GRASP Laboratory
General Robotics & Autonomous Systems and Processes

Mechatronic Modeling and Design with Applications in Robotics

Course Outline and Introduction

Instructor

Course Website:

http://grasplab.ca/modeling.html

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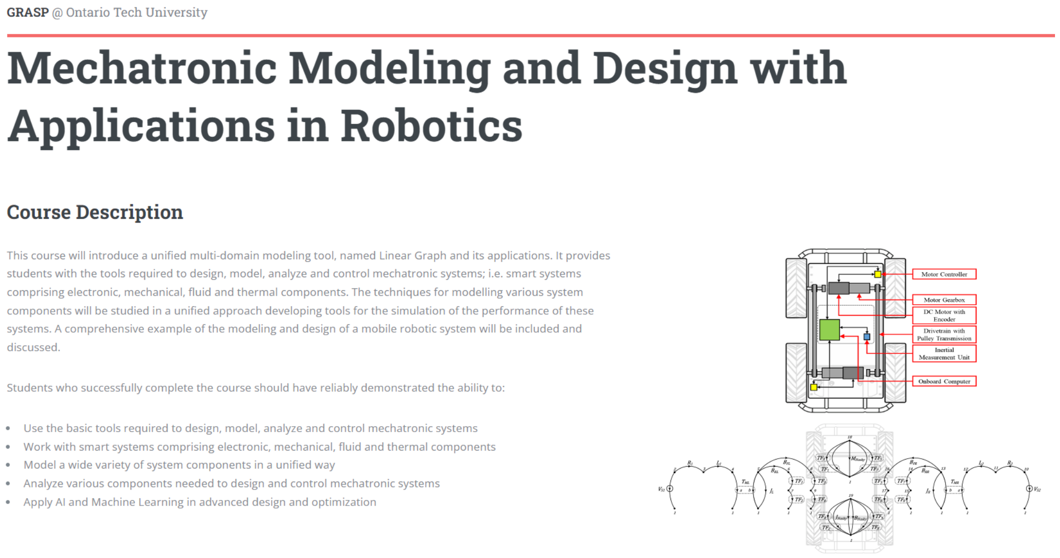

GRASP @ Ontario Tech University

Mechatronic Modeling and Design with Applications in Robotics

Course Description

This course will introduce a unified multi-domain modeling tool, named Linear Graph and its applications. It provides students with the tools required to design, model, analyze and control mechatronic systems; i.e. smart systems comprising electronic, mechanical, fluid and thermal components. The techniques for modelling various system components will be studied in a unified approach developing tools for the simulation of the performance of these systems. A comprehensive example of the modeling and design of a mobile robotic system will be included and discussed.

Students who successfully complete the course should have reliably demonstrated the ability to:

- Use the basic tools required to design, model, analyze and control mechatronic systems
- Work with smart systems comprising electronic, mechanical, fluid and thermal components
- Model a wide variety of system components in a unified way
- Analyze various components needed to design and control mechatronic systems
- Apply AI and Machine Learning in advanced design and optimization

A snapshot of the course website

Director of the GRASP Lab @ OntarioTech

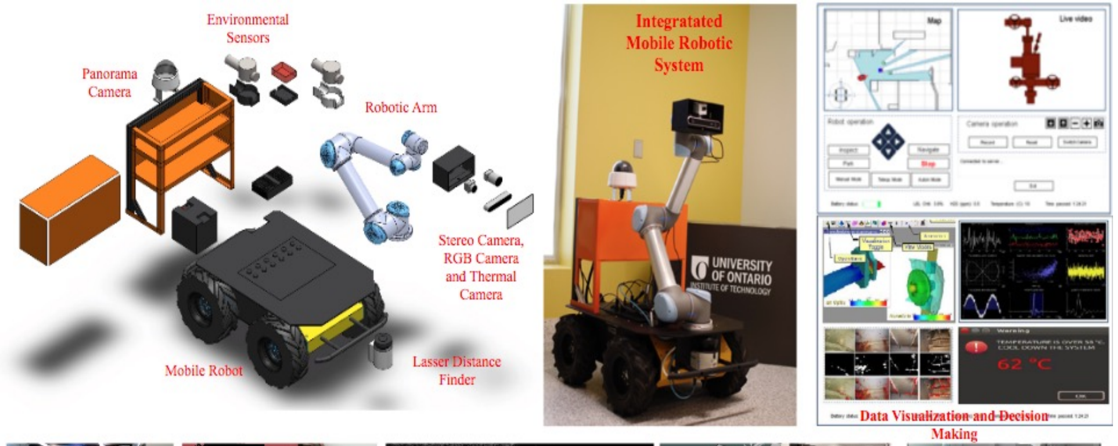
Design, development and application of advanced technologies for autonomous systems and processes

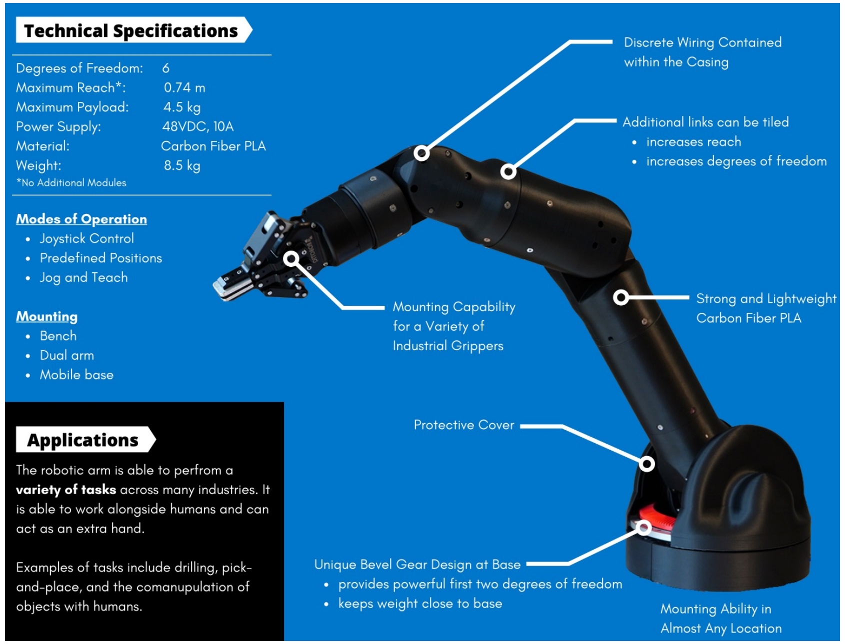
- Mechatronics
- Robotics
- Machine vision
- Advanced Control
- Artificial intelligence

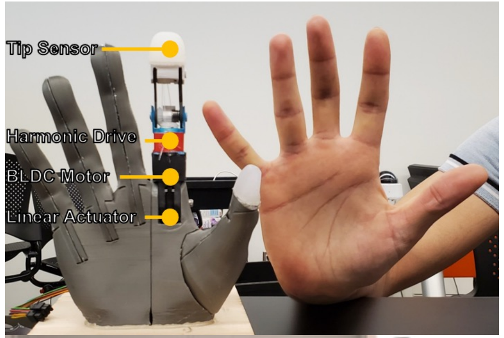
GRASP Laboratory
General Robotics & Autonomous Systems and Processes

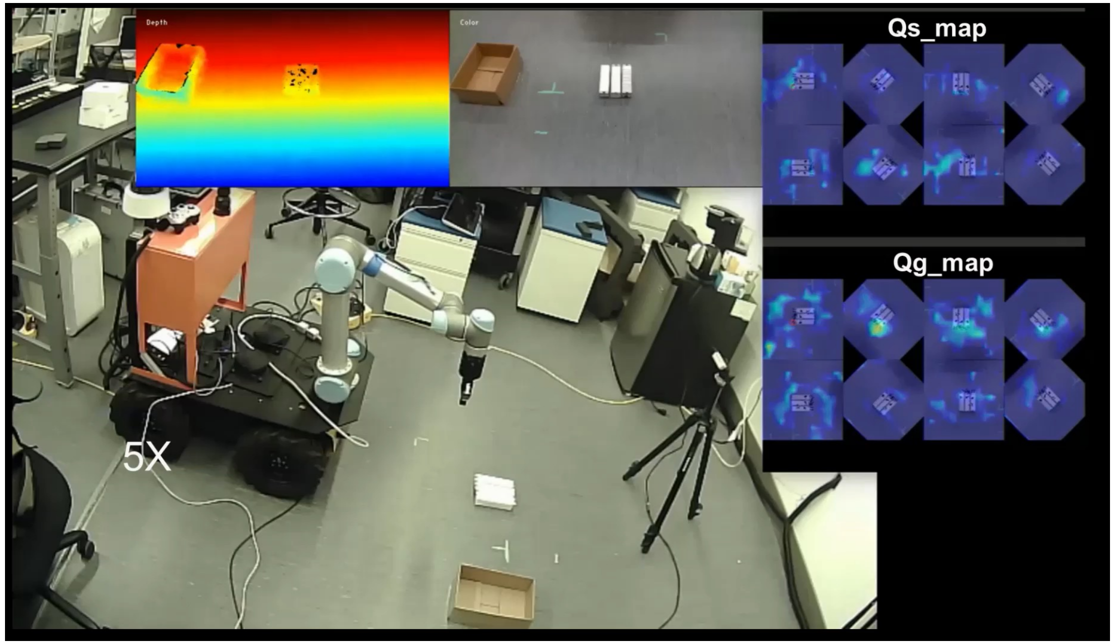
OntarioTech UNIVERSITY

Selected Projects in GRASP Lab









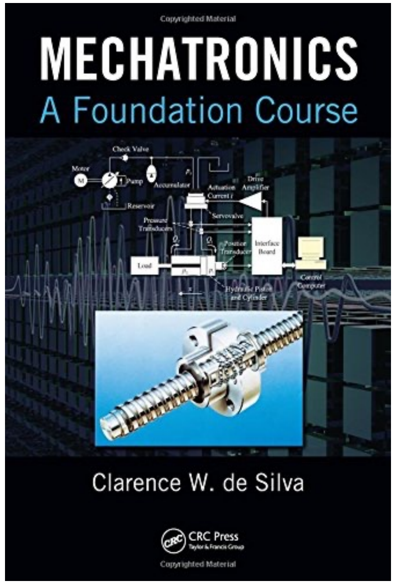
Course Outline

- Course Overview and Introduction
- Introduction to Modeling
- Basic Model Elements
- Analytical Modeling
- Graphical Models
- Linear Graph
- Linear Graph Examples
- Frequency Domain Models
- Transfer-Function Linear Graph
- Examples in Applications

Learning Outcomes

- Understand the formal meanings of a dynamic system of multi-physics systems (e.g., mechatronic systems).
- Recognize different types of models (e.g., physical, analytical, computer, experimental) and their importance, usage, comparative advantages and disadvantages.
- Under analytical models, recognize the general and specific pairs of model categories.
- Understand the concepts of through-variables and across-variables and their physical significance, and relationship to state variables.
- Recognize similarities or analogies among the four physical domains: mechanical, electrical, fluid, and thermal (this is the basis of the "unified" approach to modeling).
- In each physical domain, recognize the lumped elements that store energy and that dissipate energy, based on the analogy among different physical domains.
- Model a wide variety of system components in a unified way
- Apply AI and Machine Learning in system modeling and design optimization

Reference Books and Articles



Clarence W. de Silva, *Mechatronics: A Foundation Course*, CRC Press, 2010.

Haoxiang Lang, Eric McCormick and Clarence W. de Silva, Appendix B of *Modeling of Dynamic Systems with Engineering Applications*

Matlab Toolbox: GitHub Link
https://github.com/GRASP-ONTechU/Linear_Graph

Three Reference Articles: (downloadable on the course website)

- Research and Development of a Linear Graph-based Matlab Toolbox.
- Automated Multi-domain Engineering Design through Linear Graphs and Genetic Programming.
- Dynamic Modeling and Simulation of a Four-wheel Skid-Steer Mobile Robot using Linear Graphs.

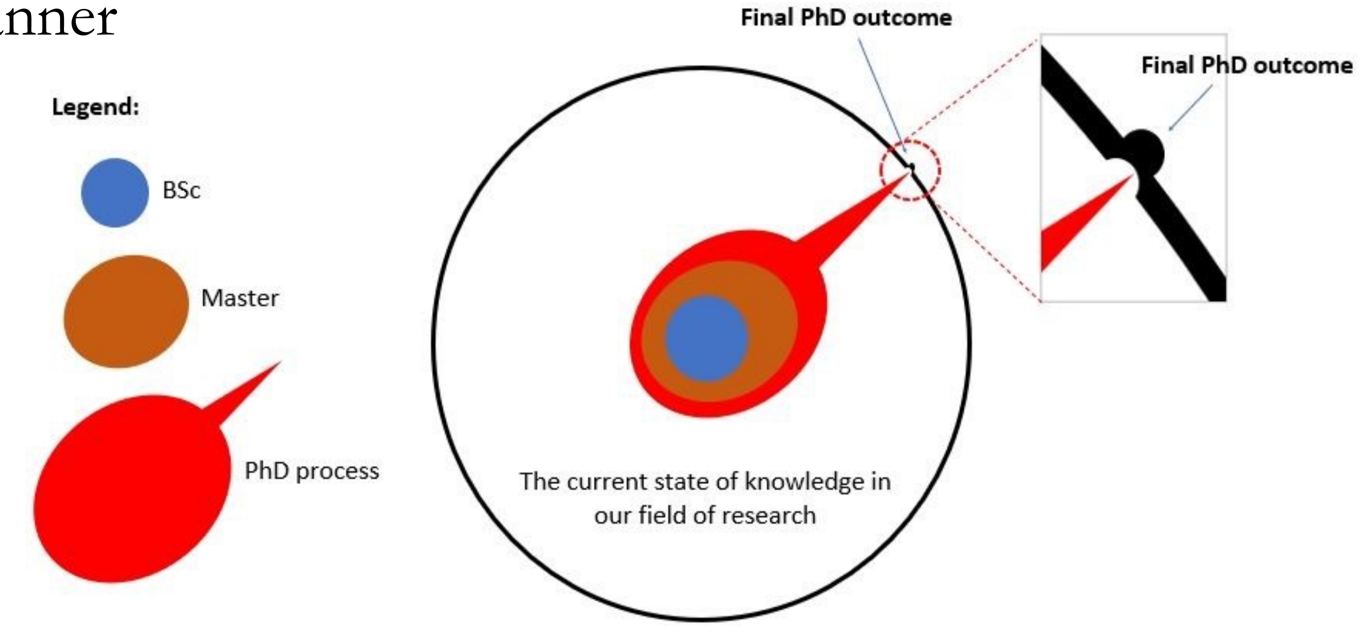
Course Evaluation

Goals:

- To understand basic modeling of dynamic systems and its procedure
- To formulate realistic modeling/design and possible control problems
- To do analysis and design for the problem using the course material
- To design and analyze of the multi-physics systems in Matlab, and implementation if possible

Ultimate Goals

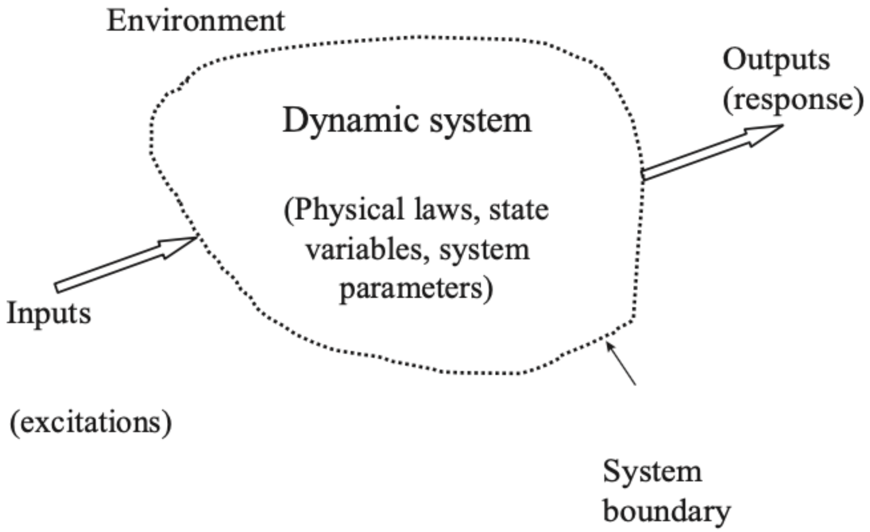
- Cutting-edge insight into system dynamics
- Foundation to develop expertise in design prototyping, control, instrumentation, experimentation and performance analysis
- Discussion of system dynamics
- Systematic, unified and integrated manner
- Introduce tools of modeling



Introduction

Introduction to Modeling

- Introduce the subject of modeling, with focus on multi-physics engineering dynamic systems.
- The importance of dynamic modeling in various applications
- The use of models in the design and control
- Common types of models and modeling techniques and their advantages and disadvantages
- The idea of integrated, unified, systematic mechatronic modeling



Basic Model Elements

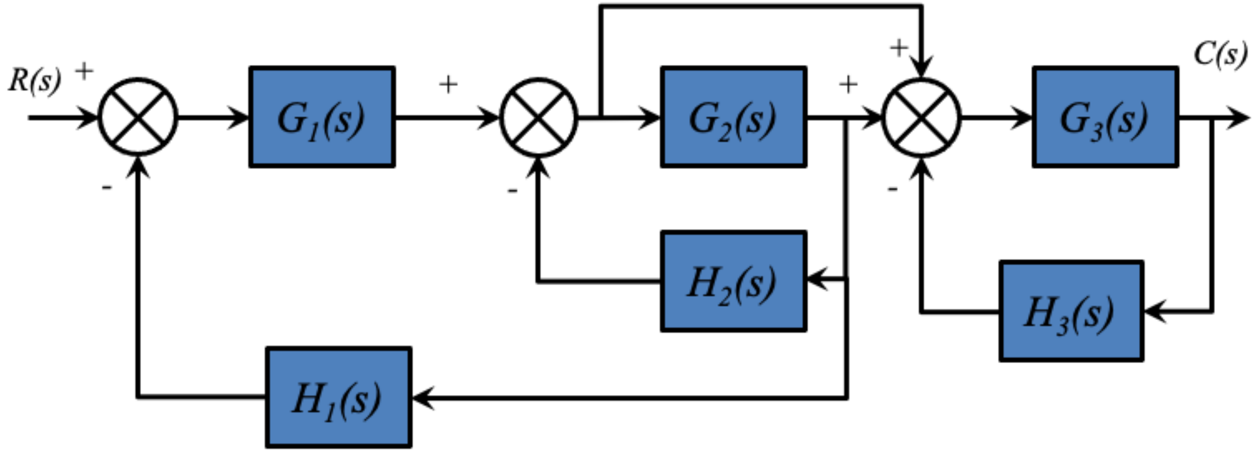
- Re-visit basic elements in mechanical, electrical, fluid and thermal domain
- Introduce two new concepts: across-variables and through-variables
- Discuss similarities across domains
- Re-define basic elements with new categories for energy storage elements, energy dissipation elements and sources.
- Identification of proper and physically meaningful state variable across multiple physics domains.

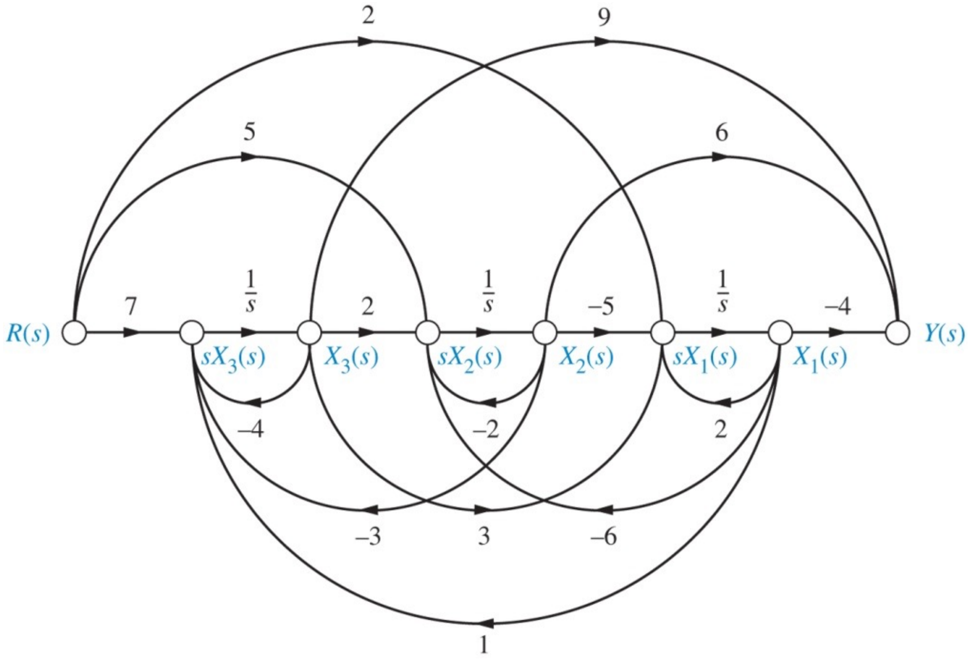
Analytical Modeling

- Formally introduces analytical modeling of dynamic systems
- Systematic development of state-space models of engineering systems in fours physical domains
- Frequency domain models: Transfer Function
- A general methods of converting a state-space model into an input-output model
- Indicate the advantages and limitations
- Examples will be discussed

Graphical Modeling Tools

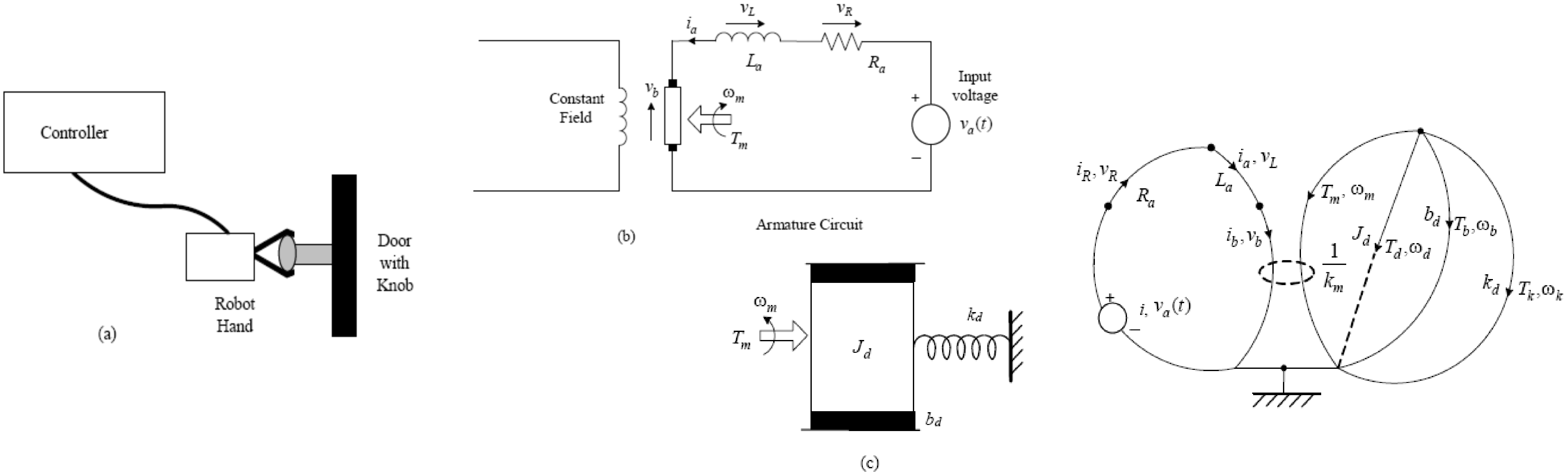
- System block diagram: formulation, simplification and generation of input-output model.
- Signal Flow Graph: formulation and calculation





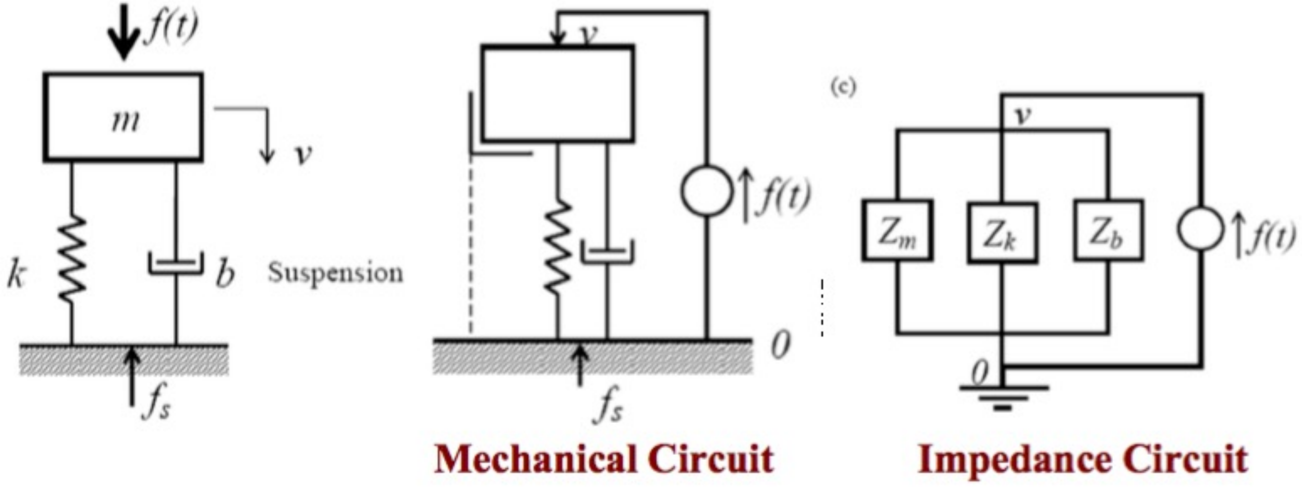
Linear Graph

- Introduce the graphical tool for developing models of dynamic systems
- State-space model formulation of any physics (mechanical, electrical, fluid and thermal) or multi-domain (mixed) systems
- Discuss more advanced method in Linear Graph



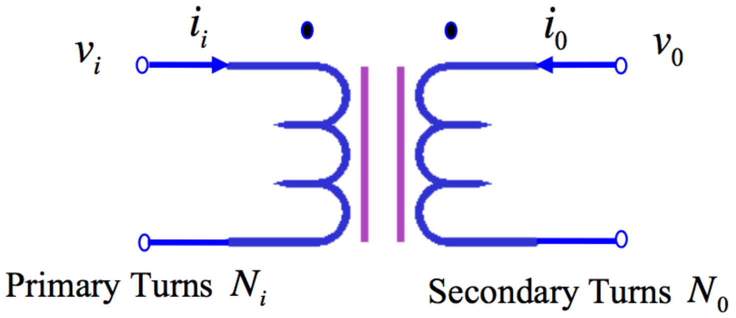
Frequency-Domain Models

- Mechanical Circuit
- Mechanical and electrical impedance
- Mechanical mobility and its interconnection laws
- Practical applications

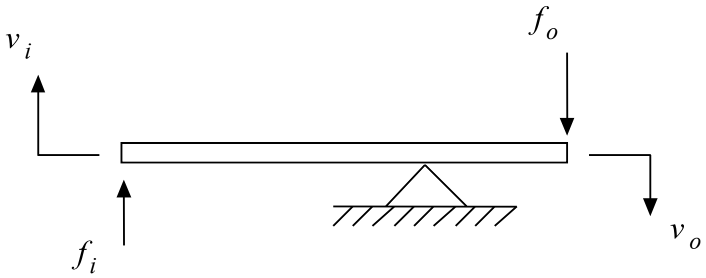


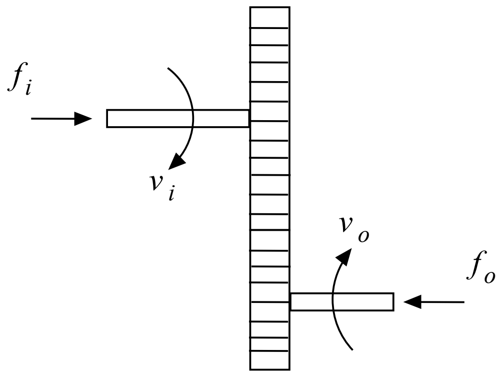
Transfer-Function Linear Graph

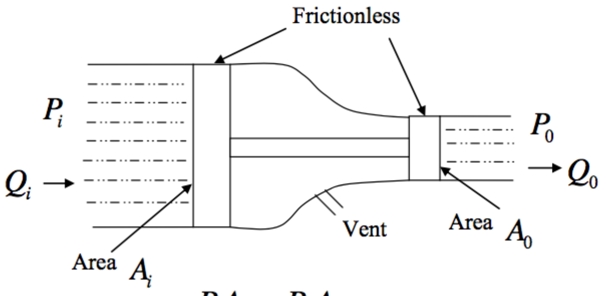
- Extension of the equivalent circuits (commonly in electrical domain) to other physical domain such as mechanical and fluid domains
- Reduction of linear graph using Thevenin and Norton equivalence
- Two port linear graph elements



$$r = \frac{N_0}{N_i} = \frac{v_0}{v_i}$$





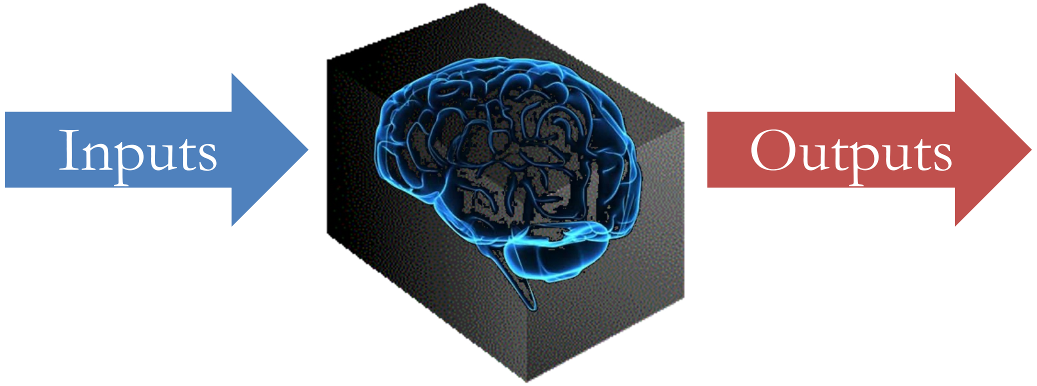


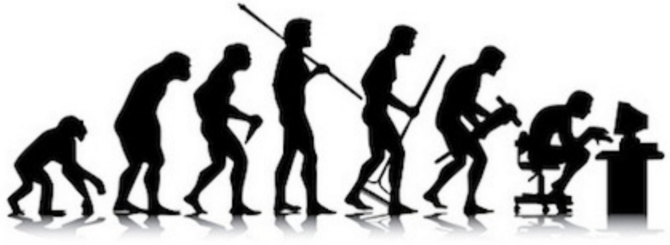
$$P_i A_i = P_0 A_0$$

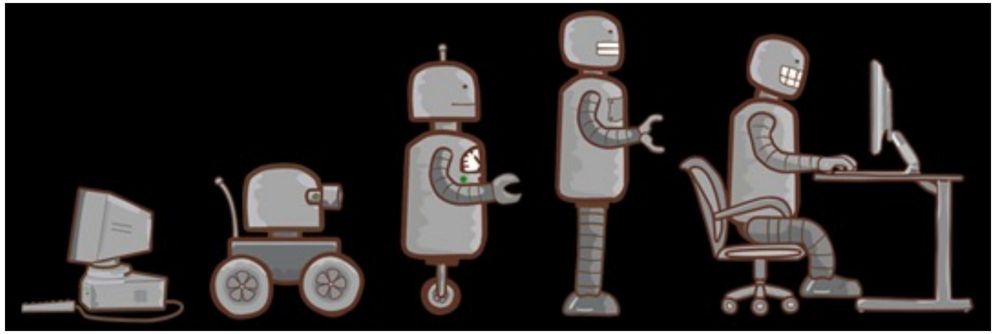
$$r = \frac{A_i}{A_0} = \frac{P_0}{P_i}$$

AI in Modeling and Design

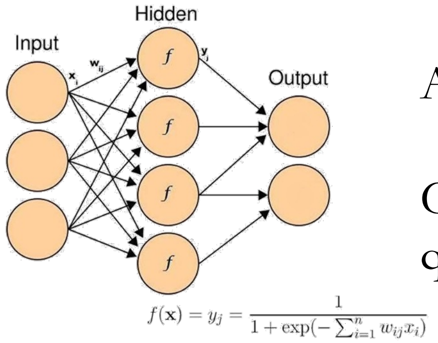
- Introduce general AI algorithms including NNs, GA and Machine Learning
- Discuss possible integration of AI in modeling and design
- Introduce examples







Reverse Engineering



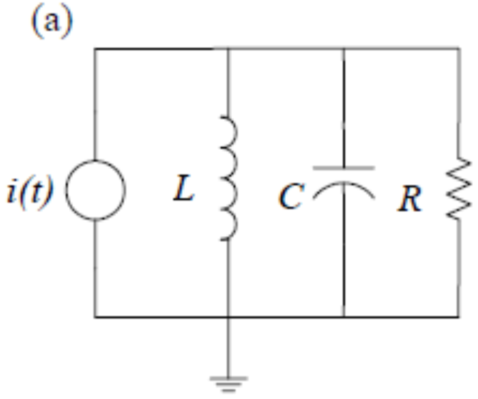
Artificial Intelligence:

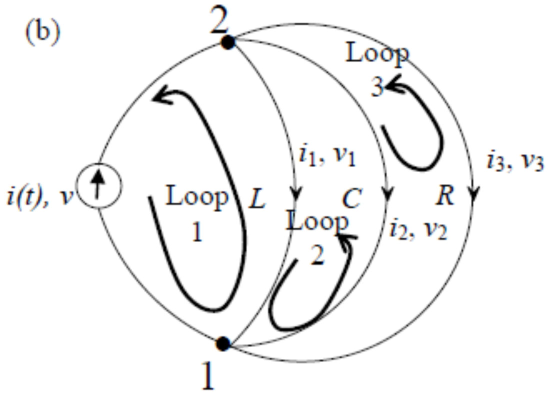
Capable of human-like qualities

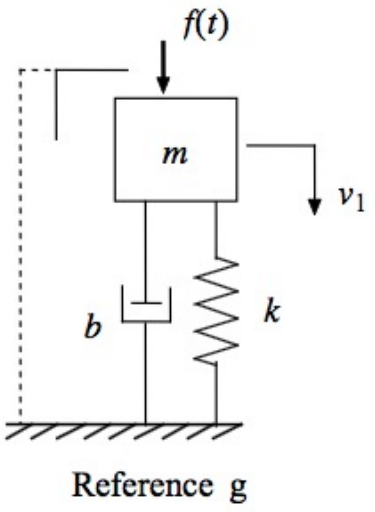
Understanding the system (e.g., human brain)

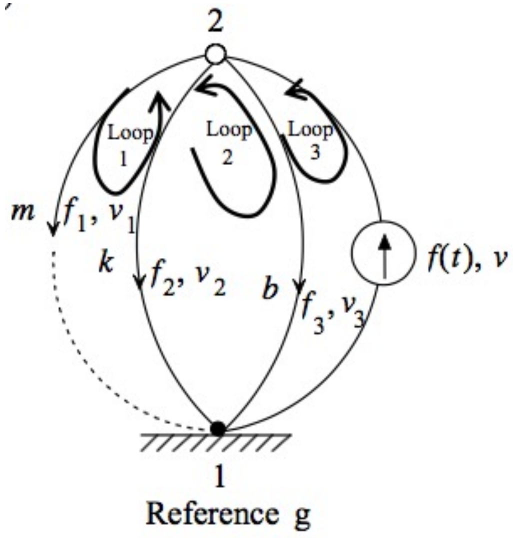
! The driving force behind the creation/evolution

Modeling and Design Example 1





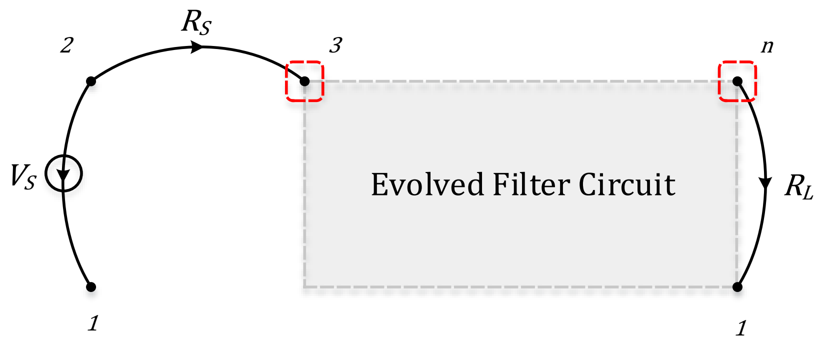


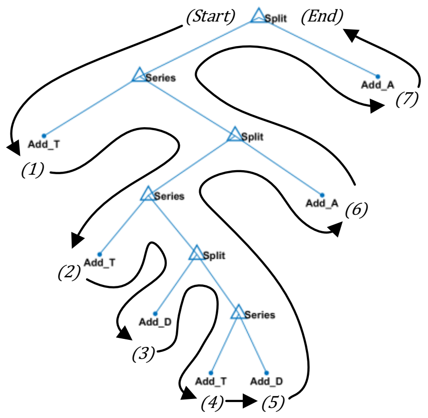


$$A = \begin{bmatrix} -b/m & -1/m \\ k & 0 \end{bmatrix} \qquad B = \begin{bmatrix} 1/m \\ 0 \end{bmatrix}$$

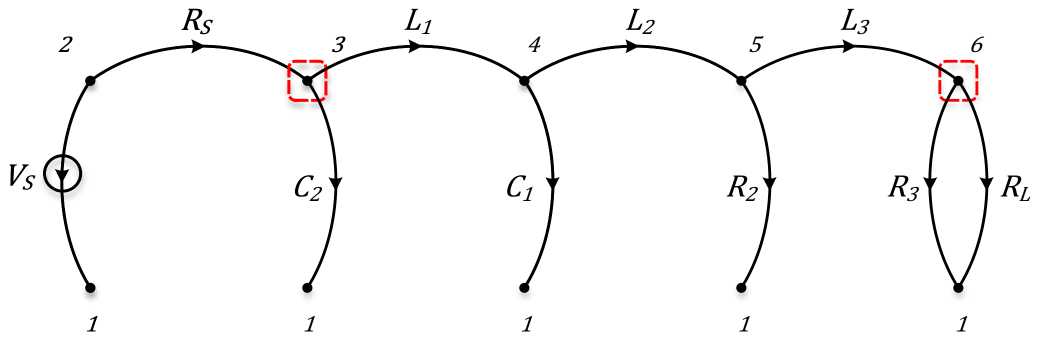
$$u = f(t) \qquad x = \begin{bmatrix} x_1 & x_2 \end{bmatrix}^T = \begin{bmatrix} v_1 & f_2 \end{bmatrix}^T$$

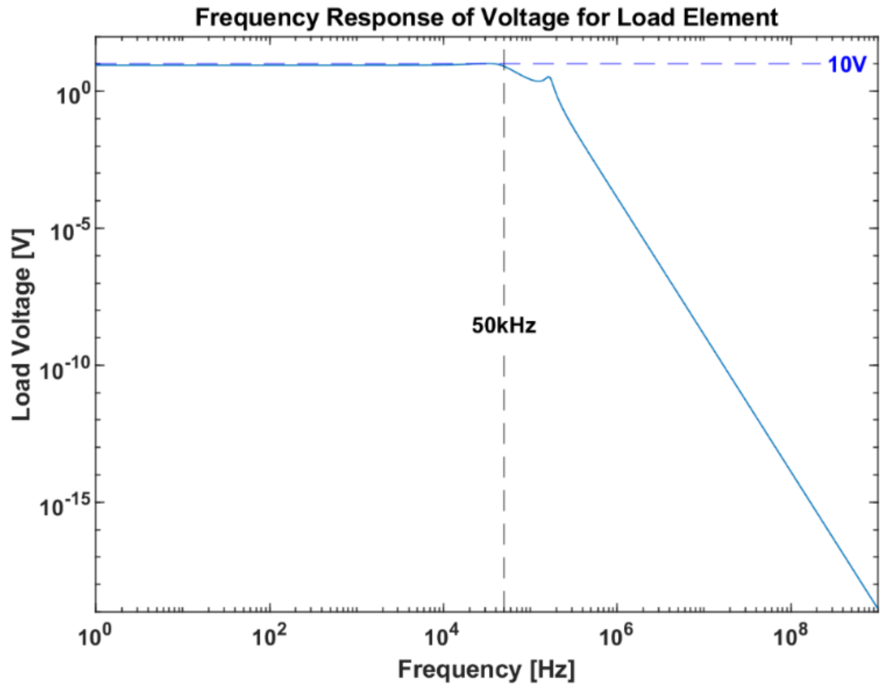
Modeling and Design Example 2

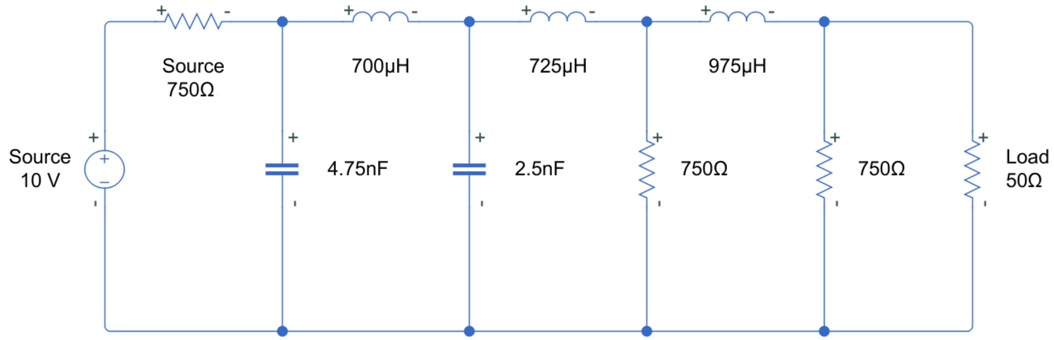




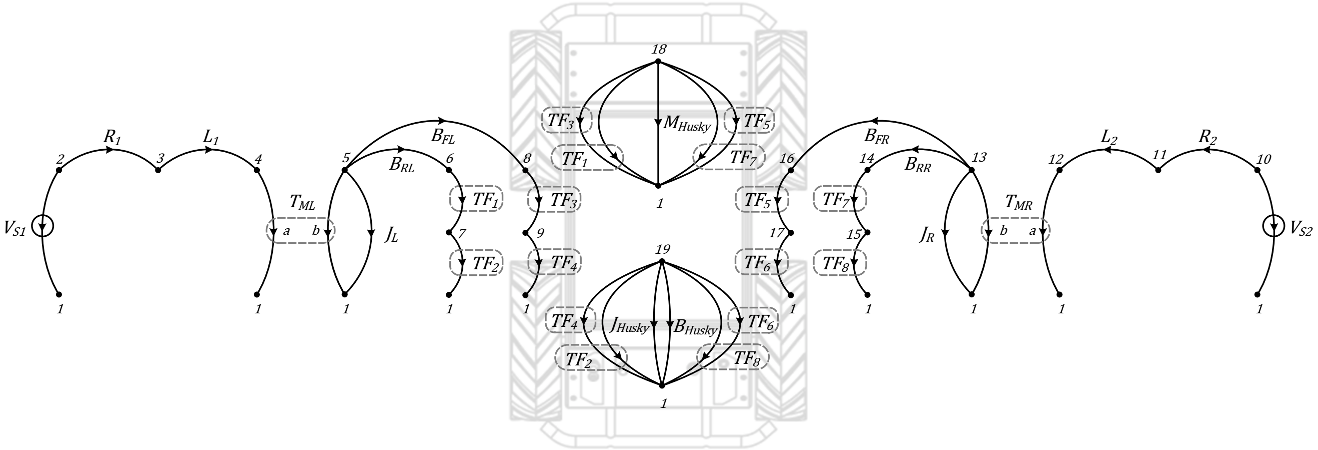
Genetic Programming





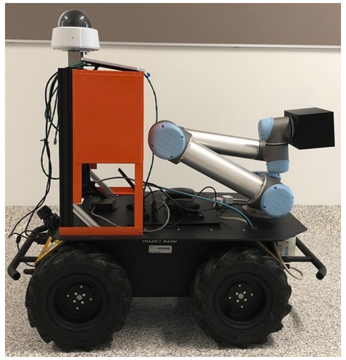


Modeling and Design Example 3



$$A = \begin{bmatrix} \frac{-B_{FL}-B_{RL}}{J_L} & 0 & \frac{B_{FL}TF_3+B_{RL}TF_1}{J_L} & \frac{B_{FL}TF_4+B_{RL}TF_2}{J_L} & \frac{T_{ML}}{J_L} & 0 \\ 0 & \frac{-B_{FR}-B_{RR}}{J_R} & \frac{B_{FR}TF_5+B_{RR}TF_7}{J_R} & \frac{B_{FR}TF_6+B_{RR}TF_8}{J_R} & 0 & \frac{T_{MR}}{J_R} \\ \frac{B_{FL}TF_3+B_{RL}TF_1}{M_H} & \frac{B_{FR}TF_5+B_{RR}TF_7}{M_H} & \frac{-B_{RL}TF_1^2-B_{FL}TF_3^2-B_{FR}TF_5^2-B_{RR}TF_7^2}{M_H} & \frac{-B_{FL}TF_3TF_4-B_{FR}TF_5TF_6-B_{RL}TF_1TF_2-B_{RR}TF_7TF_8}{M_H} & 0 & 0 \\ \frac{B_{FL}TF_4+B_{RL}TF_2}{J_H} & \frac{B_{FR}TF_6+B_{RR}TF_8}{J_H} & \frac{-B_{FL}TF_3TF_4-B_{FR}TF_5TF_6-B_{RL}TF_1TF_2-B_{RR}TF_7TF_8}{J_H} & \frac{-B_{RL}TF_2^2-B_{FL}TF_4^2-B_{FR}TF_6^2-B_{RR}TF_8^2-B_H}{J_H} & 0 & 0 \\ -\frac{T_{ML}}{L_1} & 0 & 0 & 0 & -\frac{R_1}{L_1} & 0 \\ 0 & -\frac{T_{MR}}{L_2} & 0 & 0 & 0 & -\frac{R_2}{L_2} \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \frac{1}{L_1} & 0 \\ 0 & \frac{1}{L_2} \end{bmatrix} \quad C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \quad D = [0]_{4\times 2}$$



Description	Parameter	Value	Units
Voltage Inputs	V_{s1} , V_{s2}	± 24	V
Internal Motor Resistance	R_1 , R_2	0.46	Ω
Internal Motor Inductance	L_1 , L_2	0.22	mH
Motor Torque Constant	k_t	0.044488	$N \cdot m/A$
Gear Ratio	GR	78.71 : 1	Gear Ratio
Motor Transformer Ratio	T_{ML} , T_{MR}	$k_t \times GR$	$N \cdot m/A$
Drivetrain Inertia	J_{LW} , J_{RW}	0.08	$kg \cdot m^2$
Drivetrain Damping	$B_{RL,FL,FR,RR}$	Unknown	$rad/(N \cdot m \cdot s)$
Power Conversion Transformer Ratios	TF_{odd}	Equation (7)	
	TF_{even}	Equation (8)	
Husky Mass	M_{Husky}	48.39	kg
Husky Rotational Damping	B_{Husky}	Unknown	$rad/(N \cdot m \cdot s)$
Husky Inertia	J_{Husky}	3.0556	$kg \cdot m^2$

The End!!