAM

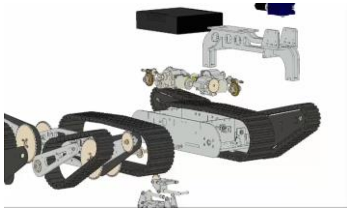
ARAS Developed Robots

2008

Silver: Championship in Rescue Robot World Competition

2017

XerXes: Teleoperated rescue robot and arm functional on semi and full autonomous operation



2012

Achilles: Teleoperated rescue robot with RGBD camera and Map generation

2020

Victor: 4th generation of rescue robot and arm: faster and more robust

UGV Products: ARAS KN2C Team

ARAS Developed Robots

KN2C Products

Silver

Semi Autonmated Rescue robot

Silver is the first generation of fully functional rescue robot which is given the championship of Robocup world competition 2008

- ✔ Silver performance clip in World Champion ship competetions.

UGV Products: ARAS KN2C Team

ARAS Developed Robots

K N 2 C Products

XerXes

Autonmated Rescue robot and Arm

XerXes is the 3rd generation of fully functional rescue robot which is presented in Robocup world competition in Japan 2017.

- Xerxes performance clip in World Championship competetions.

UGV Products: ARAS KN2C Team

ARAS Developed Robots

KN2C Products

Siren II:

Indoor Quadrotor

Reliable flight in indoor environment
Video Transmission to more than 500 meters

Siren II: The 2nd generation of fully designed and implemented quadrotors in KN2C Lab

MAV Products: ARAS KN2C Team

ARAS Developed Robots

KN2C Products

Falcon IV:

Indoor/outdoor Quadrotor

Reliable flight in indoor/outdoor environment, automated take off and landing, face recognition, autonomous flight in indoor environment, GPS controlled outdoor flight.

Falcon IV: The 6th generation of fully implemented quadrotors in KN2C Lab

MAV Products: ARAS KN2C Team

ARAS Developed Robots

KN2C Products

MAV II:

Indoor Quadrotor

Reliable and fully autonomous flight in indoor/outdoor environments, automated take off and landing from moving plane, miniature size (35 cm Diameter).

MAV II: The 8th generation of fully implemented quadrotors in KN2C Lab

MAV Products: ARAS KN2C Team

ARAS Developed Robots

KN2C Products

Nasir I:

Indoor Quadrotor

Reliable flight in indoor/outdoor environment, 3D Map generation, very small size (28 cm diameter), Longer flight duration, return to home configuration.

Nasir I: The 9th generation of fully implemented quadrotors in KN2C Lab

MAV Products: ARAS KN2C Team

ARAS Developed Robots

KN2C Products

X8 MAV:

Octocopter

Robust Flight in outdoor and windy environment, Eight rotors, Failure resilient, Fully autonomous flight.

X8 MAV: The 1st generation of fully implemented Octocopters in KN2C Lab

MAV Products: ARAS KN2C Team

ARAS Developed Robots

KN2C Products

IMAV World Championship

2016 World Championship (Beijing)

KN2C MAV research group is honored to obtain 2016 World Championship in IMAV competeions

- All the products and algorithms were designed and implemented by KN2C MAV group.

MAV Products: ARAS KN2C Team

ARAS Developed Robots

K N 2 C Products

Aquila

Fully Autonomous Outdoor Quadrotor

Aquila is a fully operated Outdoor Quadrotor for different industrial application such as, window washing, high voltage transmission line inspection, …

Aquila performance clip in windows washing, and high voltage transmission line inspection.

MAV Products: ARAS KN2C Team

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Motion Description

Coordinate systems, position and orientation representation, rotation matrix, rotation matrix properties, screw axis, unit quaternion, Euler angles.

2

Kinematics

Denavit-Hartenberg convention, forward Kinematic analysis, Successive screws, Inverse Kinematics of 6R Manipulators.

3

Jacobian

Angular velocity, velocity propagation, Jacobian, singularity and redundancy, static force and torque relation

4

Dynamics

Lagrange method, Dynamics Equation Properties, Lagrange iterative method, joint- and task-space general formulations.

5

Trajectory Generation

Joint and Cartesian space methods, cubic trajectory generation, linear with parabolic blends, optimal trajectory generation

6

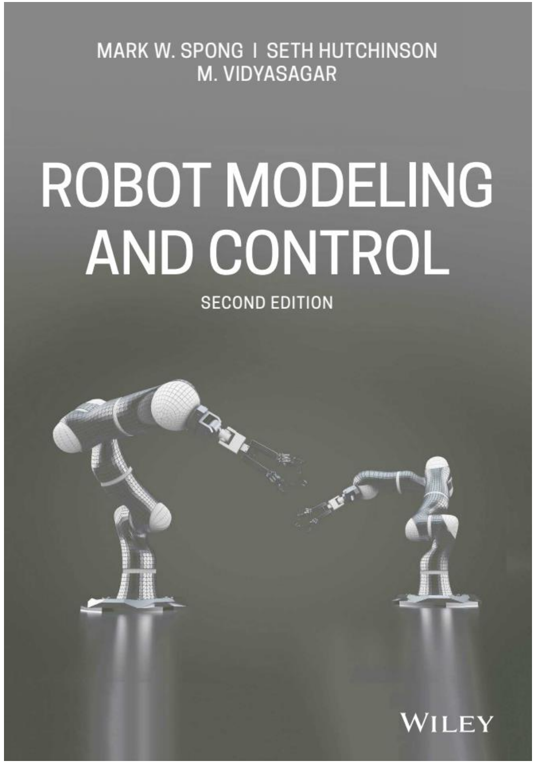
Controller Design

Linear Controllers, linear identification, PD and PID controller design, nonlinear Controllers Feedback linearization methods, Lyapunov based controllers, Robust and adaptive control.

Robotics: Mechanics and Control

- Text and Reference Books:

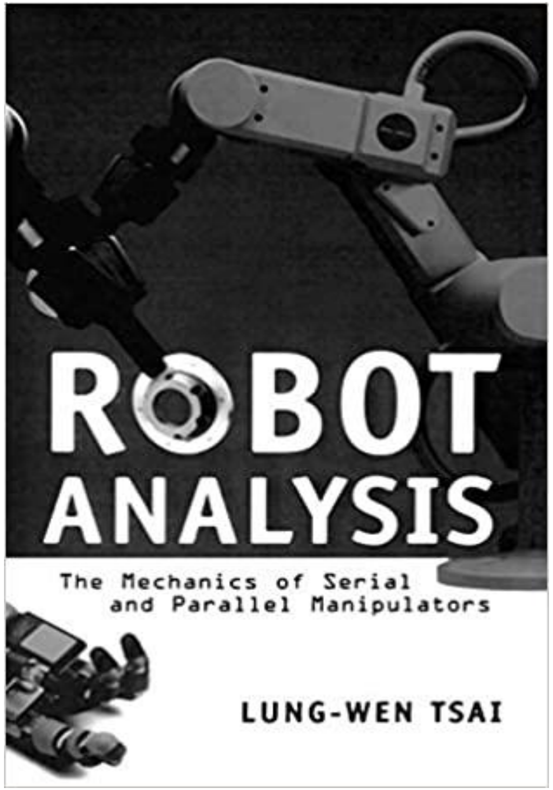
  M. W. Spong, S. Hutchinson, M. Vidyasagar, “Robot Modeling and Control”, 2nd Edition, New York, John Wiley & Sons, 2020.



Robotics: Mechanics and Control

- Text and Reference Books:

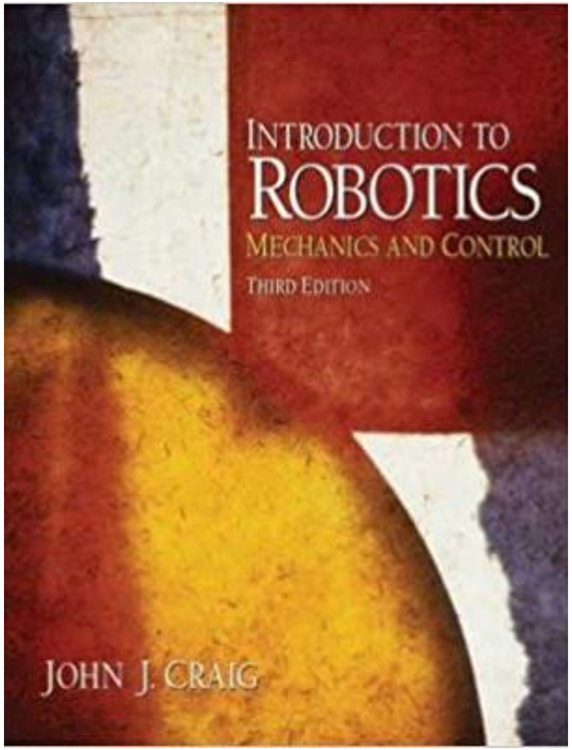
  Lung-Wen Tsai, “Robot analysis: the mechanics of serial and parallel manipulators”, New York, John Wiley & Sons, 1999.



Robotics: Mechanics and Control

- Text and Reference Books:

  John J. Craig, “Introduction to robotics: mechanics and control”, 3rd Edition, Addison Wesley, 2005.

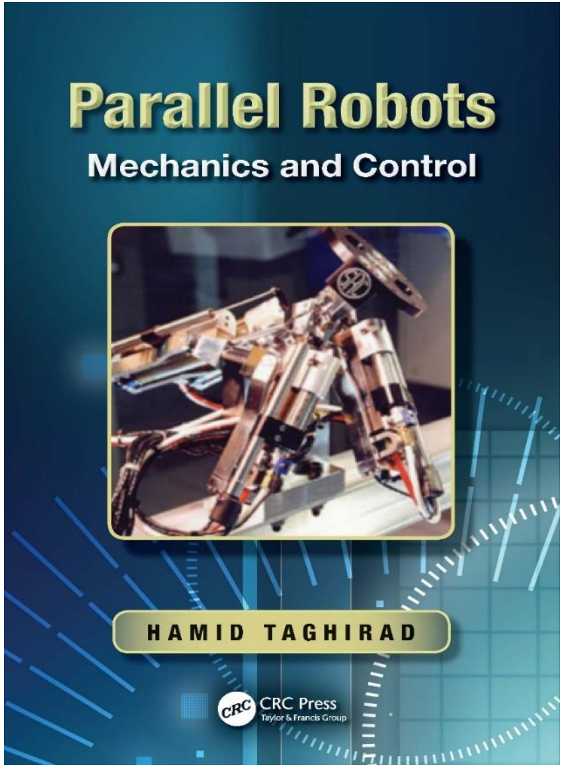


Robotics: Mechanics and Control

- Text and Reference Books:

  Hamid D. Taghirad, “Parallel Robots: Mechanics and Control”, CRC Press, 2013.

  Selected Papers



ADVANCED ROBOTICS & AUTOMATED SYSTEMS

Robotics: Mechanics & Control

Chapter 1: Introduction

To read more and see the course videos
visit our course website:
http://aras.kntu.ac.ir/arascourses/robotics/

Thank You

About Hamid D. Taghirad

Hamid D. Taghirad
Professor

Hamid D. Taghirad has received his B.Sc. degree in mechanical engineering from Sharif University of Technology, Tehran, Iran, in 1989, his M.Sc. in mechanical engineering in 1993, and his Ph.D. in electrical engineering in 1997, both from McGill University, Montreal, Canada. He is currently the University Vice-Chancellor for Global strategies and International Affairs, Professor and the Director of the Advanced Robotics and Automated System (ARAS), Department of Systems and Control, Faculty of Electrical Engineering, K. N. Toosi University of Technology, Tehran, Iran. He is a senior member of IEEE, and Editorial board of International Journal of Robotics: Theory and Application, and International Journal of Advanced Robotic Systems. His research interest is *robust* and *nonlinear control* applied to *robotic systems*. His publications include five books, and more than 250 papers in international Journals and conference proceedings.