Mechatronics System Design

EC4.404 - S2022

Lecture 7

Nagamanikandan Govindan

Robotics Research Center, IIIT Hyderabad.
nagamanikandan.g@iiit.ac.in

Course Instructors:

Dr. Nagamanikandan Govindan,

Assistant Professor, Robotics Research Centre

nagamanikandan.g@iiit.ac.in (Pls. keep EC4.404 in the subject)

Research interests

Robotics, Dynamics and Control,

Mechanism Design and Synthesis, Grasping, Manipulation and Locomotion

Dr. Harikumar Kandath,

Assistant Professor, Robotics Research Centre

harikumar.k@iiit.ac.in

INTERNATIONAL INSTITUTE OF INFORMATION TECHNOLOGY
HYDERABAD

Robotics Research Center

A Novel Hybrid Gripper Capable Of Grasping And Throwing Manipulation

Nagamanikandan Govindan, Bharadhwaj Ramachandran, Pasala Haasith Venkata Sai, K Madhava Krishna

Robotics Research Center

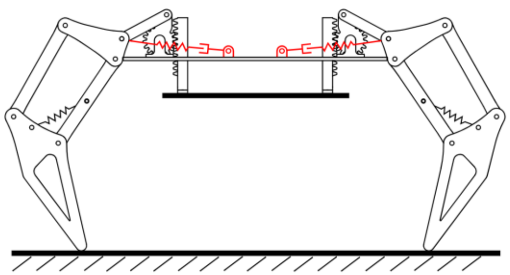
International Institute of Information Technology Hyderabad, India

Multimedia extension prepared for

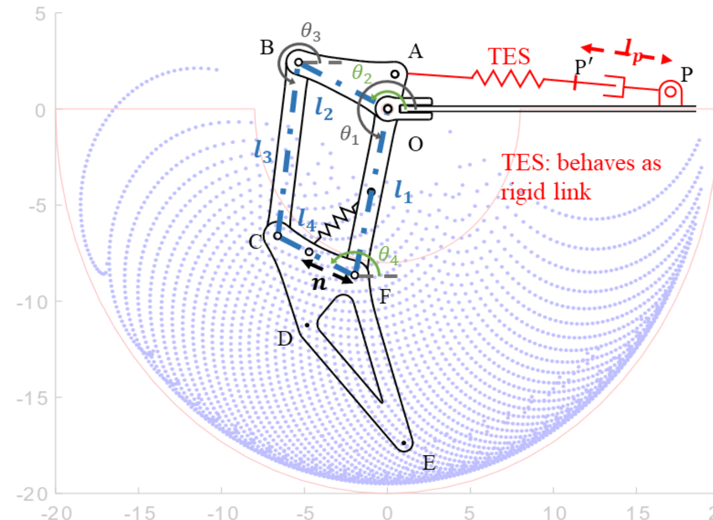
IEEE Transactions on Mechatronics

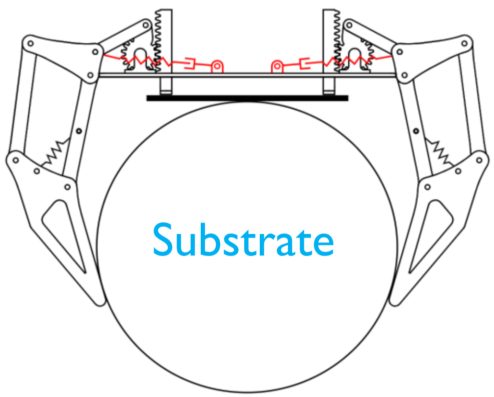
(Currently under review at the IEEE/ASME Trans. on Mechatronics)

Multifunctional Mechanism

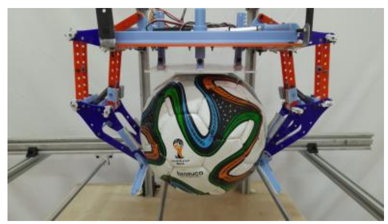


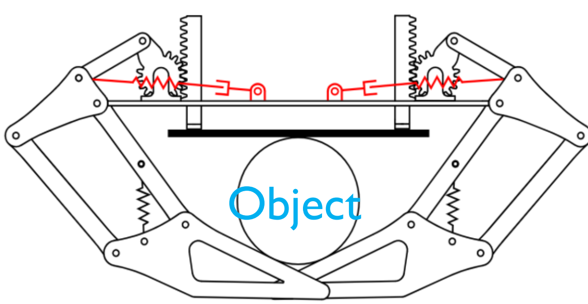
Adaptive landing gears



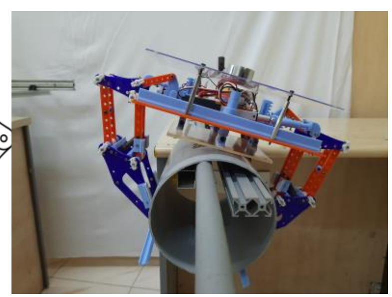


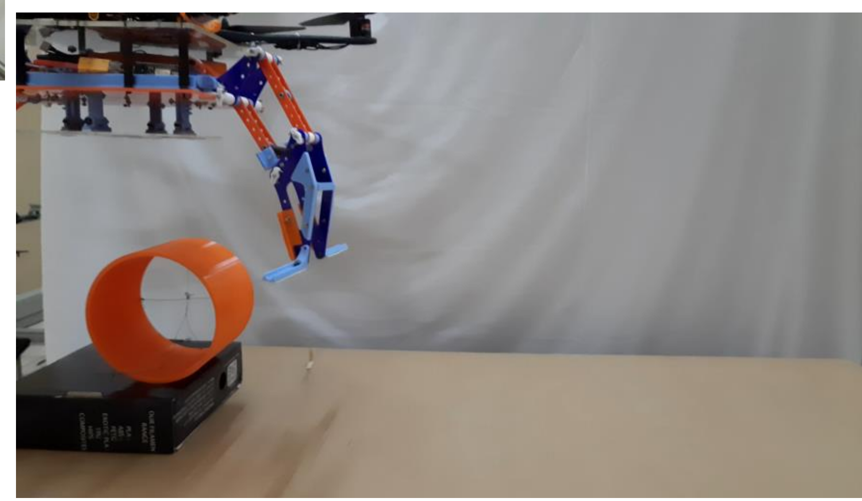
Perching





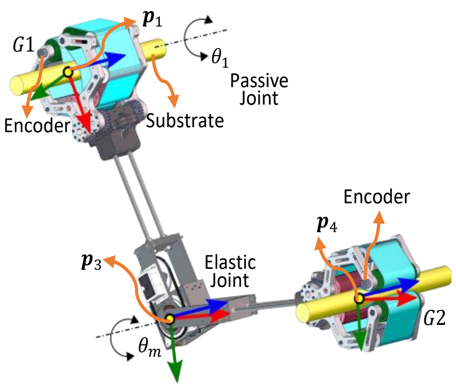
Grasping





*Unpublished

Gripper Design – Underactuated robot



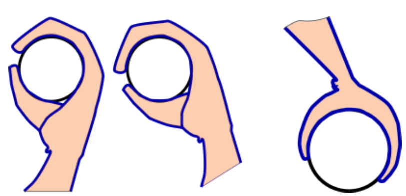
A new gripper that acts as an active and passive joint to facilitate prehensile grasping and locomotion

Nagamanikandan Govindan, Shashank Ramesh, and Asokan Thondiyath

IIIT Hyderabad

Robotics Research Center,
International Institute of Information Technology,
Hyderabad, India

Robotics Lab,
Department of Engineering Design,
Indian Institute of Technology Madras, India

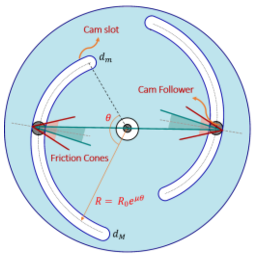


Prehensile hand and foot

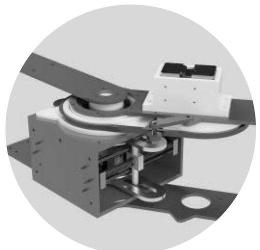
IROS 2022

Variable Stiffness Actuator

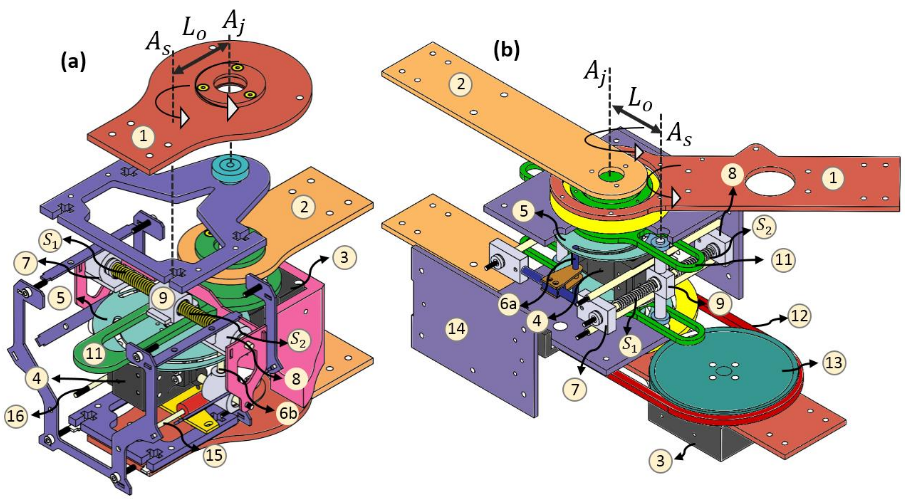
Synthesis and Analysis



CAD Modeling



Prototyping and Testing



IEEE Access 2020

Multimodal Grippers

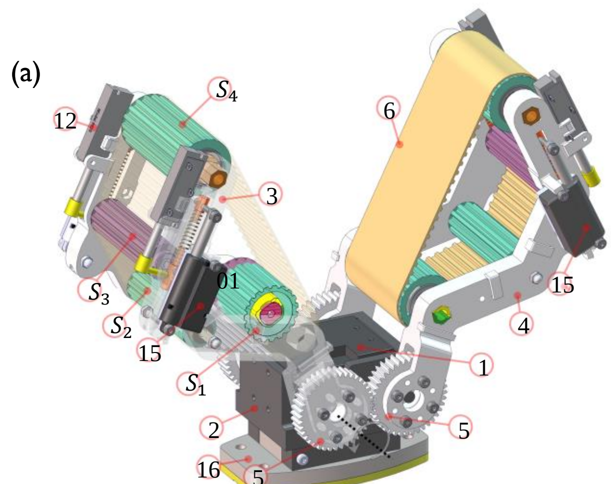
Design and Analysis of a Multimodal Grasper Having Shape Conformity and Within-Hand Manipulation With Adjustable Contact Forces

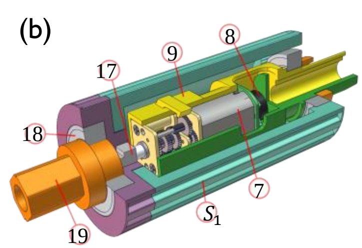
Nagamanikandan Govindan, Asokan Thondiyath

Robotics Lab
Department of Engineering Design
Indian Institute of Technology Madras, India

Multimedia Extension prepared for
ASME JOURNAL OF MECHANISMS AND ROBOTICS

Featured in **'Nature,'** titled '**A robot grasper that can climb pipes**'
https://www.nature.com/articles/nindia.2019.113





a) CAD model of the proposed gripper b) Inner section of the active sheave S_1.

1 Dynamixel motor, 2 Base support, 3 Jaw 1, 4 Jaw 2, 5 Gear, 6 Synchronous belt, 7 Micro motor, 8 Quadrature encoder, 9 Motor casing, 10 Spring, 11 Linear slot, 12 Linear potentiometer, 13 Supporting part, 14 Supporting part, 15 Micro linear servo, 16 Flange, S_1 Driver sheave, S_2, S_4 Driven sheave, S_3 Driven sheave

JMR 2019

Course Syllabus

Unit 1: Sensors and Actuators:

Sensors for robotics application - position, speed, acceleration, orientation, range.

Actuators - general characteristics, motors, control valves.

Unit 2: Computer based feedback control:

Sampled data control, sampling and hold, PID control implementation, stability, bilinear transformation.

Unit 3: Introduction to mechanical elements and transformations, basic concepts of kinematics and dynamics.

Unit 4: Design and analysis of mechanisms.

Unit 5: Programming and hardware experiments.

Course Outcomes

- CO-1 Describe important elements of mechatronics system
- CO-2 Apply the previous knowledge of microcontroller programming for controlling multidisciplinary mechatronic systems.
- CO-3 Describe and design basic mechanical elements and their feedback control.
- CO-4 Synthesize and analyze a range of mechanisms.
- CO-5 Design and execute a multidisciplinary project based on the given specifications as part of a team.

Assessment methods and weightages

~~Mid semester exam 20%~~ ~~Quiz1 10% Quiz2 10%~~

Midsemester exam 20%

Assignments 40% - Individual

– Preferred tools

MATLAB, Fusion360, ROS

– CAD Designing, 3D printing, laser cutting,

Project 40%

- Mini project 1 (5 or 6 per team) – totally 6 teams
  - Problem statement will be given
- Project 2 (not more than 5 per team)
  - Choose one out of two given problems or propose one.

Projects

- Mini project 1 (5 or 6 per team) – totally 6 teams – (15 marks)
  - Design and fabrication of an Animatronic eye
    - Analysis (3)
    - Project demonstration (3)
    - Presentation (4)
    - Report (2)
    - Any improvements (3)

(Each team will get 3 micro servos, 1 Arduino, Acrylic sheets and 3D printing materials)

- Project 2 (not more than 5 per team) – (25 marks)
  - Choose one out of two given problems or propose one.
    - Kinematic Modelling and Analysis (5)
    - Mechatronics system design (3)
    - Project demonstration (5)
    - Improvements (2)
    - Presentation (2+3)
    - Viva + Final report (2+3)

(Each team will get 2 Dynamixel motors, filaments, Acrylic sheets – Facilities available at Makers Lab)

Tutorial Sessions

Session 1: Introduction to Fusion 360 (on 1st Feb or 8th)

- Install Fusion 360 before the class (refer to Moodle)
- Intro to important tools, sketch, part design - design a simple mechanism

Session 2: Introduction to ROS (on 2th or 11th Feb)

- Install ROS before the class (refer to Moodle)
- Basics of ROS
- How to use Dynamixel motor and control it.

Session 3: ~~Importing CAD models into Gazebo, motor integration~~ Tutorial on Dynamixel motor

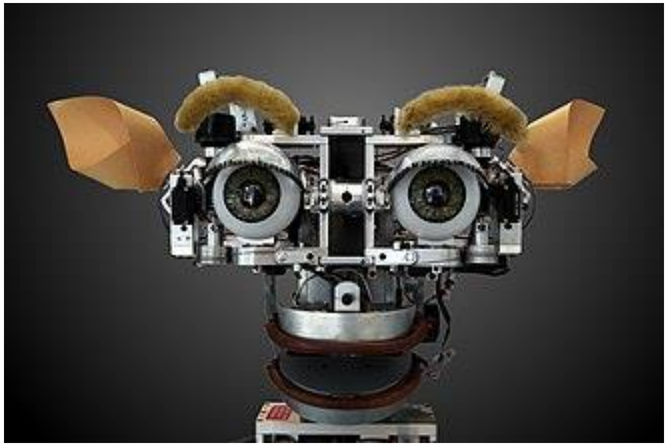
- ~~Simulating a mechanism in a Gazebo~~

Project 1 – Mini project

- Analysis, development and hardware implementation of an animatronic eye mechanism.

- Tentative duration for completing the project – XX days

More details will be given later



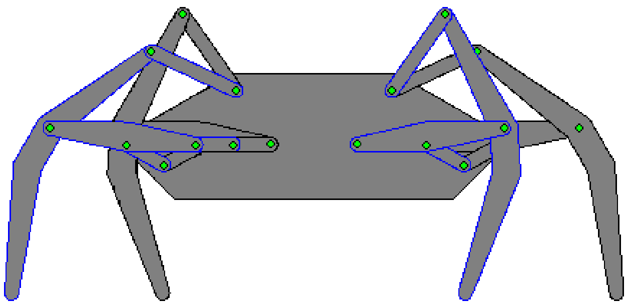
Kismet now resides at the MIT Museum in Cambridge, Massachusetts, United States.

a machine that can recognize and simulate emotions.

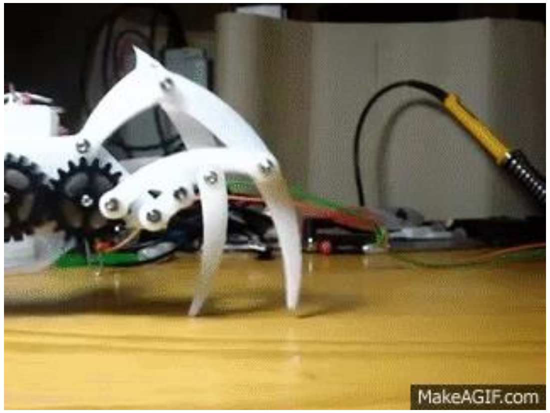
https://en.wikipedia.org/wiki/Kismet_(robot)

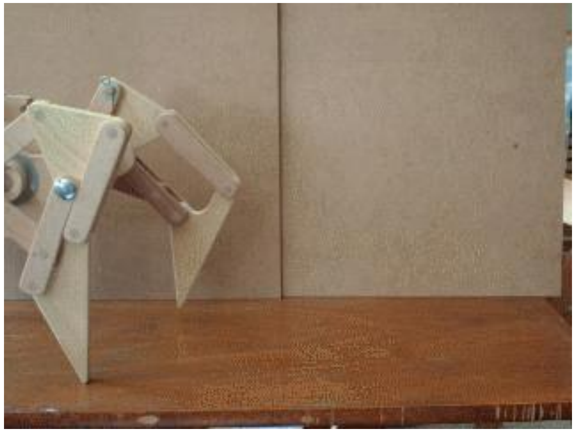
Project 2

- Design, Analysis, Development and hardware implementation of a walking mechanism.
  - ~~2R – Ball tracking robot~~
  - Walking robots using Klann Mechanism, Jansen Mechanism



https://en.m.wikipedia.org/





https://www.armure.ch/

https://www.strandbeest.com/

Fabrication

Facilities:

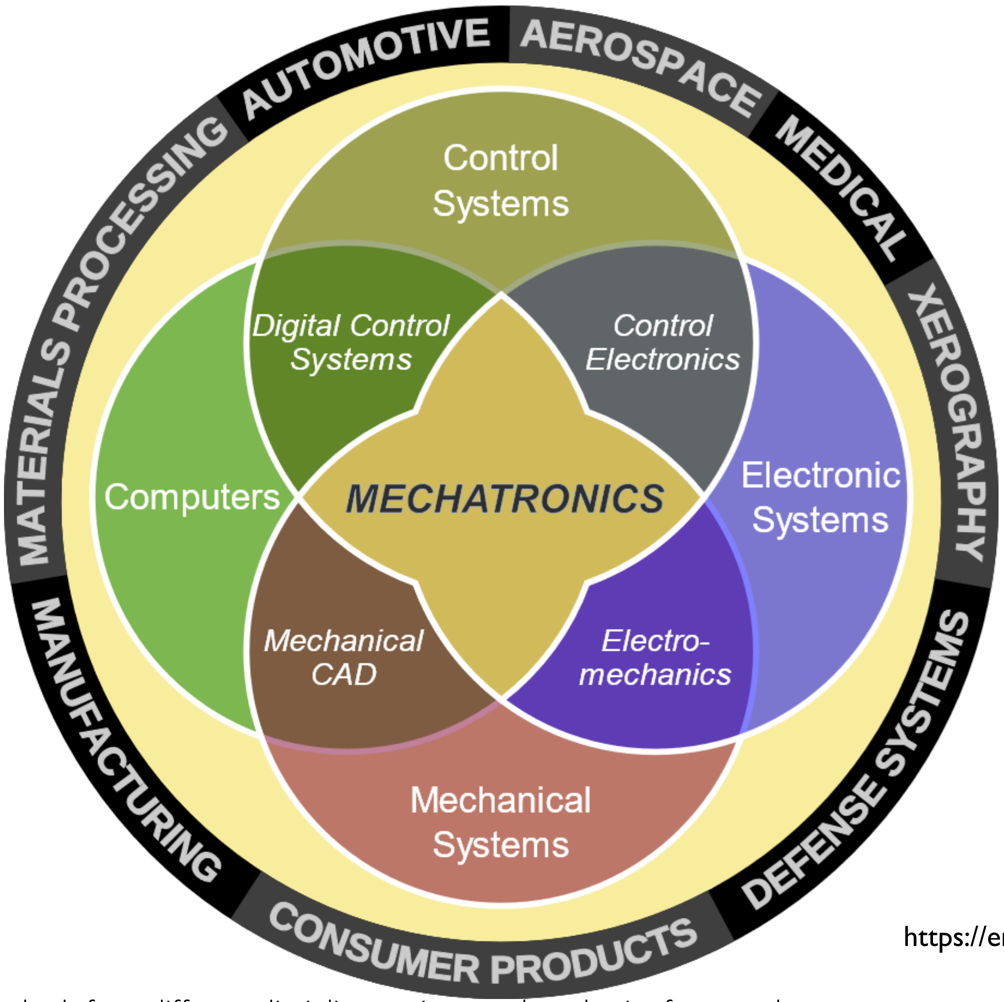
1. Basic components – motors, filament, acrylic sheet, and all electronic components will be given.
2. Use Makers Lab for 3D printing and Laser Cutting.

Procedure for using Makers Lab.

1. Before submitting the files for 3D printing and Laser cutting, take consent from TA or Me (in case TA is not available)
2. Submit the proper manufacturing files to Makers Lab. TA will assign the time slot based on availability of machine.
3. Please book the slot well in advance (at least 7 days before) and avoid last minute requests.

Introduction

- **Mechatronics** is an *interdisciplinary branch of engineering that focuses on the integration of mechanical, electrical and electronic engineering systems, and also includes a combination of robotics, electronics, computer science, telecommunications, systems, control, and product engineering.

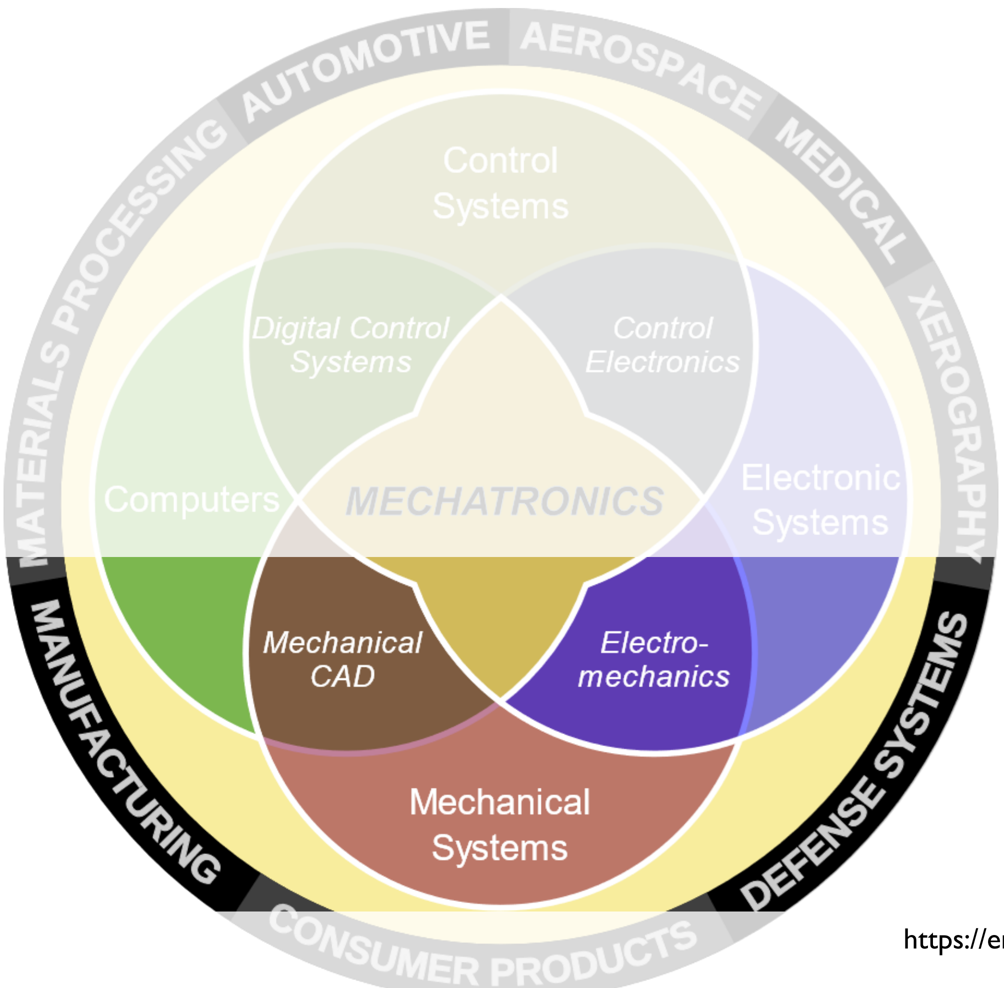


https://en.wikipedia.org/wiki/File:Mecha.gif

*Integrating knowledge and methods from different disciplines, using a real synthesis of approaches.

Introduction

- Our main focus is on



https://en.wikipedia.org/wiki/File:Mecha.gif

A DESIGN PROCESS

Engineering design typically involves the creation of a device, system, or process using engineering principles.

- Well-defined problems
- Ill-defined problems

- **Analysis Vs Synthesis**

Some Terminologies

- Mechanical design
  - To design parts, components, products, or systems of mechanical nature.
  - E.g.: designs of various machine elements such as shafts, bearings, clutches, gears, and fasteners fall into the scope of mechanical design.

- Mechanical design problem should be formulated with clear and complete statements of
  - functions,
  - specifications, and
  - evaluation criteria

Some Terminologies

- **Functions**
  - what a product can fulfil.
  - usually described by nonquantitative statements - clean floors, transport objects, sorting objects, circulating air in rooms, to either make or break the electric circuit, supply heat, project an image, etc.
- **Specifications**
  - detailed requirements described by quantitative statements.
  - E.g.: size, weight, precision, working volume, speed, or load capacity.
  - Specifications turn into design constraints in problem-solving processes.
- **Evaluation criteria**
  - are treated as design objectives to optimize the solutions in problem-solving processes
  - E.g.: loading capability, deformation, stability, and durability.

Identification of Need : What we need is a better lawn mower? Wind-shield wiper?

Background Research : Gathering background information on all the relevant aspects of the problem

- Technical literature and patent literature

Goal Statement : Concise, be general, and be uncolored by any terms that predict a solution.

recast that problem into a more coherent goal statement – "**Design a Means to Shorten Grass.**" - functional visualization

A DESIGN PROCESS

Performance Specifications : What the system must do? – Different from Design specification: How the system must do it?

- Device to have self-contained power supply.
- Device to be corrosion resistant.
- Device to cost less than $100.00
- Device to emit < 80 dB sound intensity at 10 m.
- Device to shorten 1/4 acre of grass per hour.

Ideation and Invention: Unleash your Creativity – Multiple designs can be proposed: *Prob statement: Move this object from point A to point B.*

Analysis : sophisticated analysis techniques to examine the performance of the design in the analysis phase of the design process.

Selection : When the technical analysis indicates that you have some potentially viable designs, the best one available must be selected for detailed design, prototyping, and testing.

	Cost	*Safety*	*Performance*	*Reliability*	*RANK*
Weighting Factor	.35	.30	.15	.20	1.0
Design 1	3 / 1.05	6 / 1.80	4 / .60	9 / 1.80	5.3
Design 2	4 / 1.40	2 / .60	7 / 1.05	2 / .40	3.5
Design 3	1 / .35	9 / 2.70	4 / .60	5 / 1.00	4.7
Design 4	9 / 3.15	1 / .30	6 / .90	7 / 1.40	5.8
Design 5	7 / 2.45	4 / 1.20	2 / .30	6 / 1.20	5.2

Detailed Design : This step usually includes the creation of a complete set of assembly and detail drawings or computer-aided design (CAD) part files for each and every part used in the design.

- **Prototyping and Testing:** Develop PoC and scale it up/down.

  Many a time simple experiments will save a lot

Weight distribution matters!

A DESIGN PROCESS

- **Production:** This might consist of the manufacture of a single final version of the design, but more likely will mean making thousands or even millions of your widget.

Mechanisms

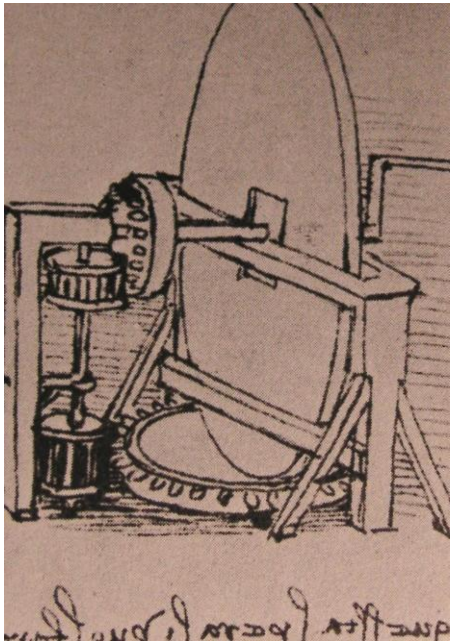
Virtually any machine or device that moves and contains one or more kinematic elements such as links, cams, gears, belts, and chains.

Name few mechanisms.

A Short History

Archimedes (287–212 BCE) studied the lever using geometry. Until the 1500s CE, Archimedes and Hero of Alexandria (circa 10 – 70 CE) were still the sources of mechanism theory.

Leonardo da Vinci (1452 – 1519) rejuvenated interest and practical design methods in machines and mechanisms during the European Renaissance.

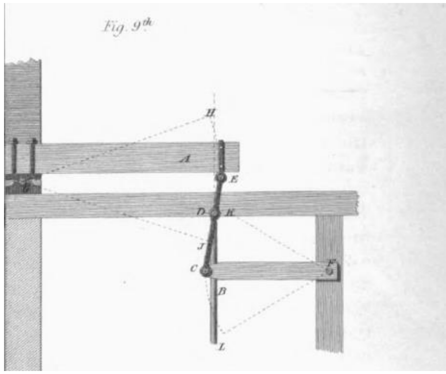


A machine for grinding convex lenses

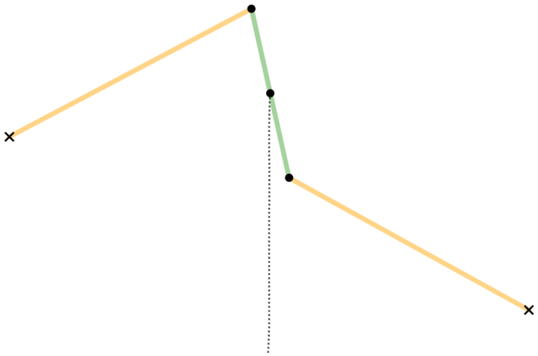
*MORE INFO: https://www.ohio.edu/mechanical-faculty/williams/html/PDF/HistoryOfMechanisms.pdf

A Short History

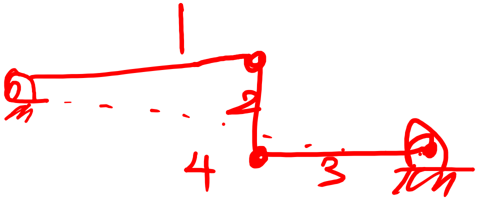
In 1782 **James Watt** (1736 – 1819) invented the six-bar Watt's linkage to convert rotational shaft motion into translating motion. He was a Scottish inventor, perhaps the first mechanical engineer (before that noble field was formally recognized).



James Watt's patent application (top left part) showing the straightline linkage



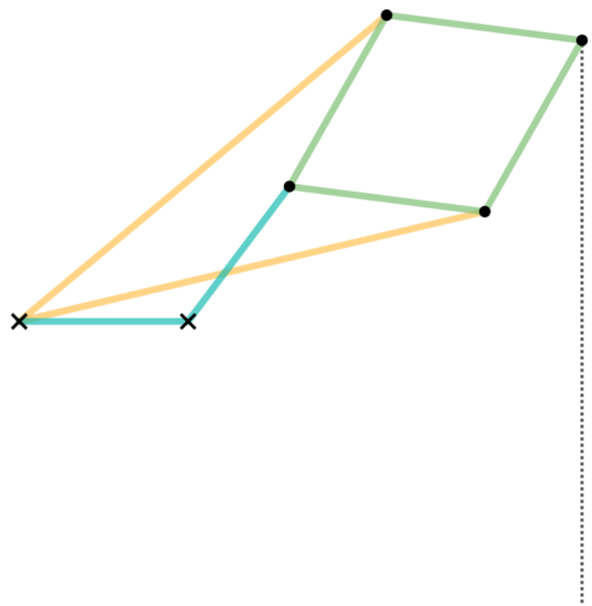
https://en.wikipedia.org/wiki/Watt%27s_linkage



*MORE INFO: https://www.ohio.edu/mechanical-faculty/williams/html/PDF/HistoryOfMechanisms.pdf

A Short History

The Peaucellier–Lipkin linkage, invented in 1864, was the first true planar straight line mechanism – the first planar linkage capable of transforming rotary motion into perfect straight-line motion, and vice versa.



https://en.wikipedia.org/wiki/Peaucellier%E2%80%93Lipkin_linkage

English mathematician James J. Sylvester (1814 – 1897) expounded on the Peaucellier Linkage (invented in 1864), to generate an exact straight line from a rotating input.

*MORE INFO: https://www.ohio.edu/mechanical-faculty/williams/html/PDF/HistoryOfMechanisms.pdf

A Short History

- Franz Grashof (1826 – 1893), a German professor, developed his famous law to determine the rotatability of the input / output links of the four-bar linkage.

- Alfred B. Kempe (1849 – 1922), mathematician who extended linkages to trace a given algebraic curve

- In the late 1800s German Franz Reuleaux (1829 – 1905), Englishman Alexander B. W. Kennedy (1847 – 1928), and German Ludwig E. H. Burmester (1840 – 1927) rigorized the analysis and synthesis of linkage using descriptive geometry.

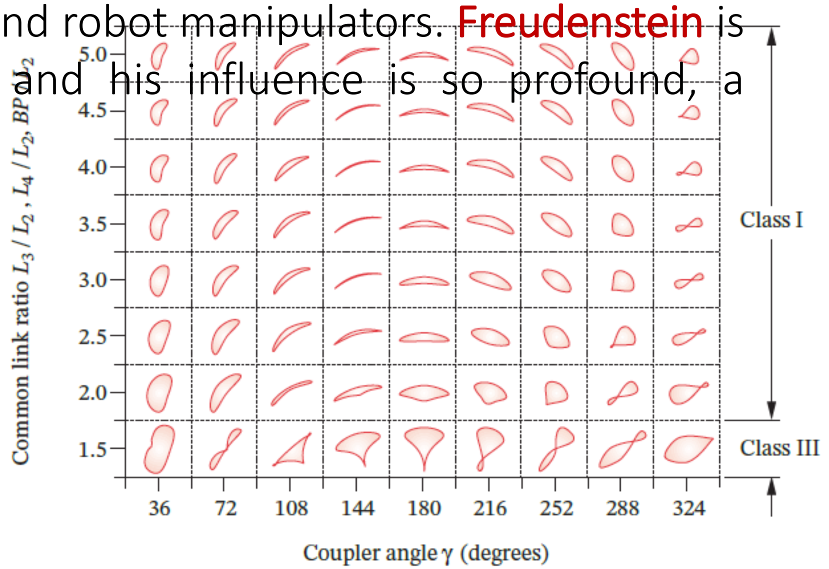
A Short History

Russian mathematician L. Chebyshev (1821 – 1894) developed analytical methods for the analysis and synthesis of linkages. Chebyshev Polynomials are used to provide optimal spacing of precision points for function generation and path generation.

In the mid-1900s American engineering professors Ferdinand Freudenstein (1926 – 2006) and one of his 500 Ph.D. students, George N. Sandor (1929 – 1996), initiated the computer-aided design of mechanisms at Columbia University.

By the mid-1970s these computer methods became important in the analysis, synthesis, and control of complicated machines and robot manipulators. Freudenstein is known as the "Father of Modern Kinematics" and his influence is so profound, a "Freudenstein Doctoral Descendent Tree"

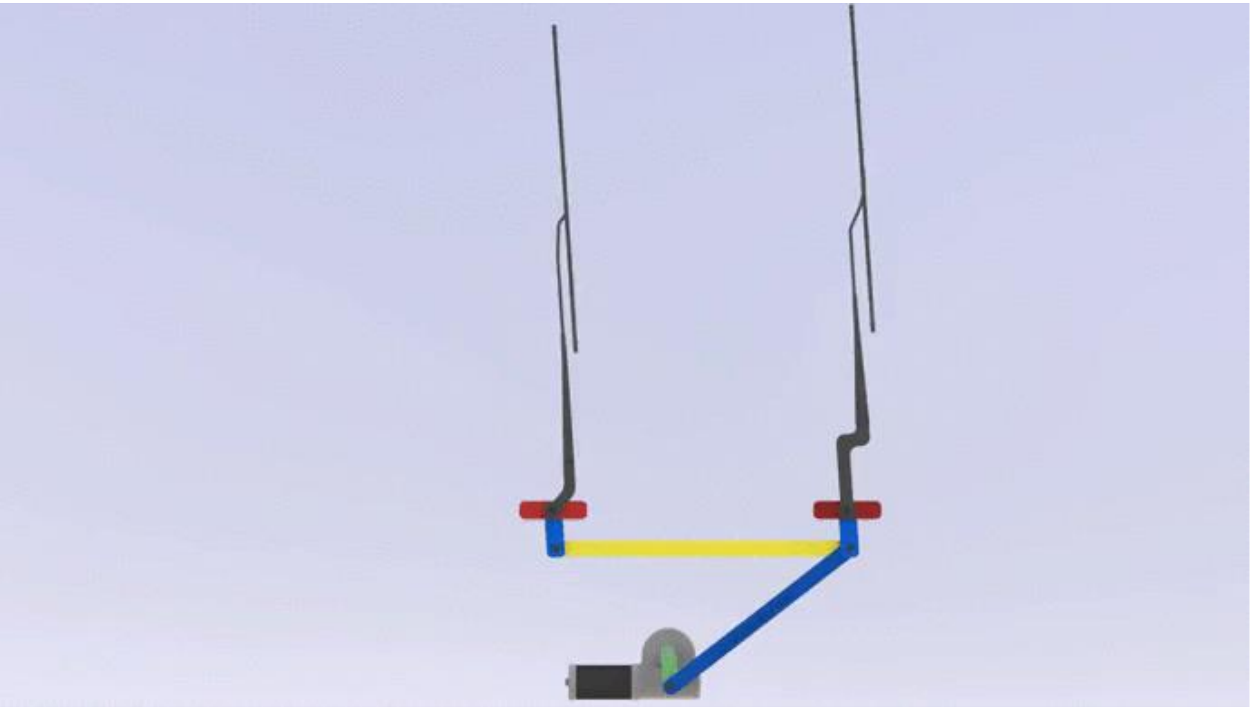
https://sites.google.com/view/freudensteintree



*MORE INFO: https://www.ohio.edu/mechanical-faculty/williams/html/PDF/HistoryOfMechanisms.pdf

Planar Linkages

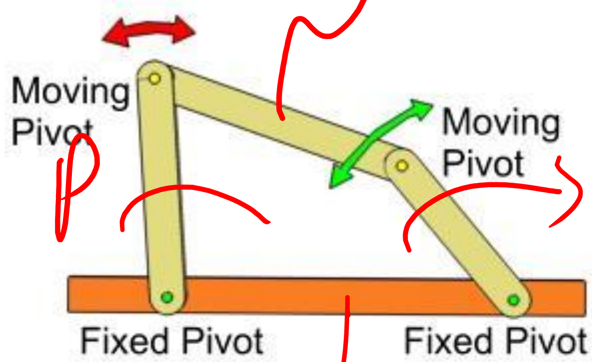
- Wondered what kind of mechanism causes the wind shield wiper to oscillate?



Planar Linkages

- Four bar mechanism

coupler



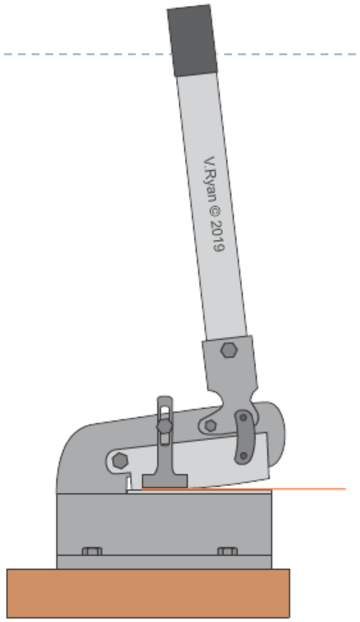
O/P

I/P

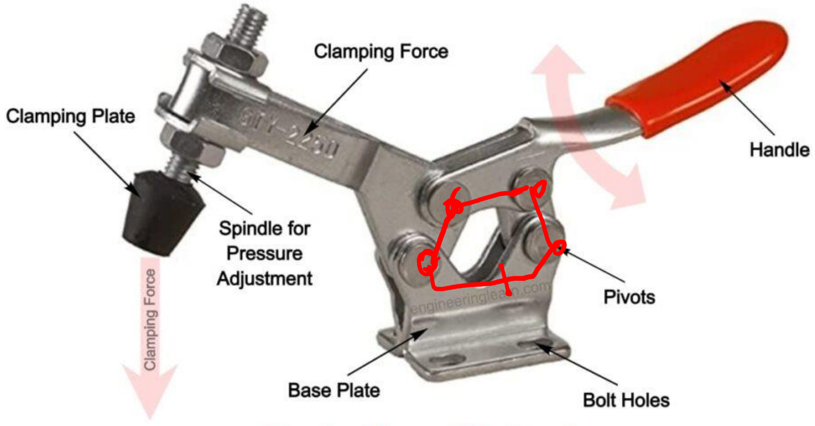
fixed link

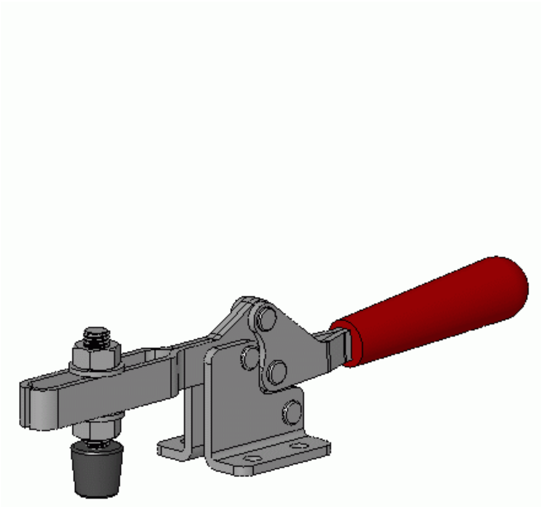
Four-bar Mechanisms

Sheet Metal Shear



https://technologystudent.com/equip_flsh/shears1.html





https://commons.wikimedia.org/wiki/File:Toggle-clamp_manual_horizontal_3D_animated.gif

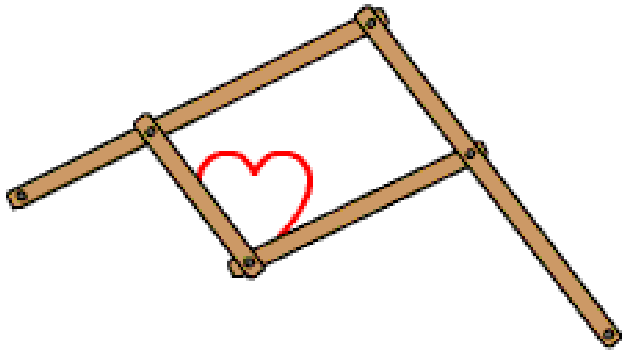
Four-bar Mechanisms

Brake of a Wheelchair

Folding Chair

Planar Linkages

- instrument for duplicating a motion or copying a geometric shape to a reduced or enlarged scale.

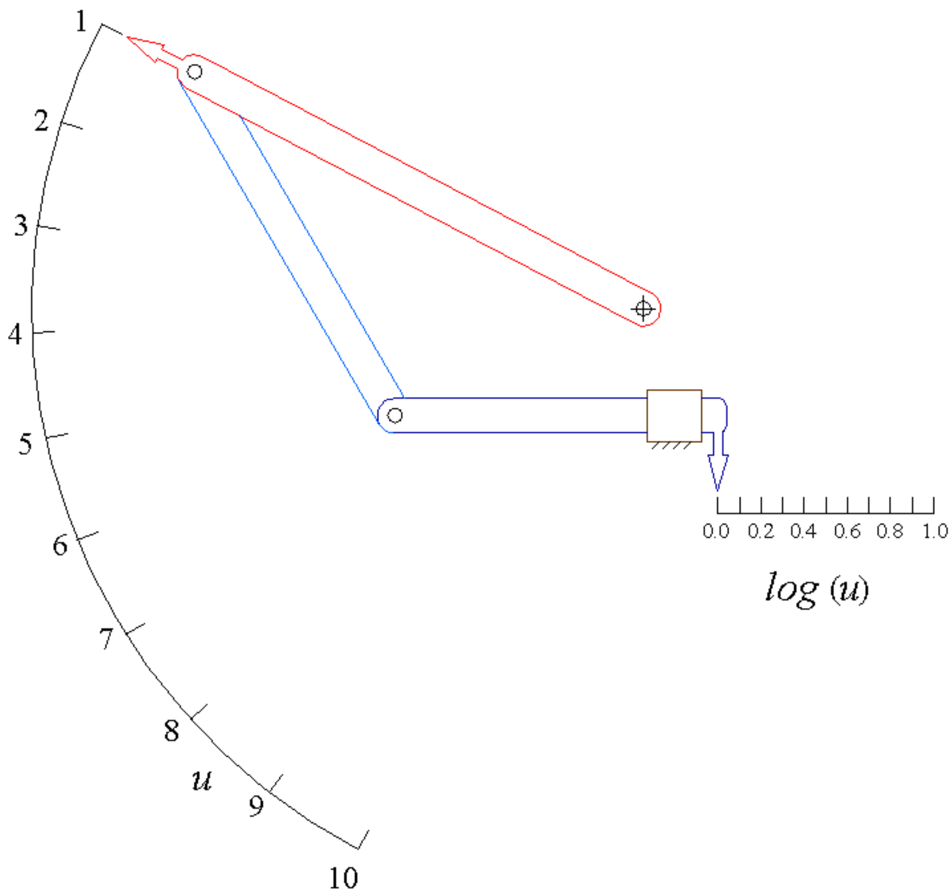


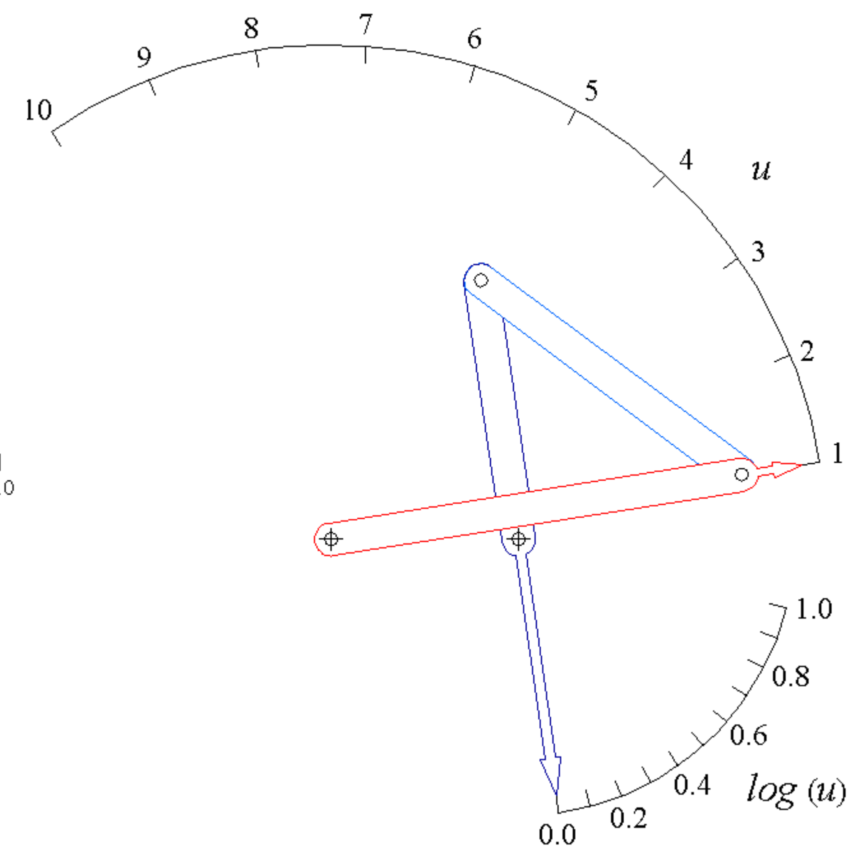
Pantograph used for scaling a picture.
The red shape is traced and enlarged.

Forms of duplication in areas such as sculpture, minting, engraving, and milling.

Planar Linkages

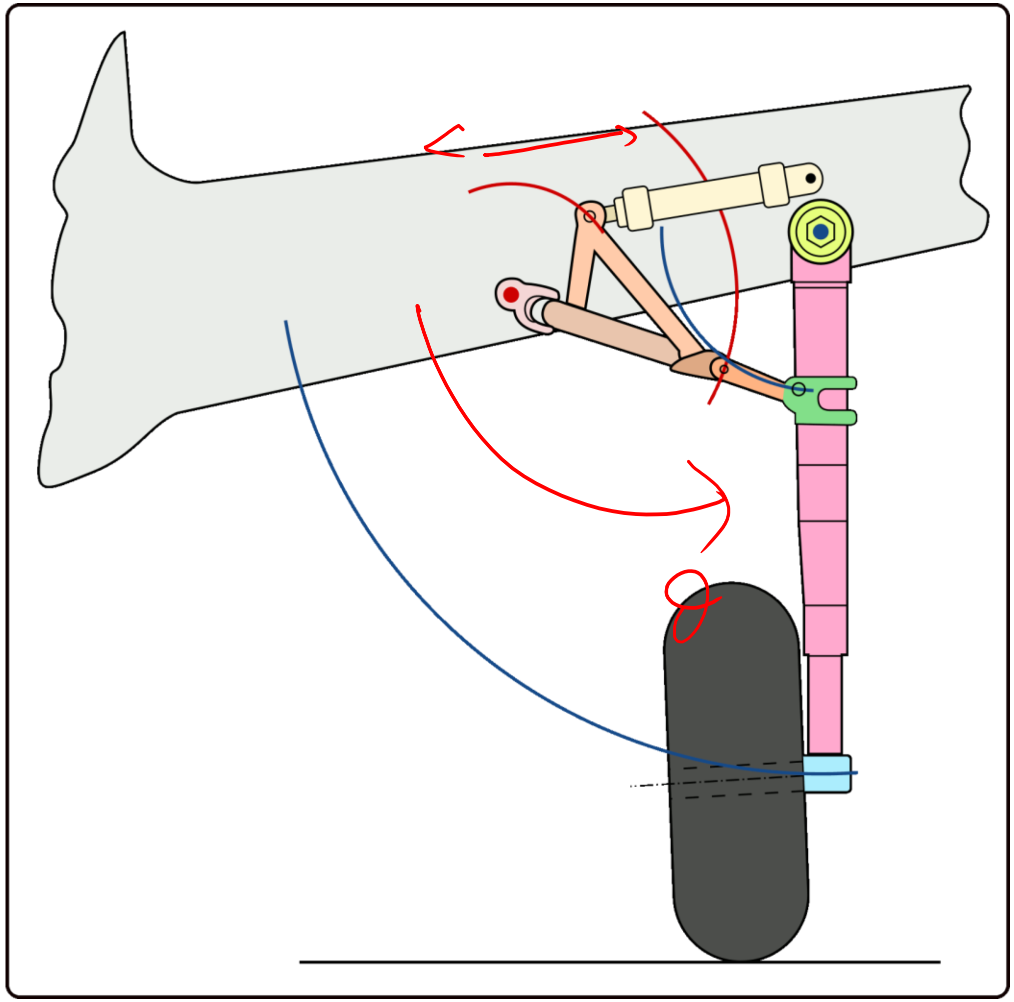
- Four-bar function generator approximating the function Log(u) for 1 < *u* < 10.





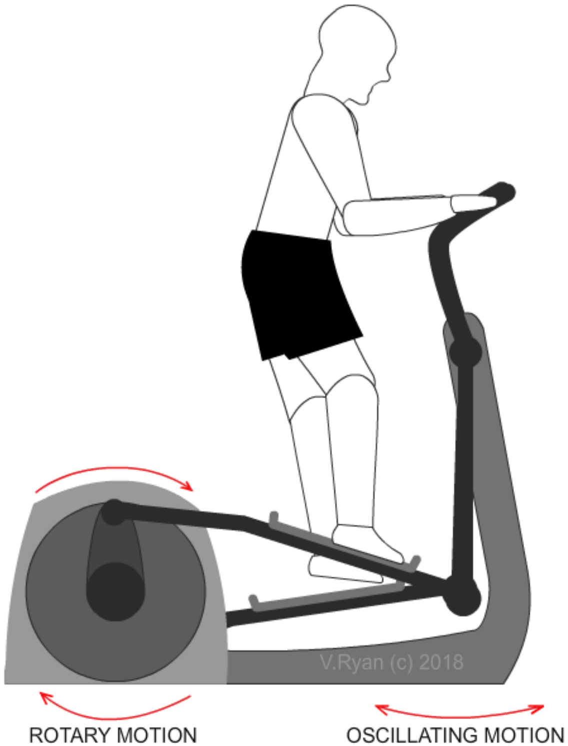
Planar Linkages – Landing Gears

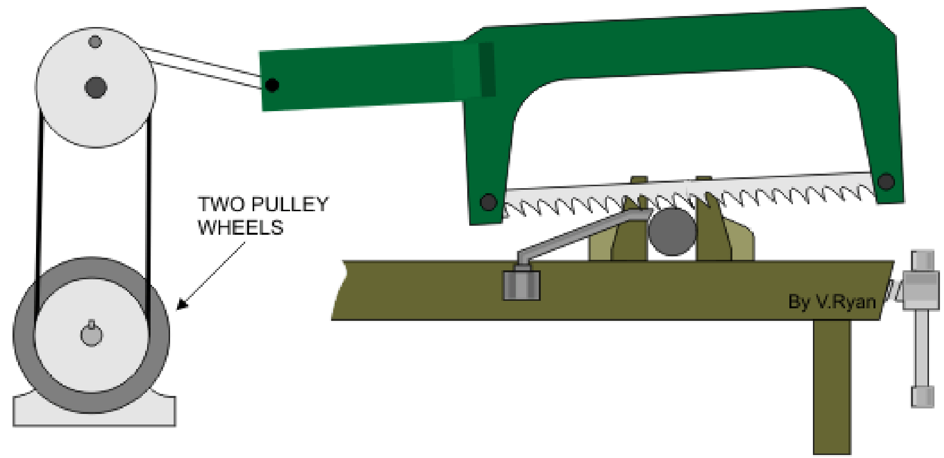
- Open position to folded position.
- Stroke length vs folding angle
- What rate it should expand?
- How much force is required?

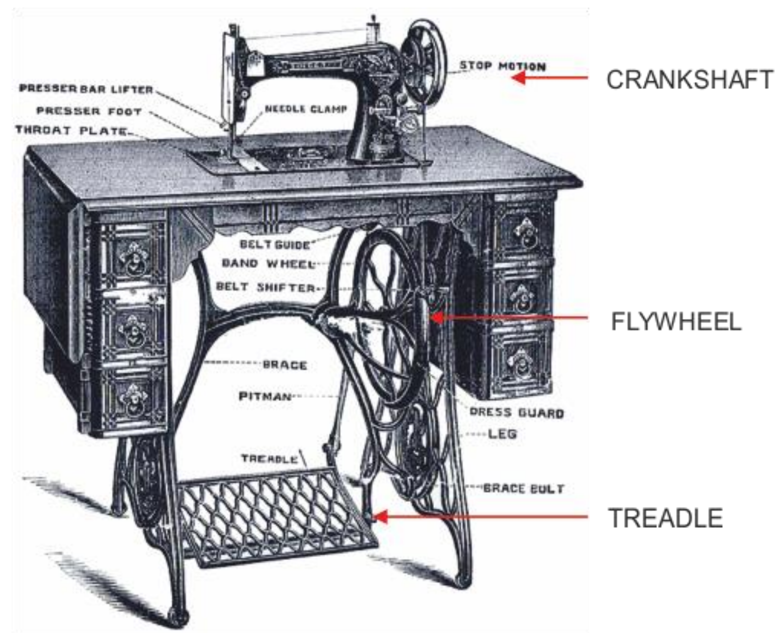


https://commons.wikimedia.org/wiki/File:Landing_gear_schematic-colored-animation.gif

Planar Linkages

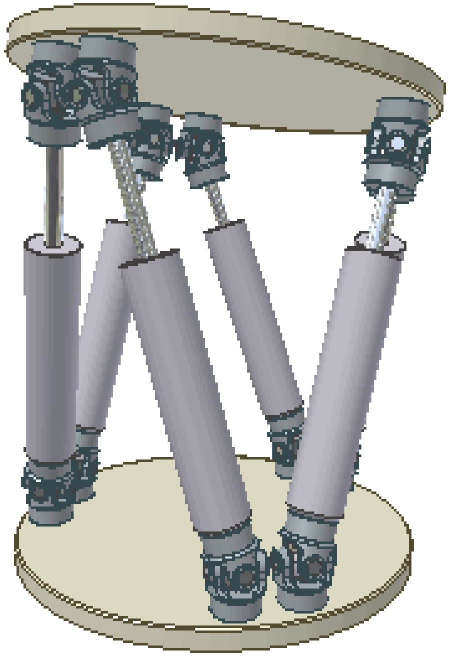






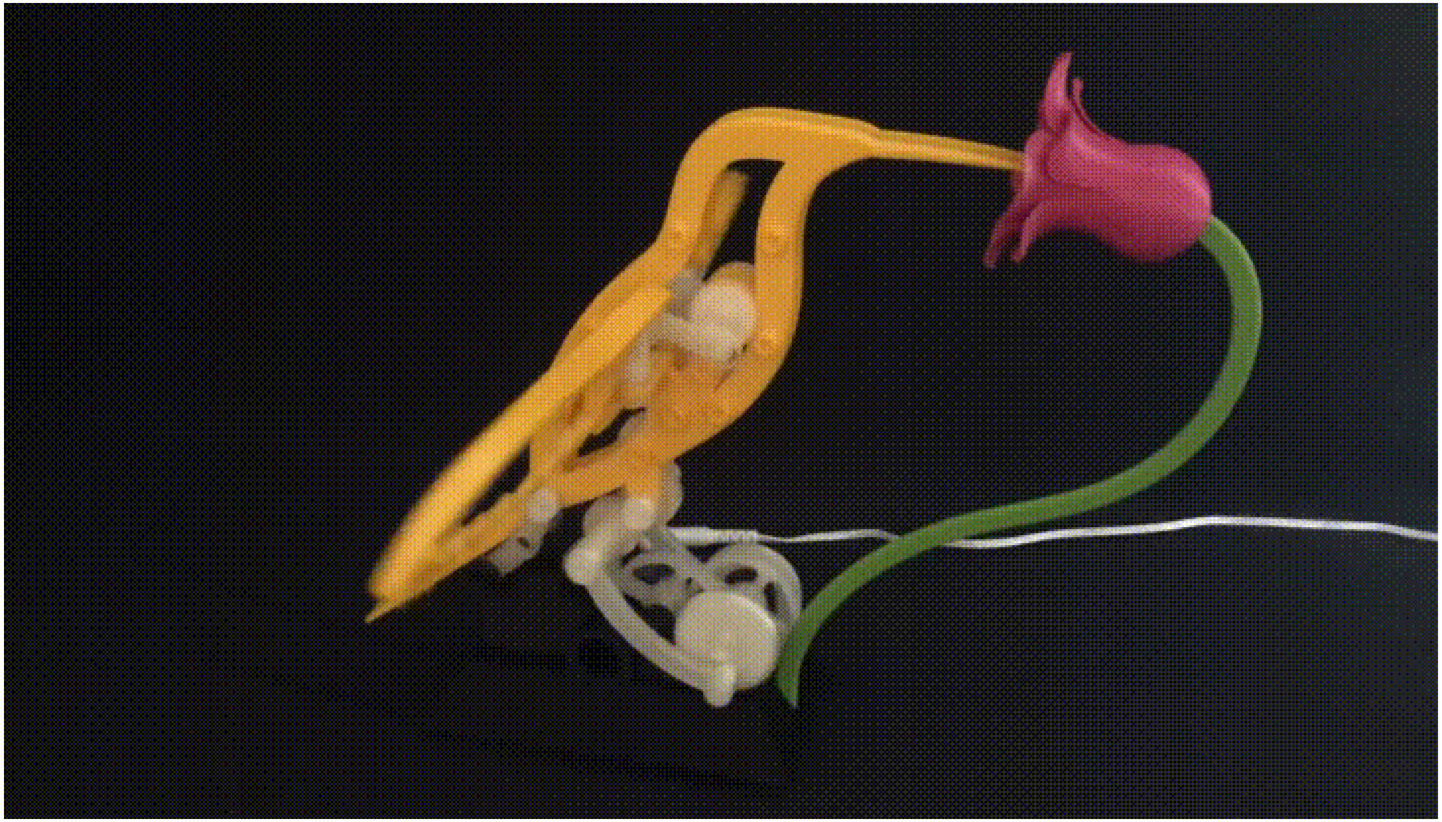
Spatial Linkages - Simulators

- occupant-controlled motion simulators are flight simulators, driving simulators, and hydraulic arcade cabinets for racing games and other arcade video games.



Example of a full flight simulator (FFS) with a 6-axis hexapod motion platform

Spatial Linkages



https://imgur.com/t/automata/xjfNpwr

Interesting Applications