Iranian society of MECHATRONICS

انجمن مکاترونیک ایران

Mechatronics

A Design Philosophy

Amir H. Davaie-Markazi
Yaser Shanjani
Mahdi Abbasi
and
All students of Mechatronics II course

Iran Univ. of science and technology
Iranian Society of Mechatronics

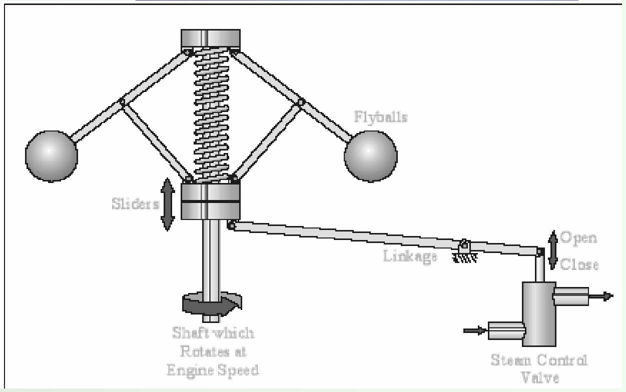
May 2006

Outline

- History
- Definition
- Integrated Product Design
- A Teaching Experience at IUST

History
(Ktesibios water clock)

- Ktesibios water clock
- Watt Governer
- Space Projects
- 1969: Japanese engineer (electric co.) coined MechaTronics
  (Mechanism+electronics)



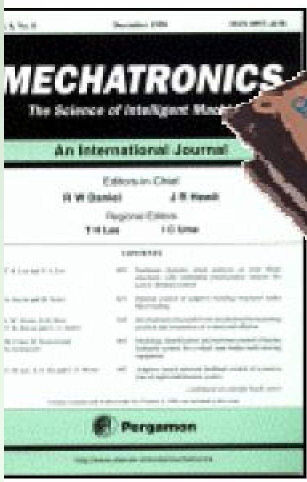
Recent Trends

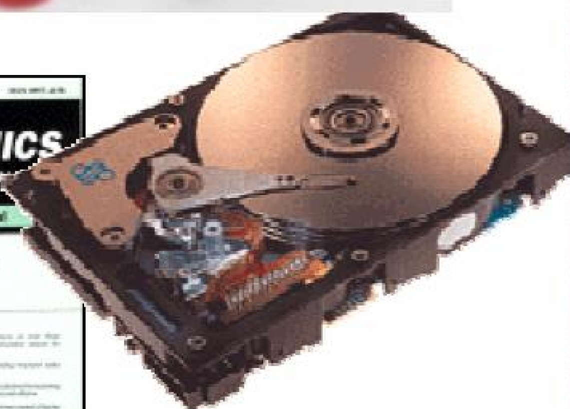
- 1970s – Servo technology (vending machines, auto focus cameras, etc)
- 1980s – Embedded microprocessors (N/C, robots, EMS, ABS, etc)
- 1990s – Communication technology (remotely controlled micro sensors and actuators, MEMS, tiny sensors in airbags, etc)
- Today – Vast educational programs worldwide.

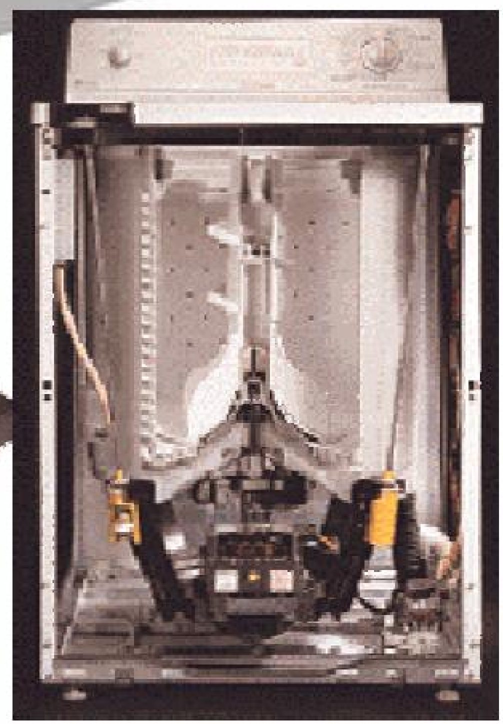
Divergence/Convergence

- Primary engineering disciplines (mech/elecr/chem) separated in the 19'th and most of the 20'th century,
- Electronics/IT part of almost any product today,
- The re-merging of primary engineering disciplies and computer technology widens the engineering perspective for producing very complex products.

Mechatronic products







Following mechatronic principles, General Electric's Profile Super 32 clothes washer features a sensor-based feedback control that maintains correct water temperature no matter the load size

Consumer products

Robots

Cars

Computer products

Space/Weapons

Photo copier

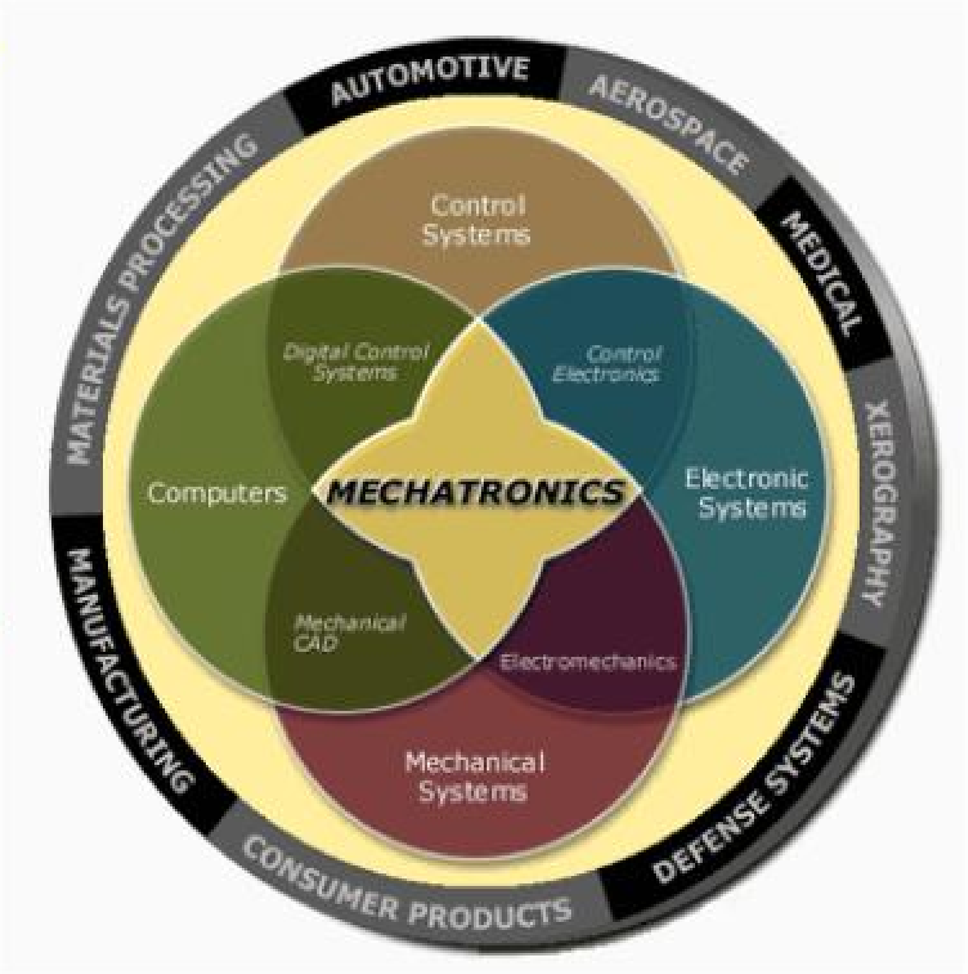
Anti lock brakes

Etc etc etc

NOT a mechatronic product: the BBQ

What is Mechatronics?

Mechatronics is the *synergistic* combination of mechanical engineering, electronics, controls engineering, and computers, all *integrated* through the design process. It involves the application of *complex decision making* to the operation of physical systems. Mechatronic systems depend for their unique functionality on computer software.



Involved Knowledge

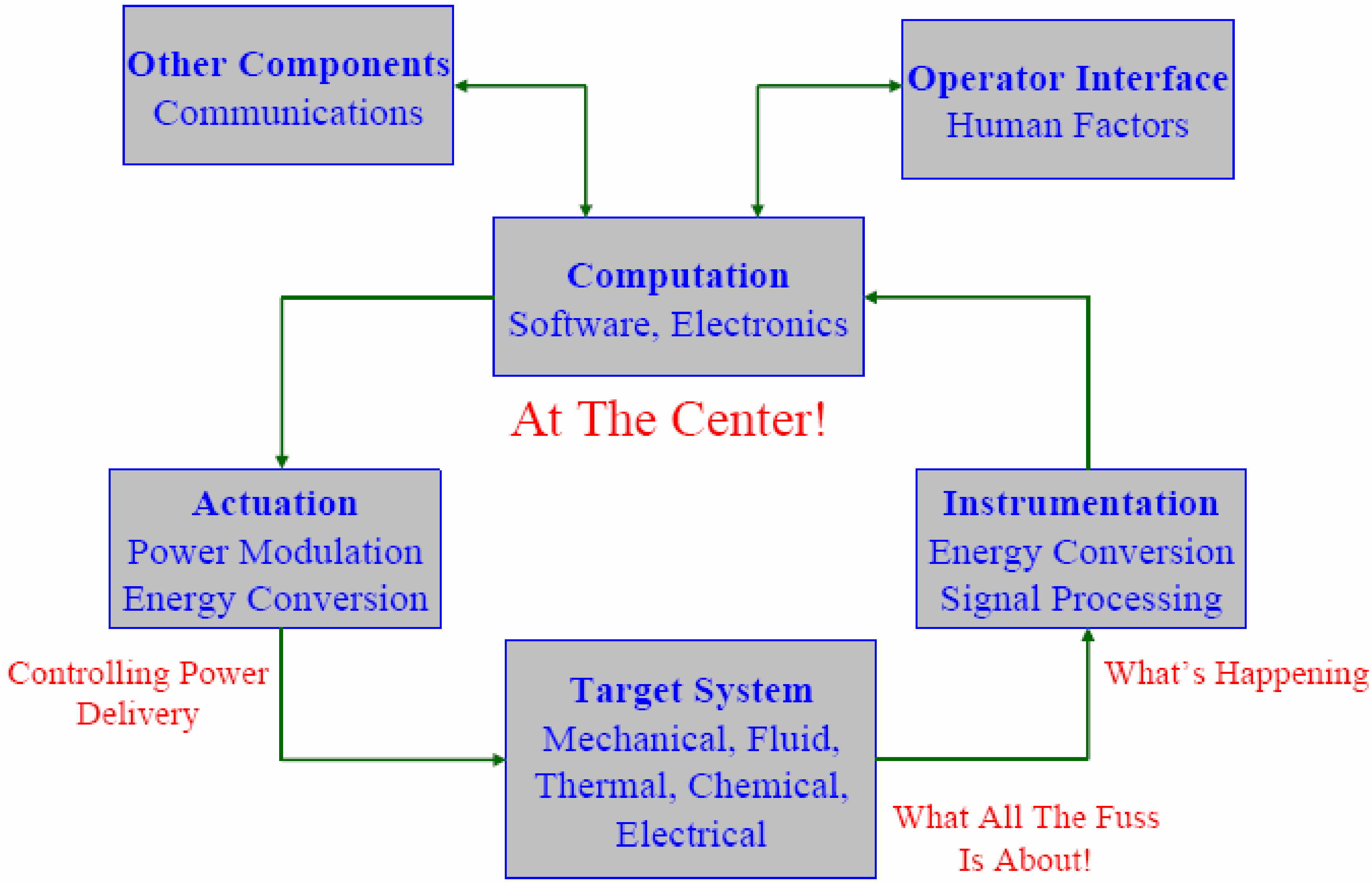
- Concurrent Multi-Domain Modeling
- Engineering Design
- Material Properties
- Electrical Measurement
- Digital/Analog Control
- Sensors/Actuators
- Micro ElectroMechanical Systems (MEMS)
- Power Electronic Control
- Markat Assessment
- Laws and Regulations
- Development Method
- Team Management
- Production Technology
- Industrial Design
- Surface Coating
- Packaging
- Marketing
- Distribution

No Single One Can Do All

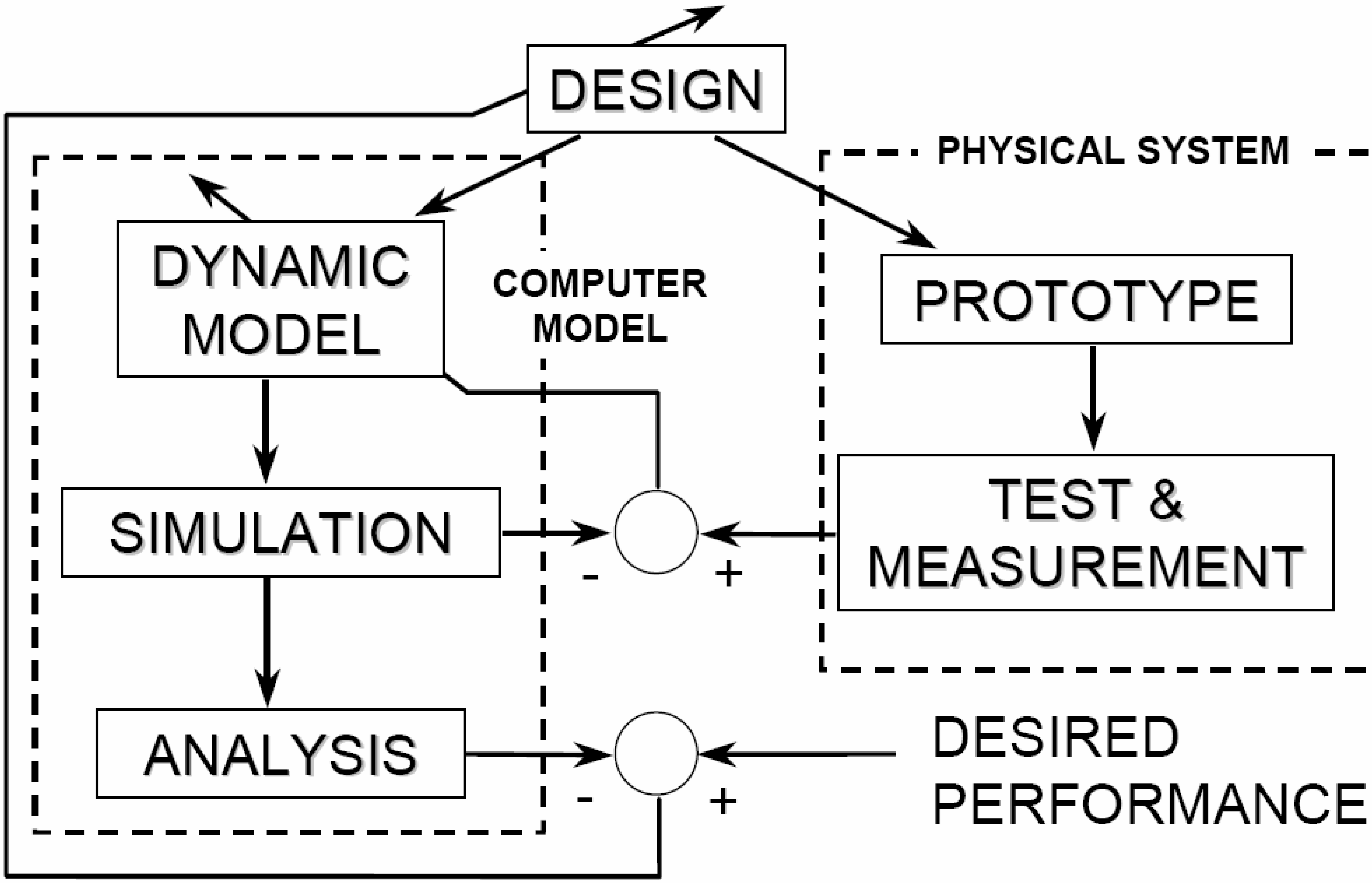
- Teamwork is Necessary
- Cultural Barriers
- Geographically Distant Experts
- Innovative Organizing
- Innovative Development Process
- Innovative Resource Allocation
- Mutual Understanding Among Team Members
- Interdisciplinary Knowledge
- Competence/Cooperation
- Respect Other Experts Competence

Mechatronic System Elements

The 4 Central Components are energetically isolated



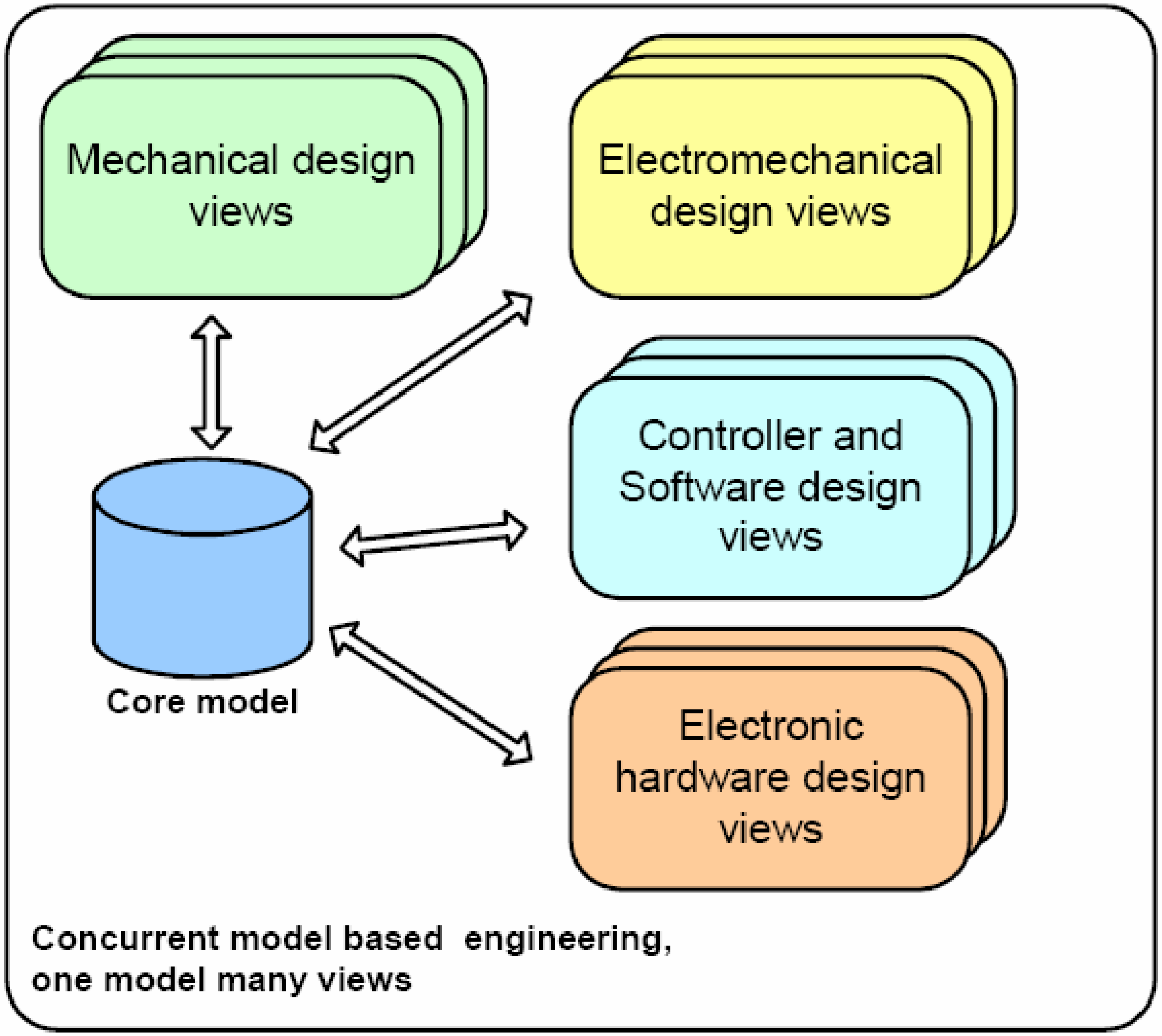
Integrated Product Design



Mechatronics Integrated Design

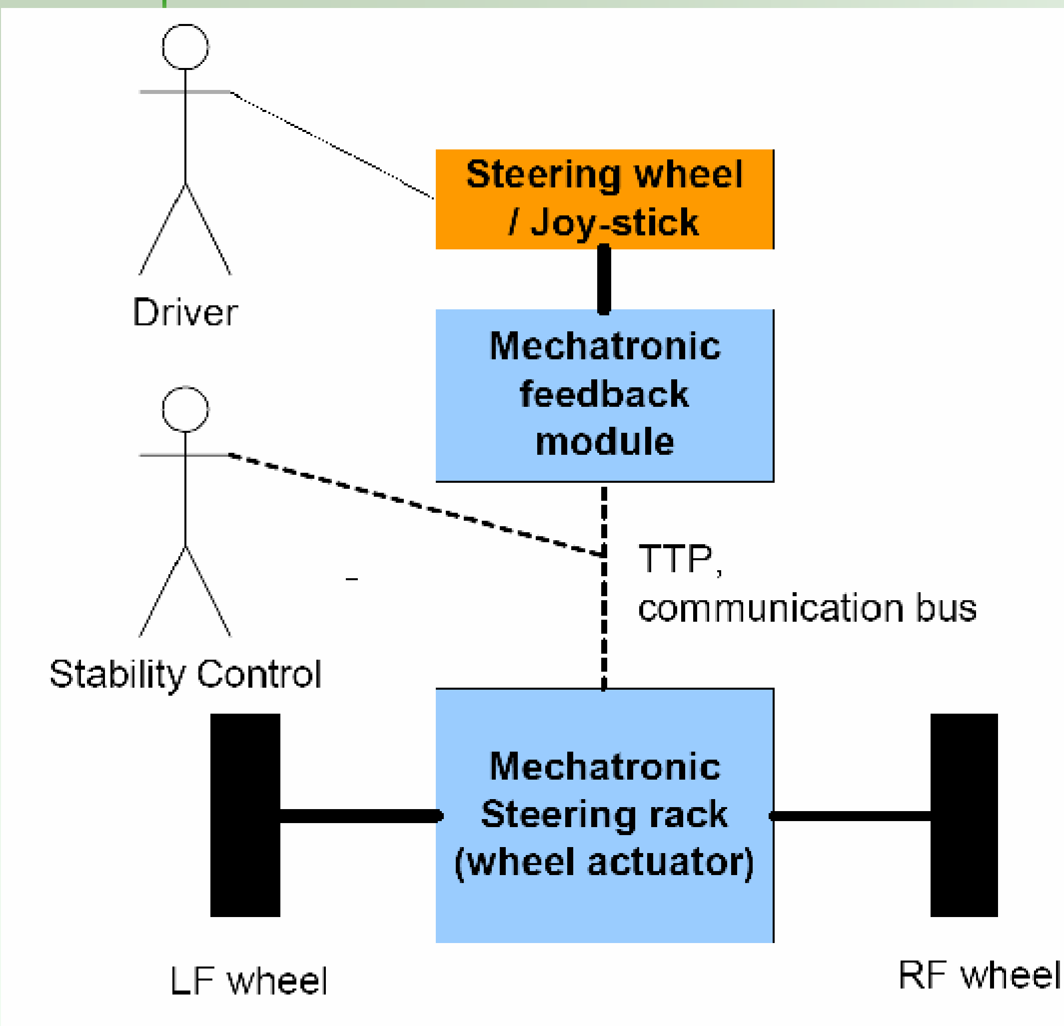
- Complex Problems
- Multi-Domain SubSystems
- Optimization in Subsystems may not Lead to an Optimal Total Design
- Concurrent (Integrated) Optimization is needed
- Multi-Domain Physical Modeling
- Powerful Software Framework Needed

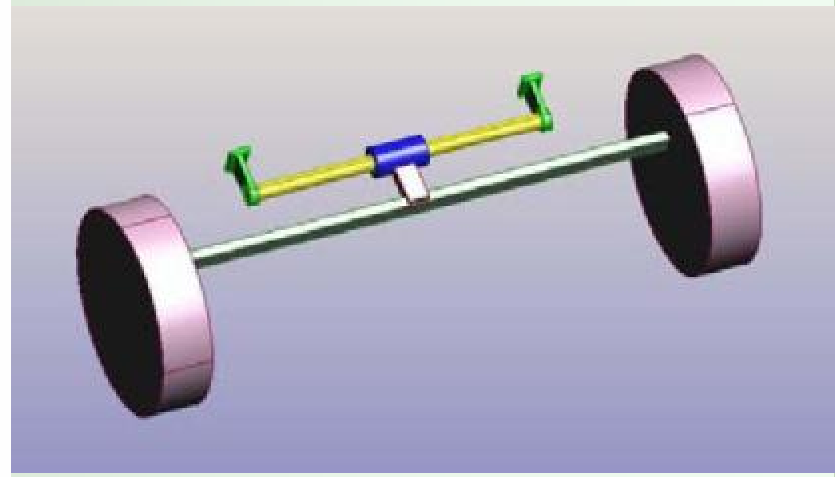
Different Design Views



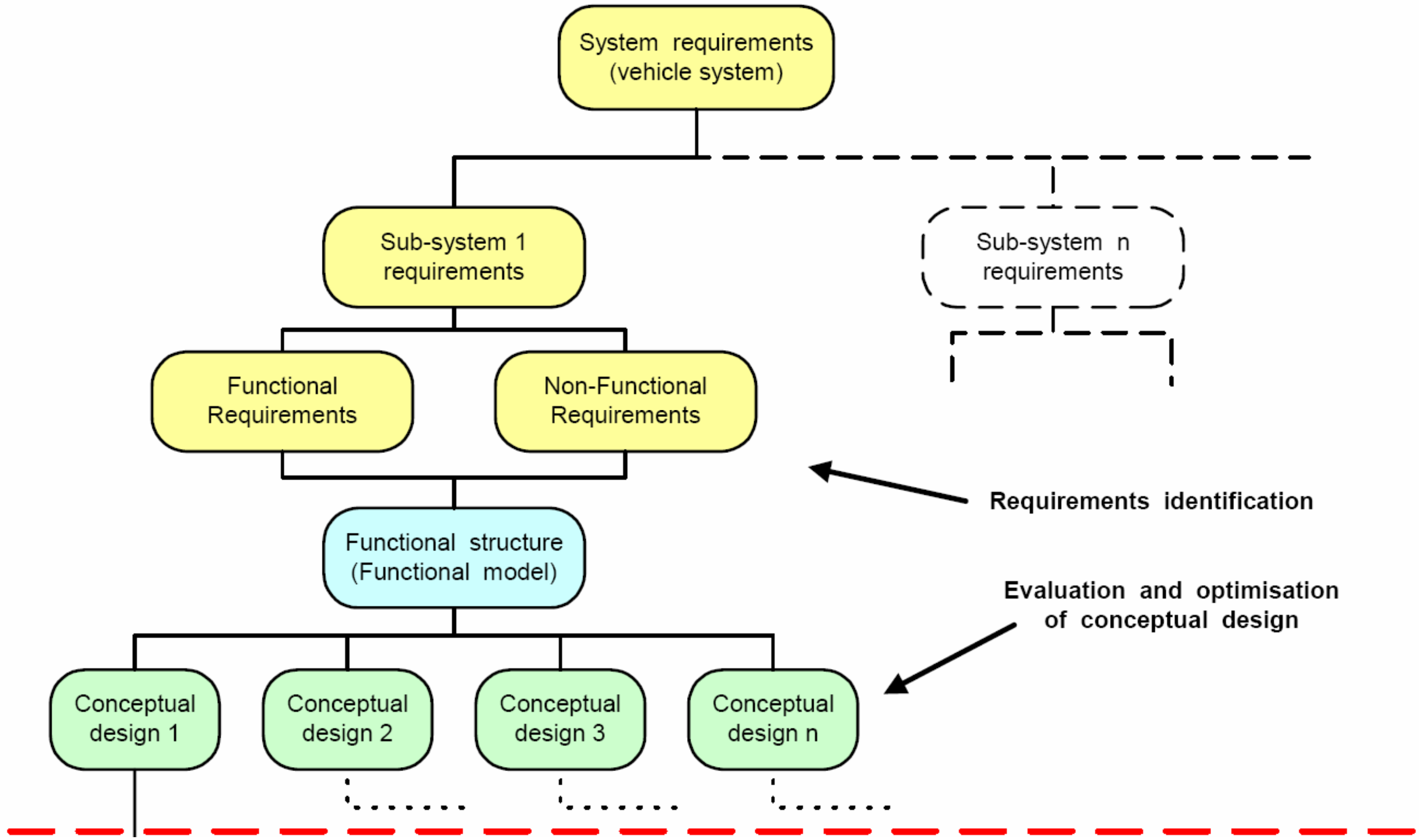
Steer-by-Wire System

(Roos & Wikendar)

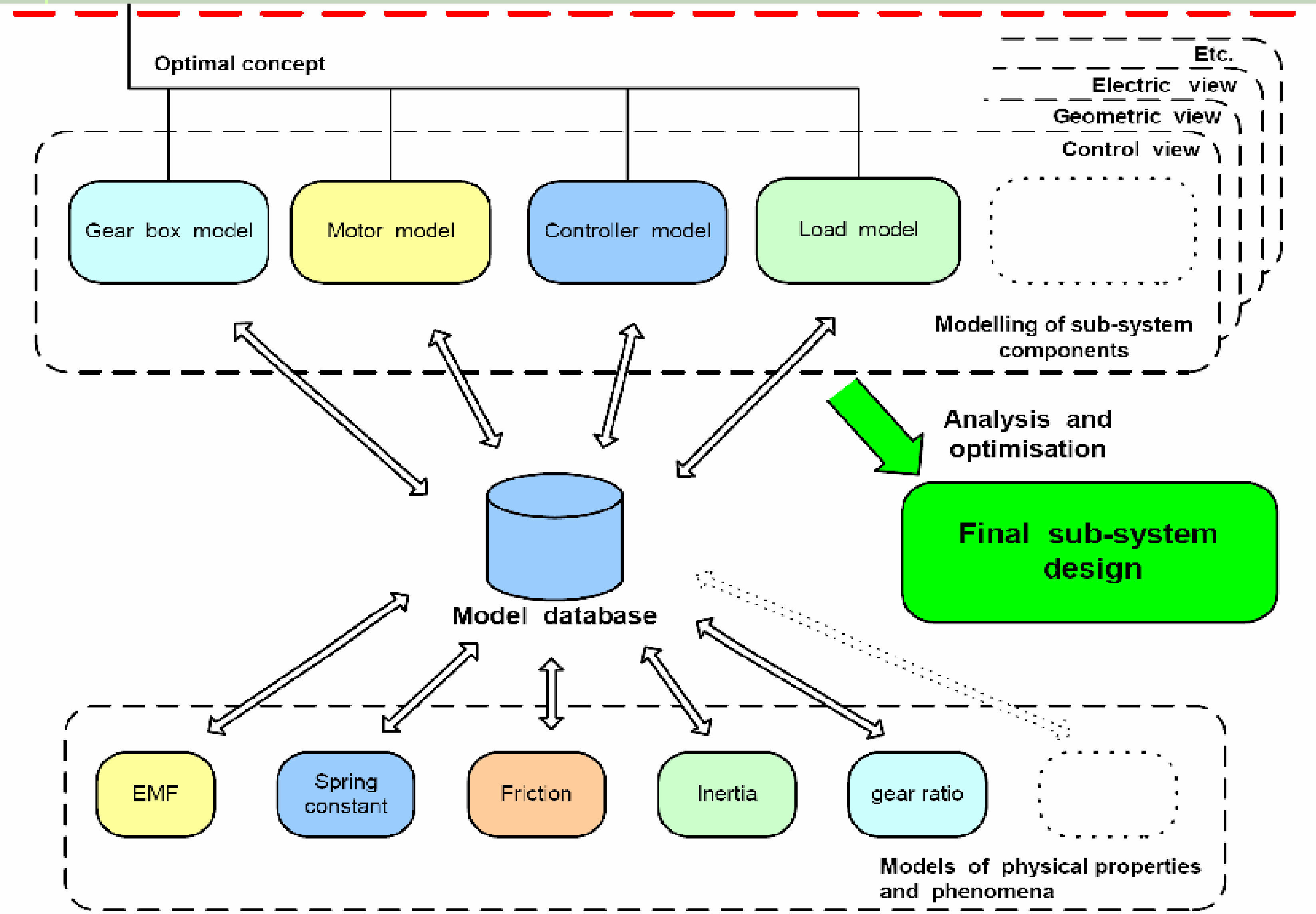




Conceptual Design



Sub-system Design



The Mathematical Model

Physical equations

$$J_\ell \frac{d\omega_\ell}{dt} = T_g$$

$$J_m \frac{d\omega_m}{dt} = k_m I - T_m$$

$$\omega_m = n\omega_\ell$$

$$T_g = nT_m$$

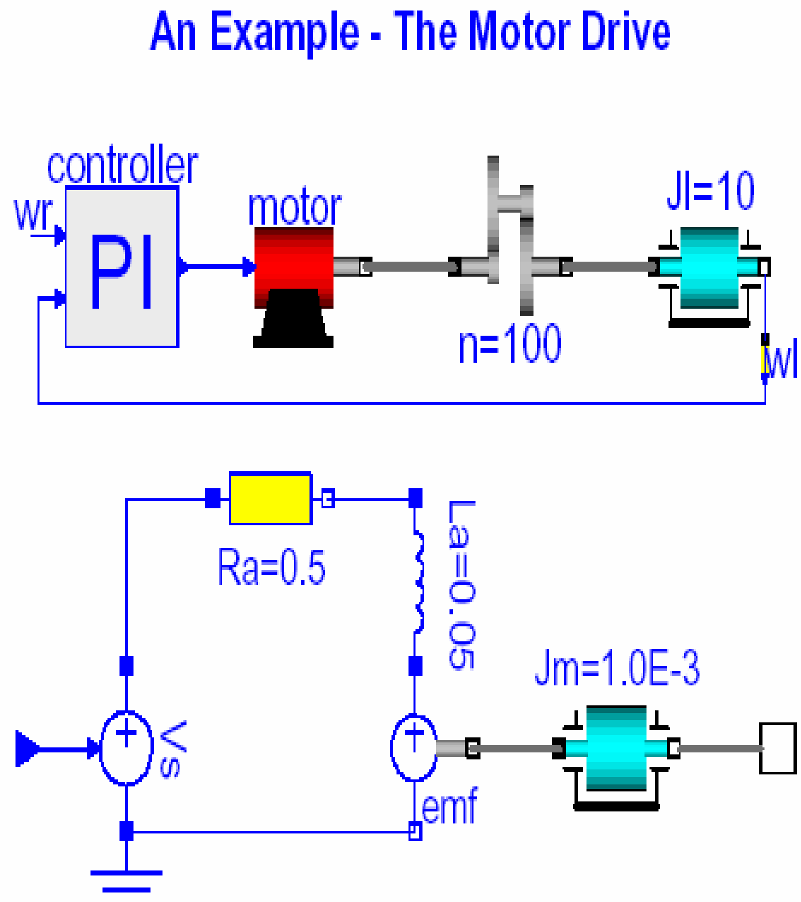
$$L_a \frac{dI}{dt} + R_a I = V_s - k_m \omega_m$$

$$V_s = k(\omega_r - \omega_\ell + \frac{1}{T_i}x)$$

$$\frac{dx}{dt} = \omega_r - \omega_\ell$$

Four differentiated variables

Three algebraic equations



The Mathematical Model

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$$V_s = k(\omega_r - \omega_\ell + \frac{1}{T_i} x)$$

$$\frac{dx}{dt} = \omega_r - \omega_\ell$$

Four differentiated variables
Three algebraic equations

State space model

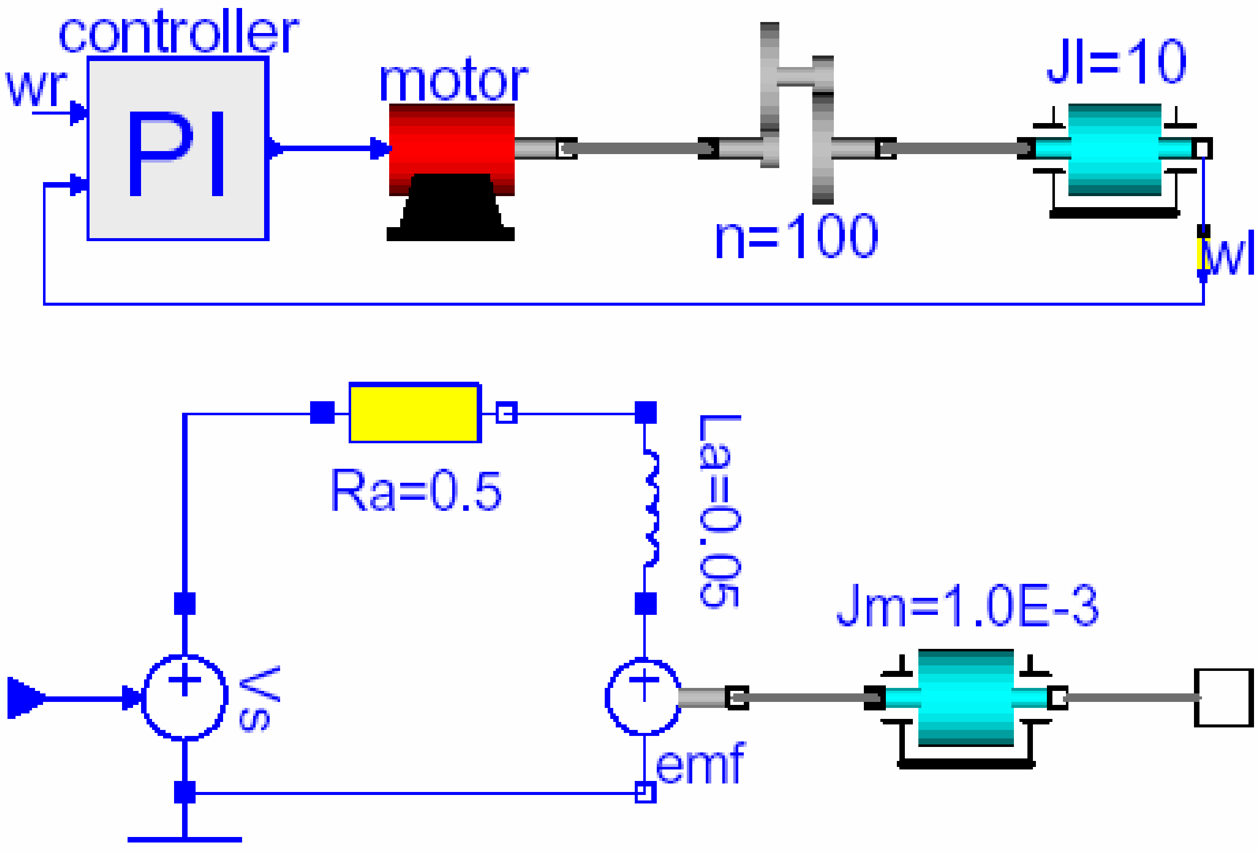
$$\frac{d\omega_\ell}{dt} = \frac{nk_m}{J_\ell + n^2 J_m} I$$

$$\frac{dI}{dt} = -\frac{R_a}{L_a} I + \frac{k}{L_a}(\omega_r - \omega_\ell + \frac{1}{T_i} x) - \frac{nk_m}{L_a}\omega_\ell$$

$$\frac{dx}{dt} = \omega_r - \omega_\ell$$

Three state variables
Parameters of motor and load mixed
Algebraic loops

An Example - The Motor Drive



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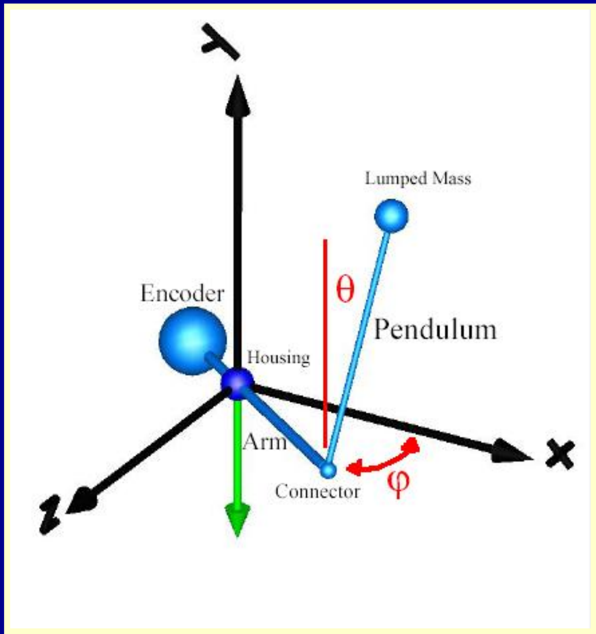
MECHATRONICS

A Case Study on
Design, Manufacturing &
PC-based Real-Time Control
of
Furuta Inverted Pendulum



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Mechanical Engineering Department
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ISEE 2006-ISME 2006

MECHATRONICS
Team Members

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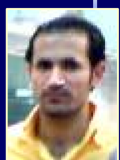
Associate Prof, Mech. Eng. Dep.
IUST
Control, Mechatronics

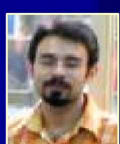
Control Group
Yaser Shanjani *Applied Mechanics- Control, Manufacturing*



Mahmood Arefian
Applied Mechanics- Control

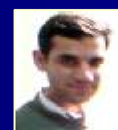
Sensors & Actuators Group
Roozbeh Ahmadi
Manufacturing- Robotics, Measurement

Mohsen Shokri
Manufacturing- Robotics



Simulation Group
Vahid Azimi *Manufacturing- Robotics*

Manufacturing Group
Mahdi Abasi *Manufacturing- Control, Simulation*



Esmaeil Bagheri *Manufacturing- Vibration, Metallurgy*

Real-Time Group
Amir Fasih *Manufacturing- Control, Railways*

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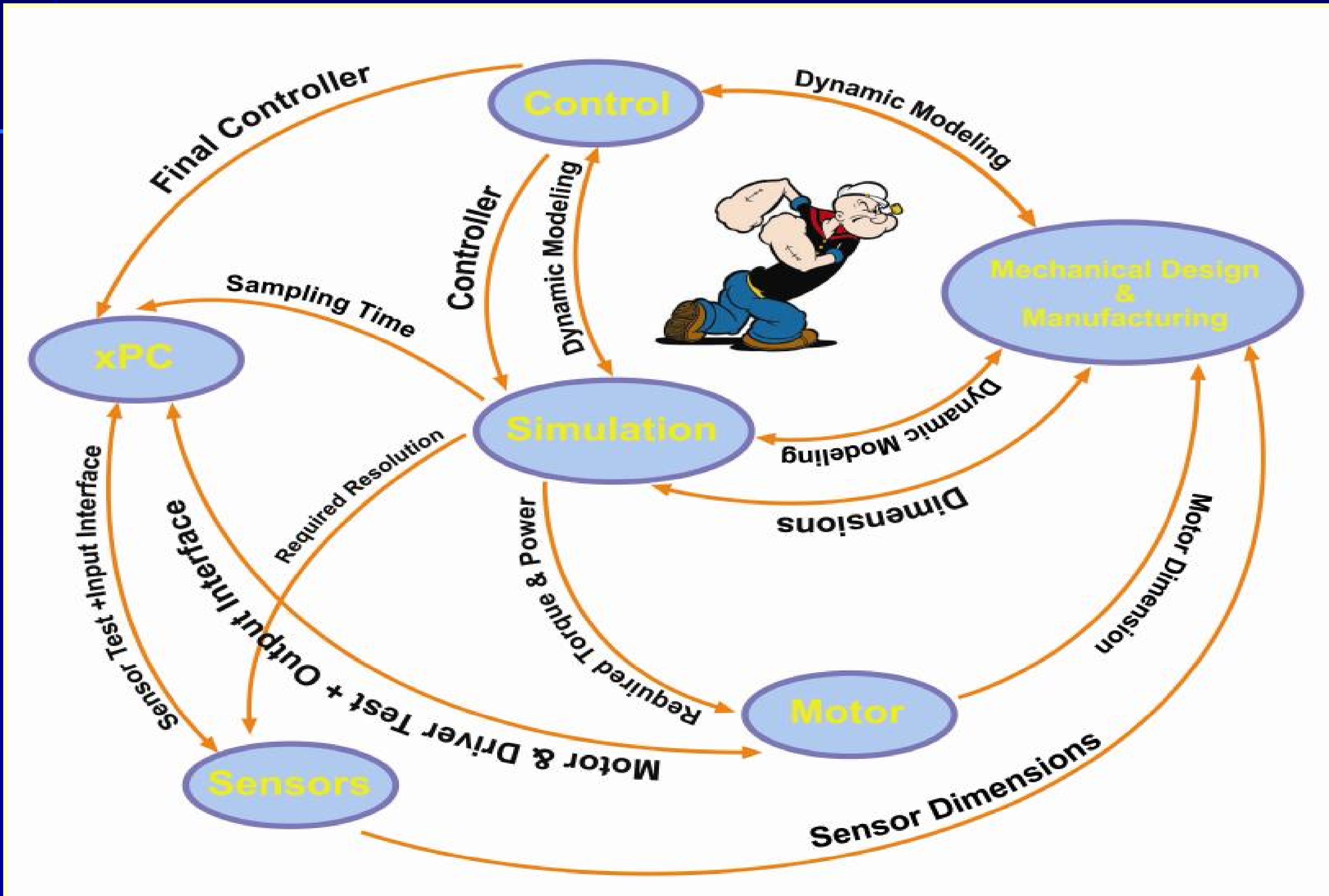
MECHATRONICS
Interdisciplinary flow of information



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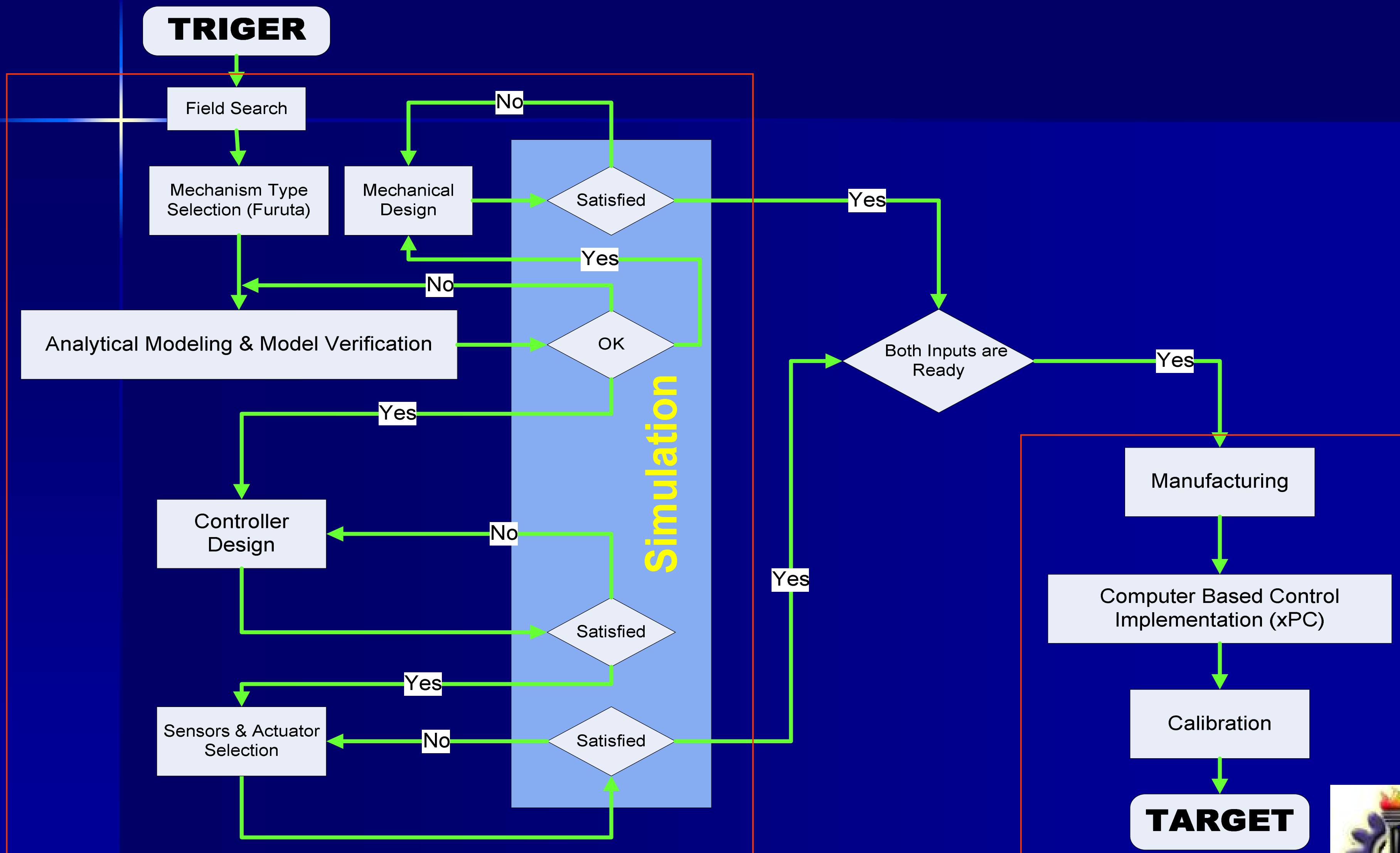
Interdiscipliary Collaborations

	Simulation	*Control*	*Mechanical Design & Manufacturing*	*Sensor*	*Motor*	*Real-time*
Simulation		Dynamic Modeling of controlled system	Dynamic Modeling + Mechanical parameter study	Dynamic/static characteristics Resolution	Required Torque & Power	Effects of quantizatio error/ Sampling Time
Control	Controller + Dynamic Modeling		Dynamic Modeling + Mechanical tuning	Dynamic/static characteristics Resolution		Controller Algorithm
Mechanical Design & Manufacturing	Dynamic Modeling + Dimensions Confirmation	Dynamic Modeling		Options for locatiion of sensors	Location and Size limitations	
Sensor	Dynamic/static characteristics Resolution Noise characteristics	Dynamic/static characteristics Resolution Noise characteristics	Sensors Dimensions			Sensor Test + Input Interface
Motor	Specifications Static/dynamic	Specifications Static/dynamic	Motor Dimensions			Motor & Driver Test + Output Interface
Real-time				Sensor Test + Input Interface	Motor & Driver Test + Output Interface	

MECHATRONICS
Project Flowchart



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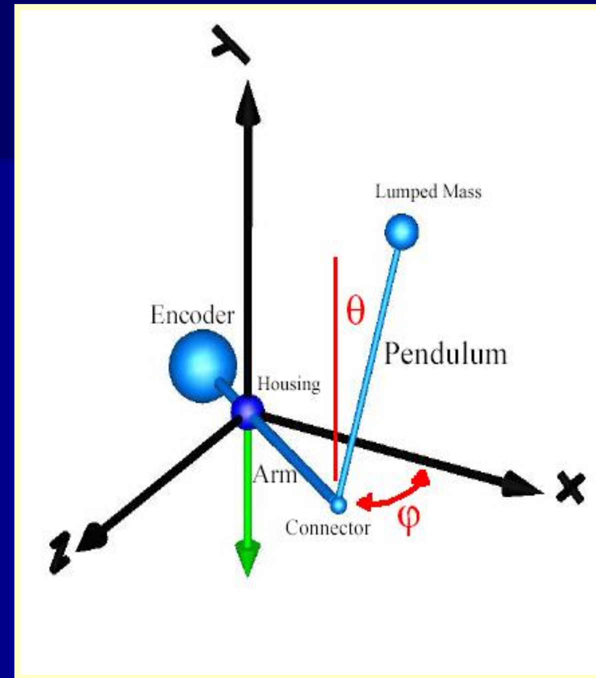
MECHATRONICS
Modeling

$$a \cdot \cos q \cdot \ddot{j} + \left(b + J_{EA}\right) \cdot \ddot{q} - b \cdot \sin q \cdot \cos q \cdot \dot{j}^{2} + g \cdot \sin q = 0 \qquad \#1$$

$$\left(b \cdot \sin q^{2} + l + K_g^2 \cdot J_r\right) \cdot \ddot{j} + a \cdot \cos q \cdot \ddot{q} + 2b \cdot \sin q \cdot \cos q \cdot \dot{j} \cdot \dot{q} - a \cdot \sin q \cdot \dot{q}^{2} = K_g \cdot K_m . i \qquad \#2$$

$$\dot{i} = -\frac{R}{L} \cdot i + \frac{V}{L} - \frac{K_g \cdot K_m}{L} \cdot \dot{j} \qquad \#3$$



$$\dot{\tilde{x}} = [A] \cdot \tilde{x} + [B] \cdot \tilde{u}$$

$$\tilde{y} = [C] \cdot \tilde{x} + [D] \cdot \tilde{u}$$

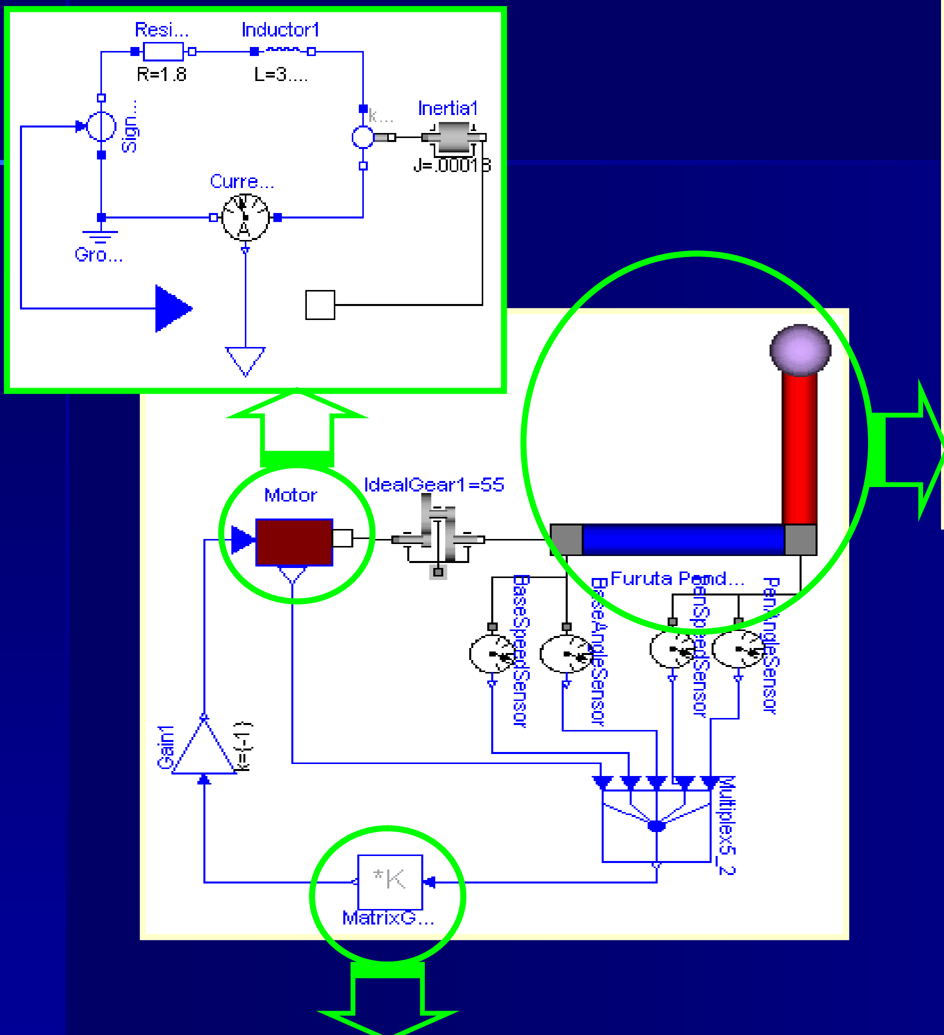
$$\tilde{x} = \begin{Bmatrix} q \\ \dot{q} \\ j \\ \dot{j} \\ i \end{Bmatrix} \quad A = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ \frac{-g \cdot l}{l \cdot b - a^2} & 0 & 0 & 0 & \frac{-a \cdot z}{l \cdot b - a^2} \\ 0 & 0 & 0 & 1 & 0 \\ \frac{g \cdot a}{l \cdot b - a^2} & 0 & 0 & 0 & \frac{-b \cdot z}{l \cdot b - a^2} \\ 0 & 0 & 0 & -\frac{z}{L} & -\frac{R}{L} \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \frac{1}{L} \end{bmatrix} \quad C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \quad D = [0]$$

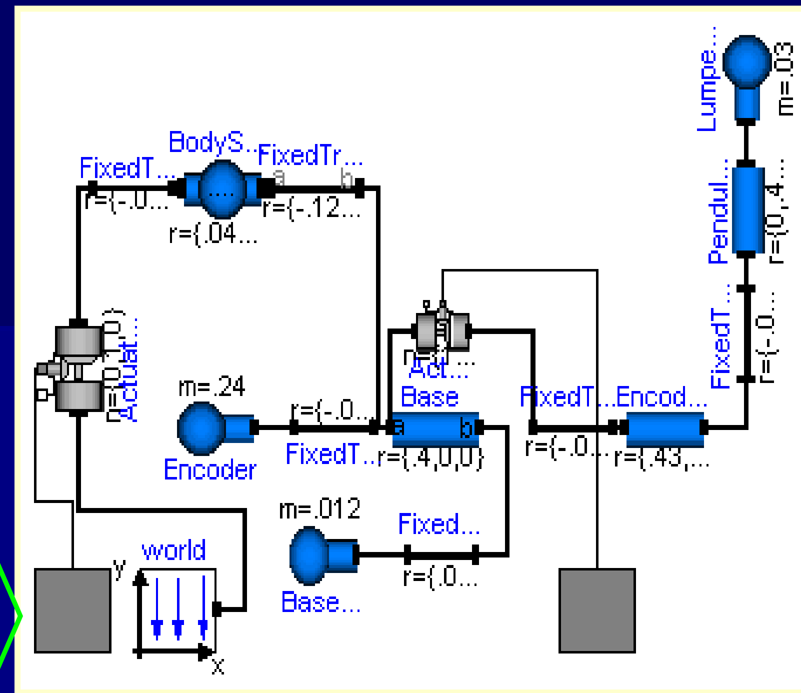
$$\begin{Bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \\ \dot{x}_5 \end{Bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 26.96 & 0 & 0 & 0 & -4.91 \\ 0 & 0 & 0 & 1 & 0 \\ -0.25 & 0 & 0 & 0 & 5.45 \\ 0 & 0 & 0 & -840.3 & -500 \end{bmatrix} \cdot \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{Bmatrix} + \begin{Bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 277.8 \end{Bmatrix} \cdot v$$

$$y = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{Bmatrix}$$

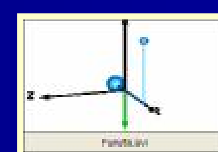
MECHATRONICS

Multi-domain physical modeling





State Feedback Controller Gain Matrix



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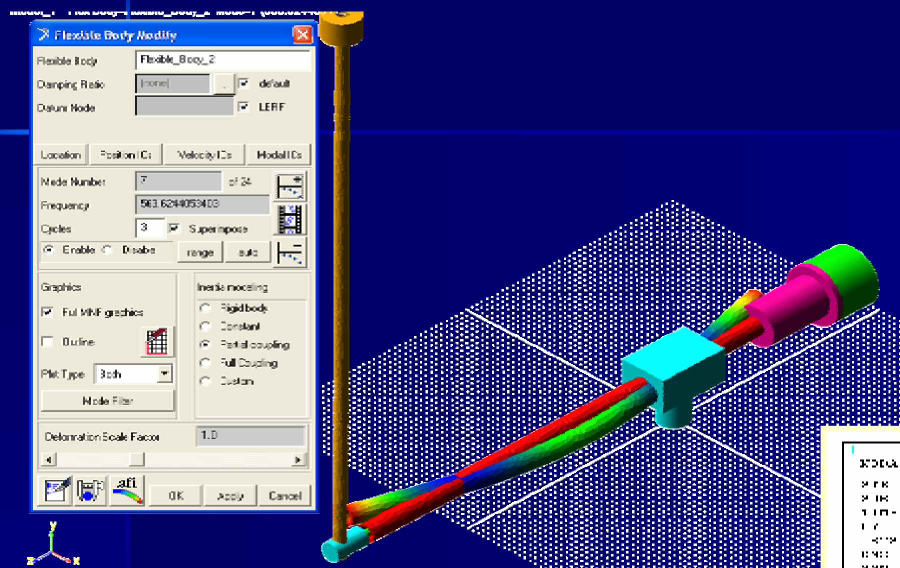
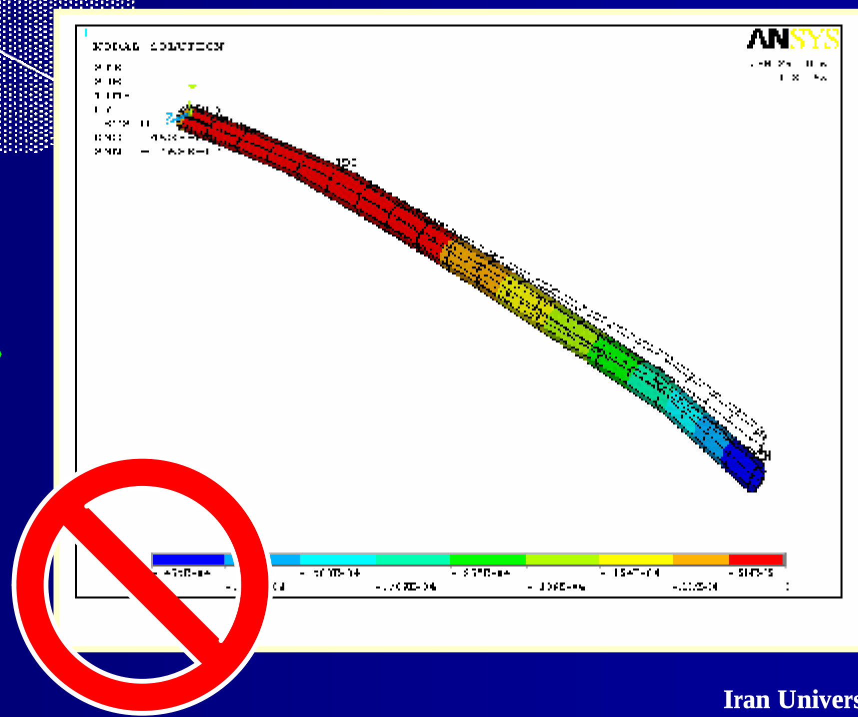
MECHATRONICS
Mechanical Analysis



Modal Analysis

Material Strength Analysis



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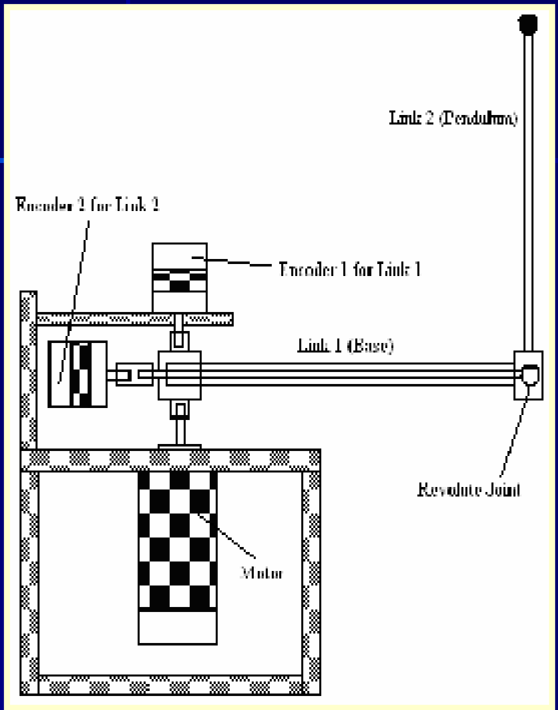
MECHATRONICS
Mechanical Design & Manufacturing



Conceptual Design

CAD

Manufacturing

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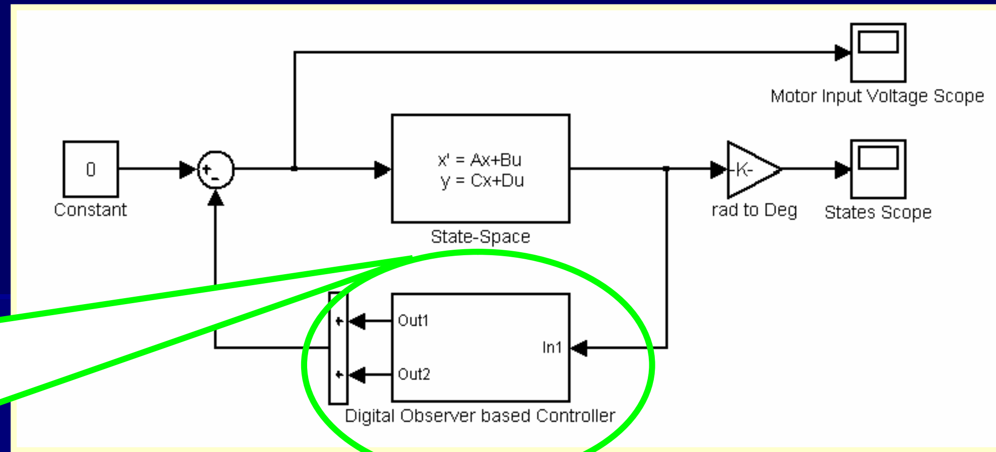
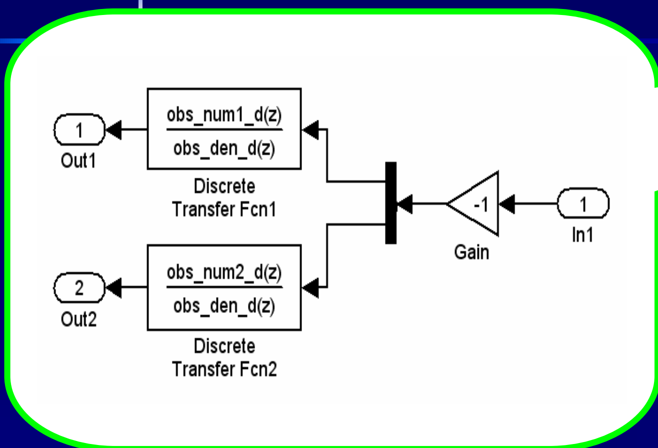
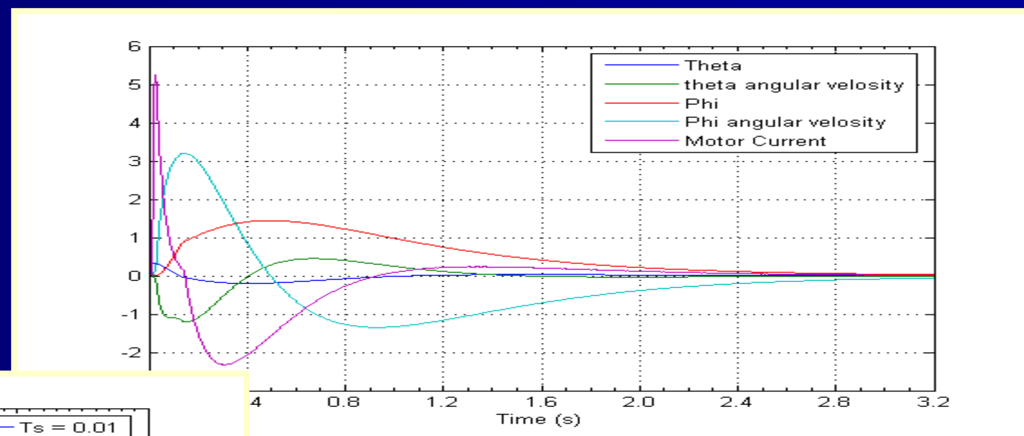
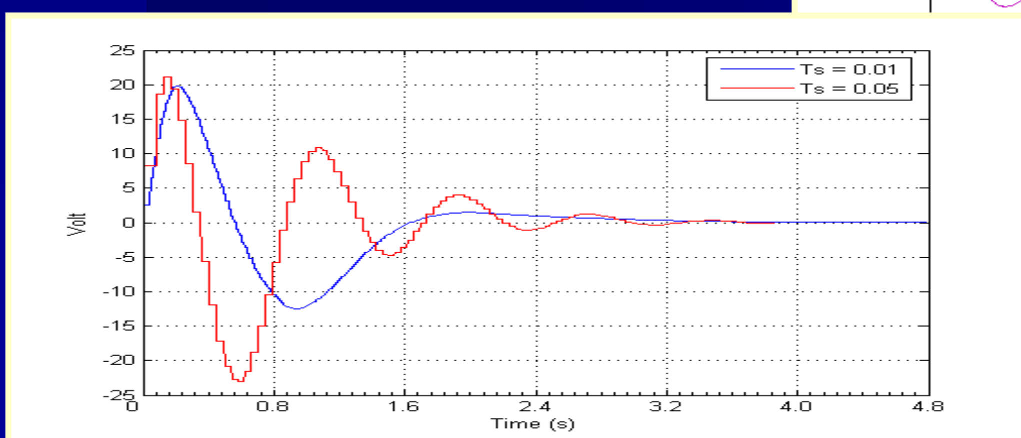
MECHATRONICS
Controller Design









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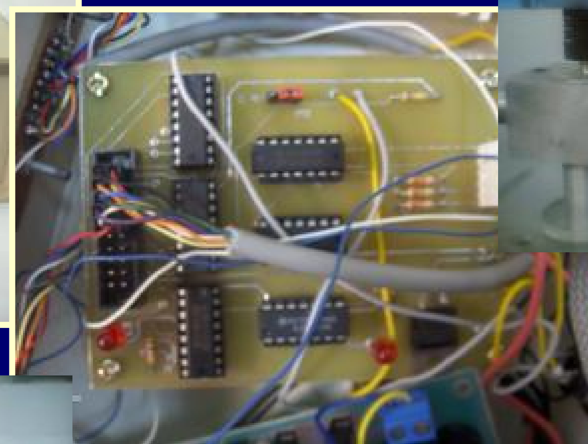
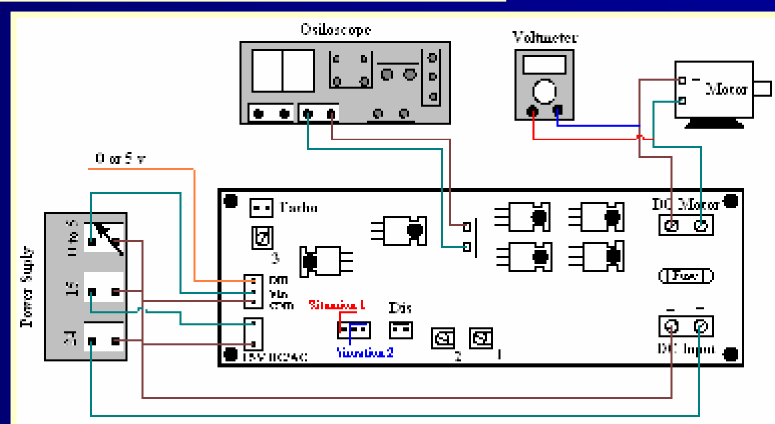
MECHATRONICS
Sensors & Actuator

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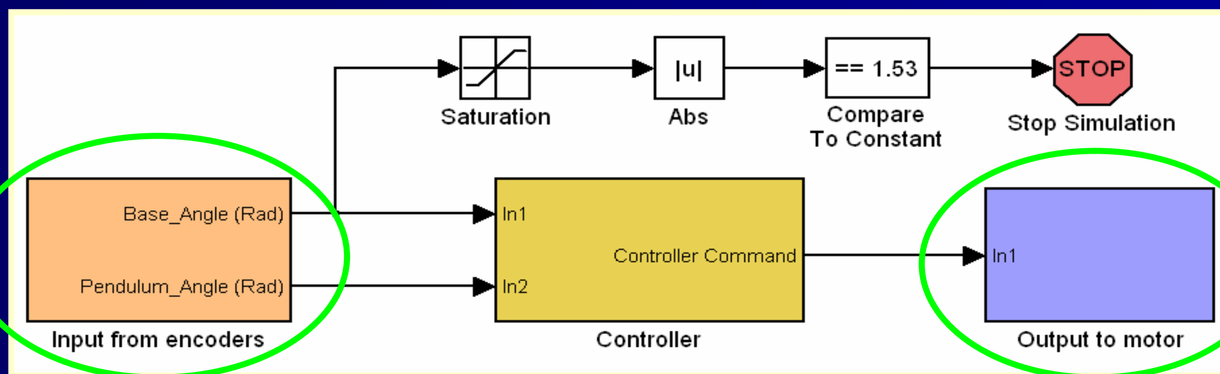
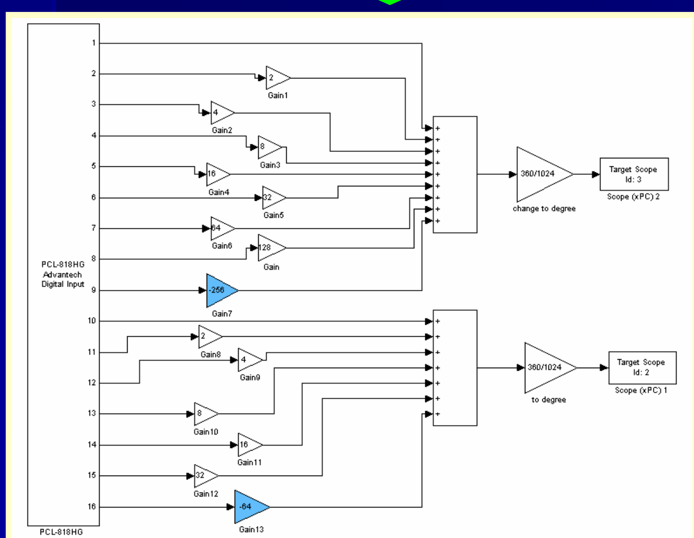
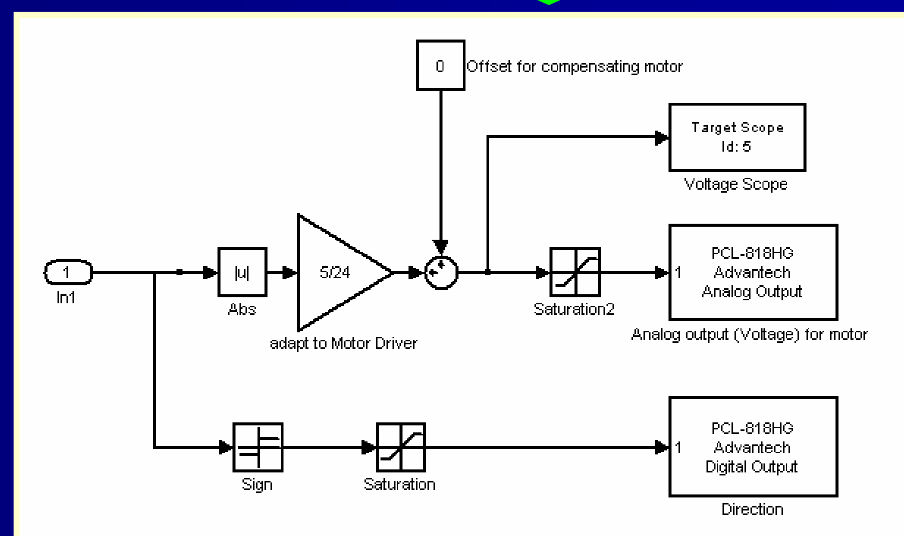
MECHATRONICS
Real-time control







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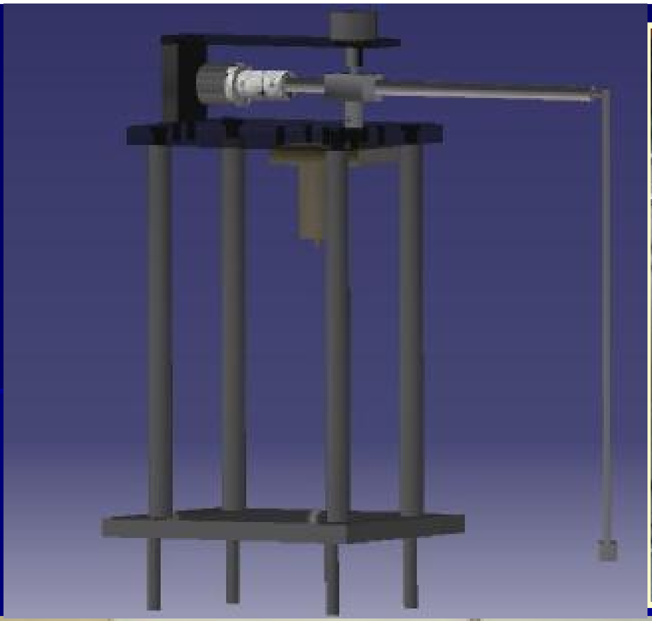
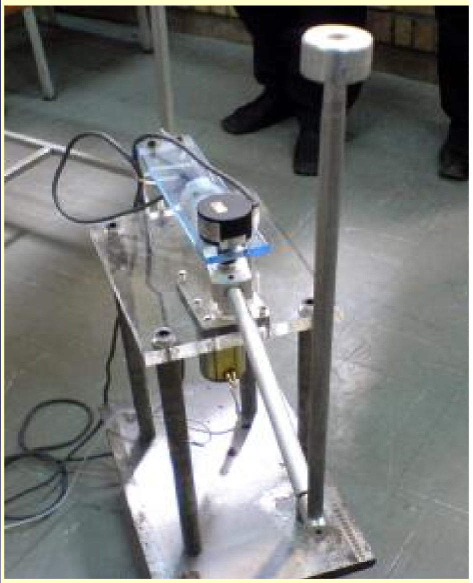
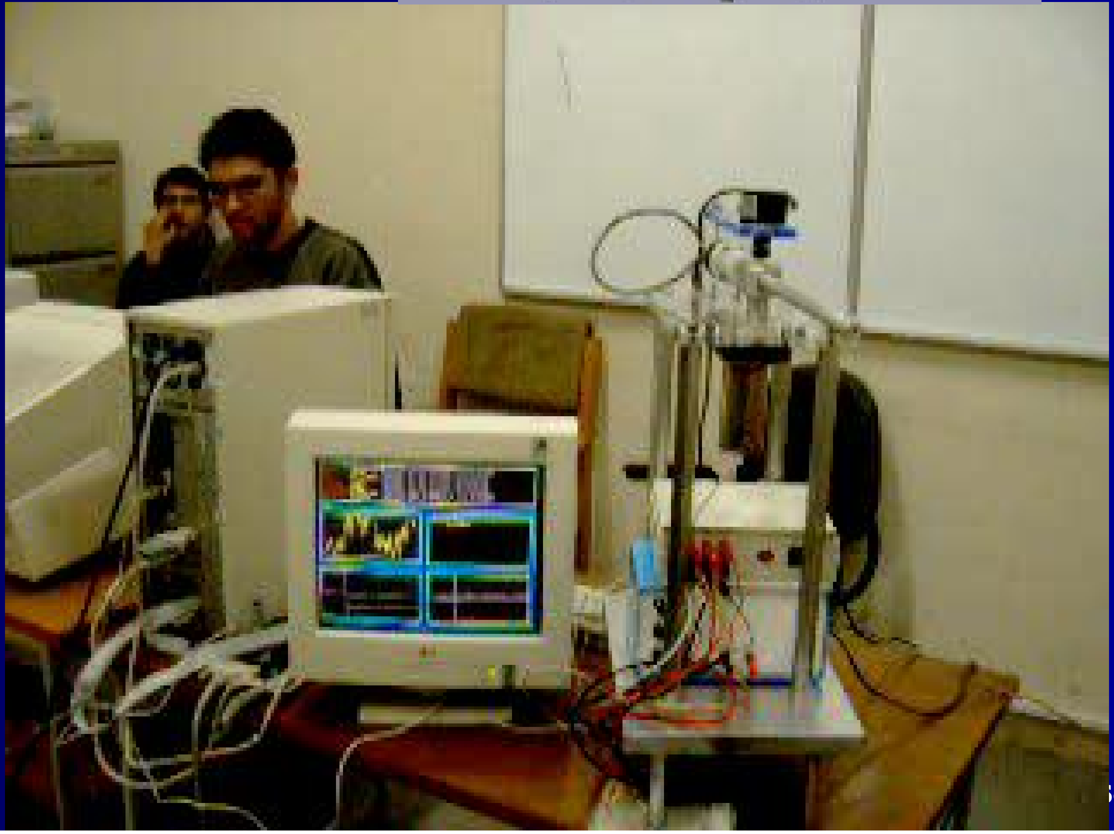
MECHATRONICS
Result







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MECHATRONICS
Time Table

ID		Task Name	Start	Finish
1	✓	**Furuta Inverted Pendulum**	Tue 05/03/01	Sat 05/12/31
2	✓	start	Tue 05/03/01	Tue 05/03/01
3	✓	**Mechanic**	Wed 05/03/02	Wed 05/12/21
4	✓	search +select (overal)	Wed 05/03/02	Tue 05/04/05
5	✓	search + select	Wed 05/04/06	Mon 05/07/04
6	✓	mechanical construction	Tue 05/07/05	Mon 05/08/08
7	✓	modification	Fri 05/12/02	Wed 05/12/21
8	✓	**Control**	Wed 05/03/02	Sat 05/12/31
9	✓	search+ select	Wed 05/03/02	Tue 05/04/05
10	✓	modeling & verification	Wed 05/04/06	Tue 05/06/14
11	✓	controller design (LQR)	Tue 05/06/14	Wed 05/08/03
12	✓	controller design (fuzzy)	Tue 05/10/04	Sat 05/12/10
13	✓	test	Mon 05/12/05	Sat 05/12/31
14	✓	**Sensor**	Wed 05/03/02	Mon 05/11/14
15	✓	search+ select	Wed 05/03/02	Tue 05/04/05
16	✓	Electronical Design	Wed 05/04/06	Wed 05/06/29
17	✓	circuit construction	Thu 05/06/30	Fri 05/09/09
18	✓	test	Mon 05/09/12	Mon 05/11/14
19	✓	**Simulation**	Wed 05/03/02	Sun 05/09/04
20	✓	search+ select	Wed 05/03/02	Tue 05/04/05
21	✓	verification	Wed 05/04/06	Thu 05/07/14
22	✓	simulation	Thu 05/08/04	Sun 05/09/04
23	✓	**Motor**	Wed 05/03/02	Sun 05/12/04
24	✓	search+ select	Wed 05/03/02	Tue 05/04/05
25	✓	motor driver selection	Wed 05/04/06	Thu 05/07/14
26	✓	test1	Fri 05/07/15	Mon 05/08/08
27	✓	test2	Tue 05/11/15	Sun 05/12/04
28	✓	**xPC**	Wed 05/03/02	Sat 05/12/31
29	✓	search+ select	Wed 05/03/02	Tue 05/04/05
30	✓	motor connection test	Fri 05/07/15	Mon 05/08/08
31	✓	sensor connection test	Mon 05/09/12	Mon 05/11/14
32	✓	test	Mon 05/12/05	Sat 05/12/31

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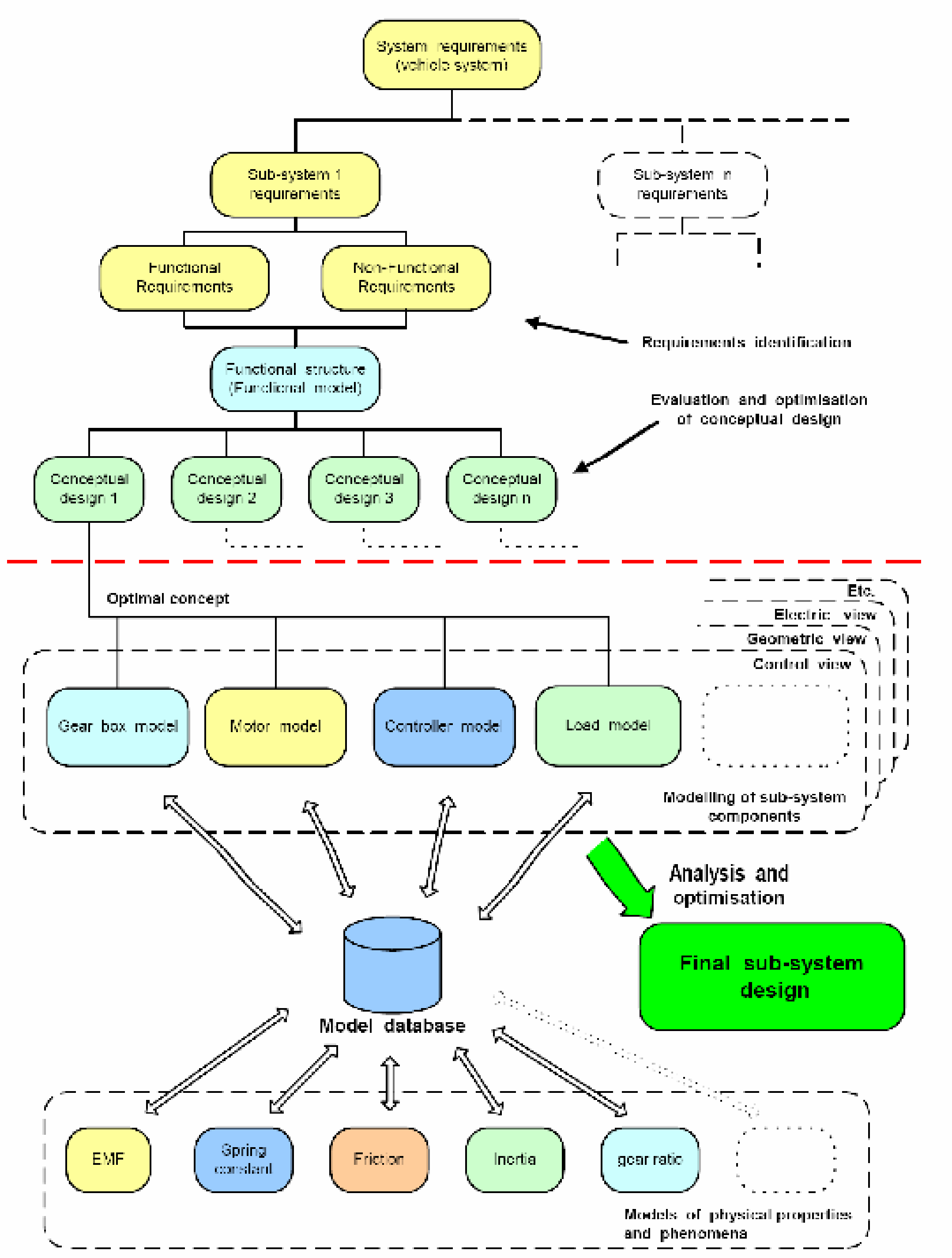
01-Nov-05

Conclusion

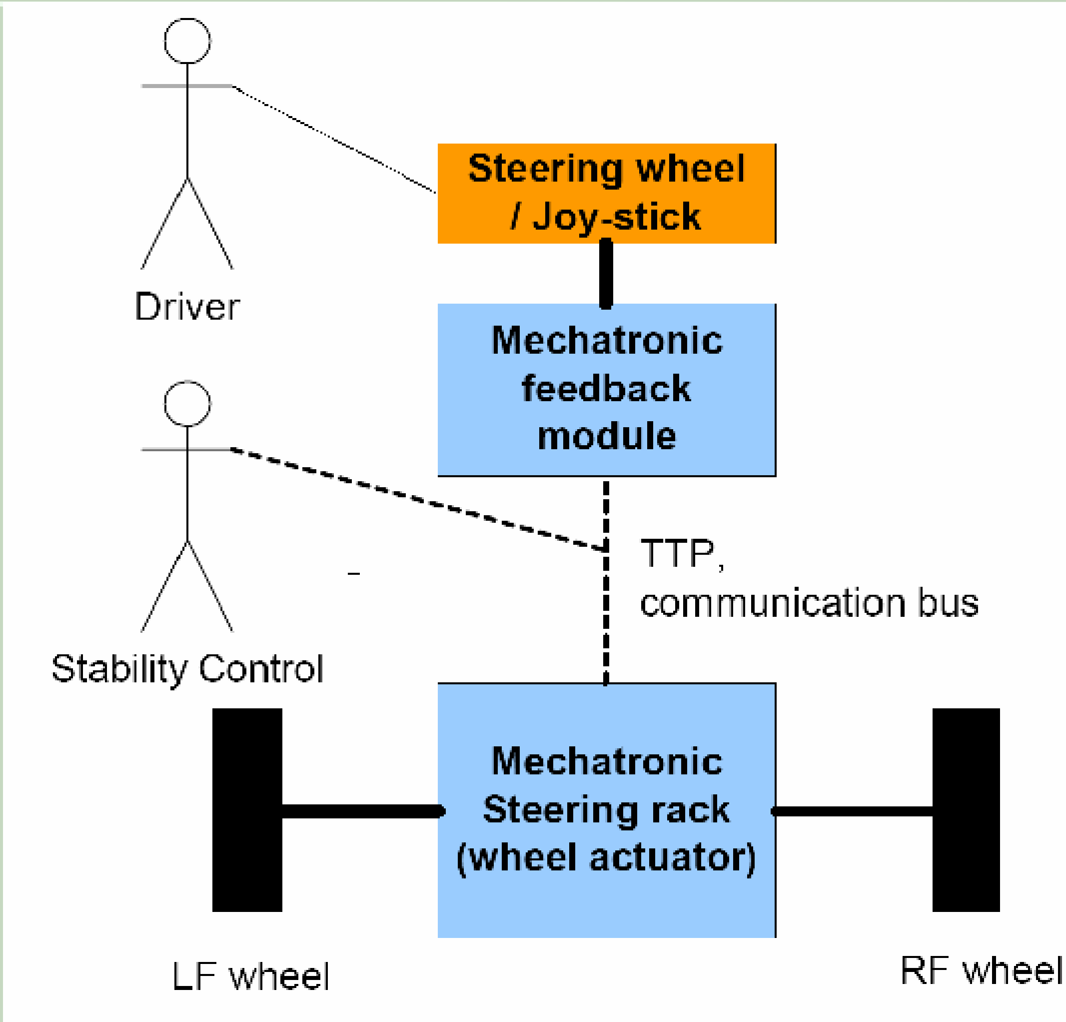
- Higher performance, less expensive and on-time products need Mechatronics.
- Educational and technical discipline.
- A design philosophy
- Involves technical as well as teamwork barriers
- Multi-domain Physical modeling is a must.
- Mechatronic is best learnt by doing.

از توجه شما متشکرم

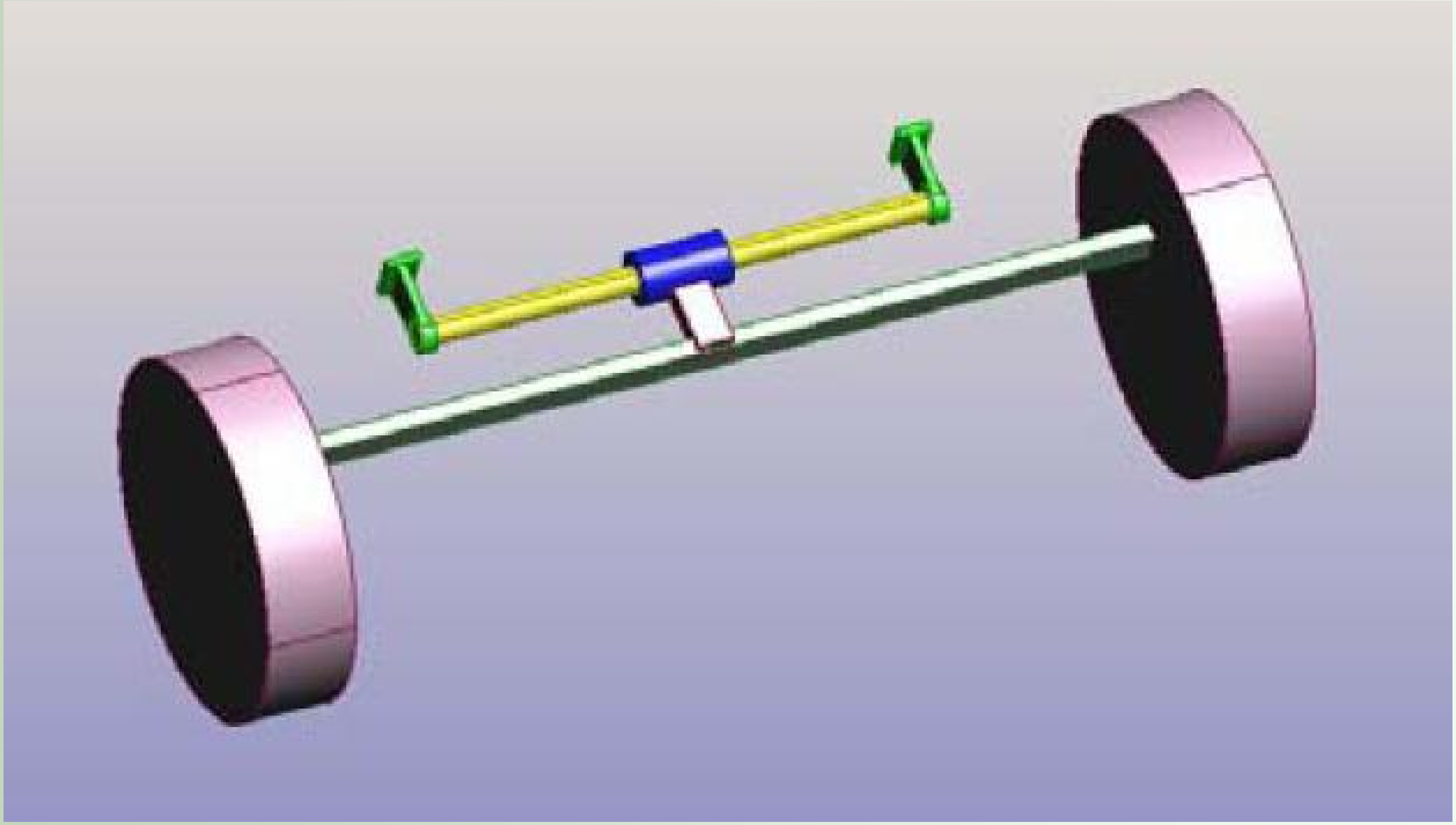

System requirements (vehicle system)
Sub-system 1 requirements
Sub-system n requirements
Functional Requirements
Non-Functional Requirements
Requirements identification
Functional structure (Functional model)
Evaluation and optimisation of conceptual design
Conceptual design 1
Conceptual design 2
Conceptual design 3
Conceptual design n
Optimal concept
Etc.
Electric view
Geometric view
Control view
Gear box model
Motor model
Controller model
Load model
Modelling of sub-system components
Analysis and optimisation
Final sub-system design
Model database
EMF
Spring constant
Friction
Inertia
gear ratio
Models of physical properties and phenomena

Steer-by-Wire System

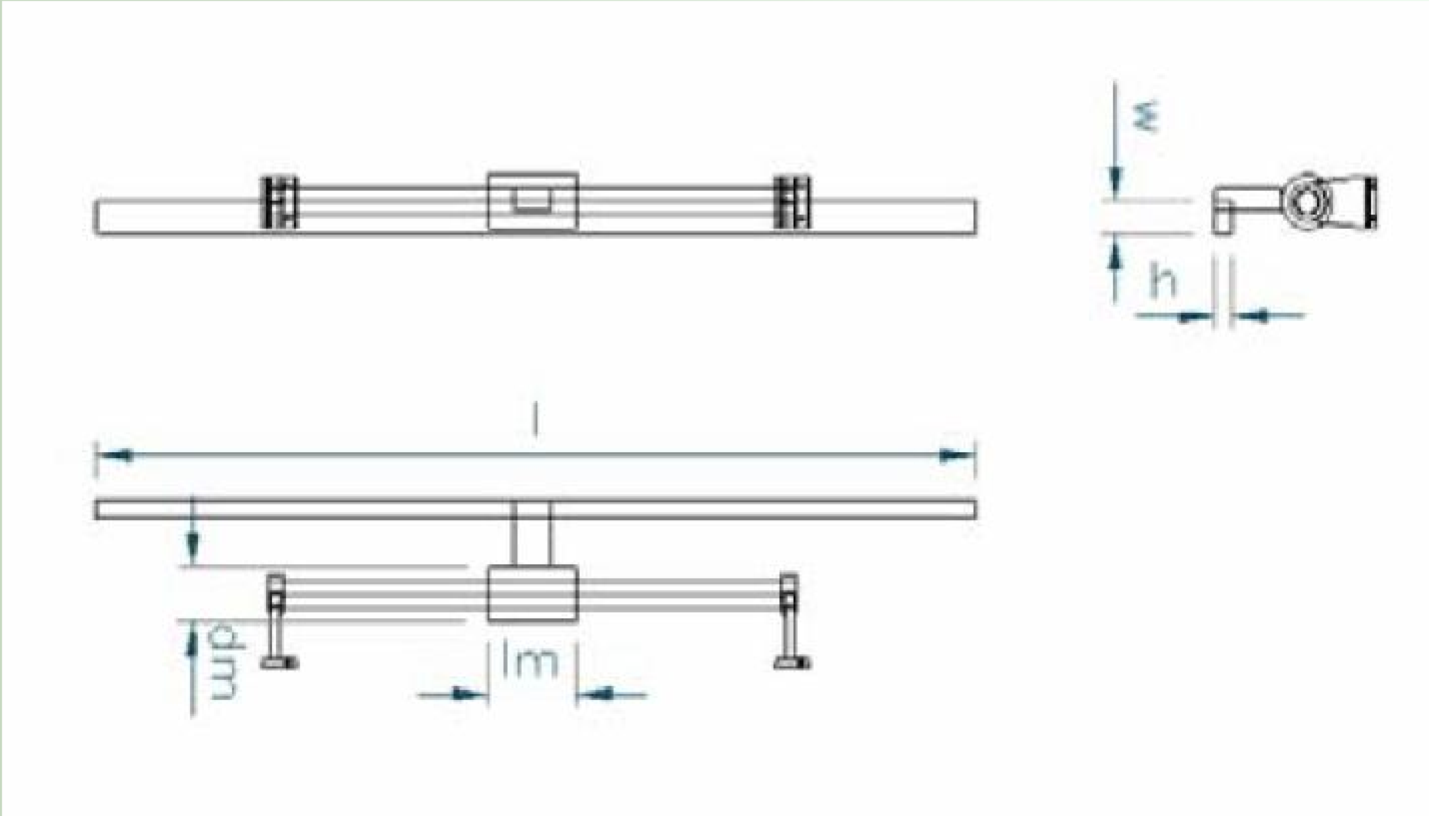
(Roos & Wikendar)



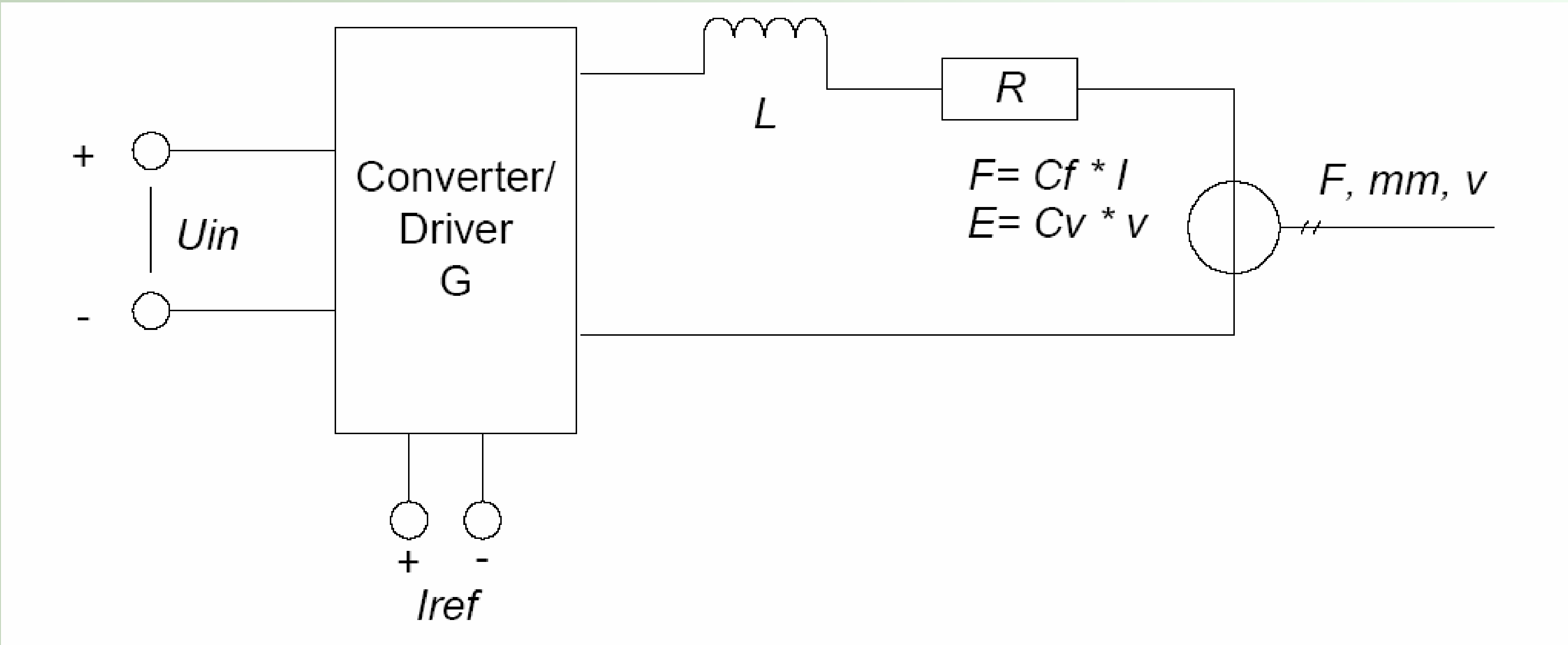
3-D Geometric View



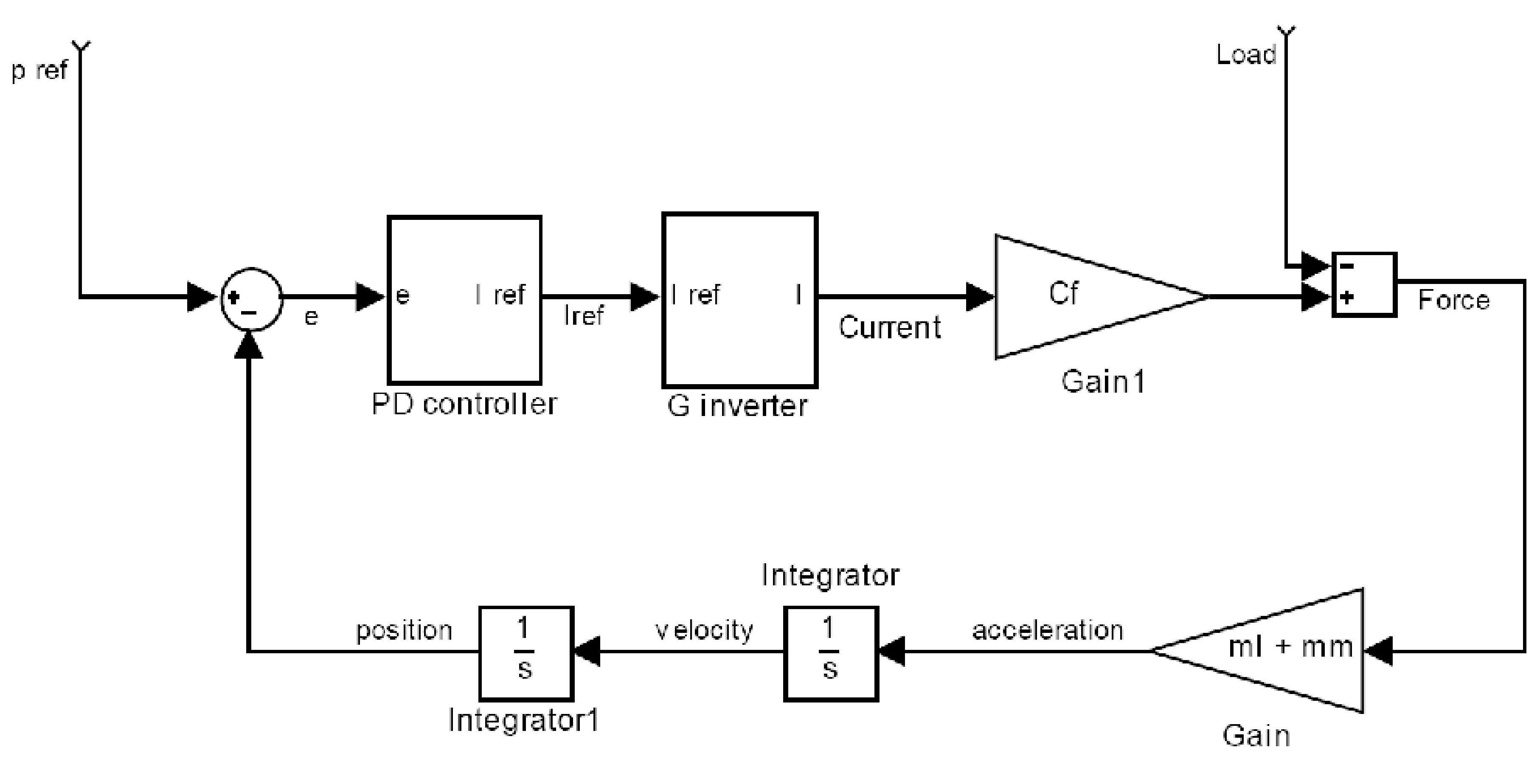
Geometric CAD view



ElectroMechanical View



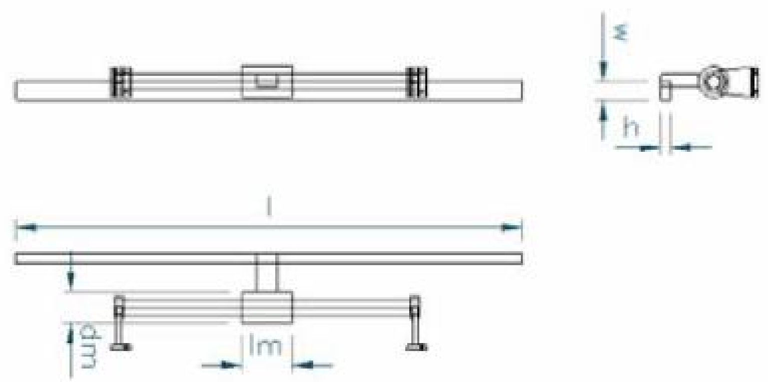
Control View

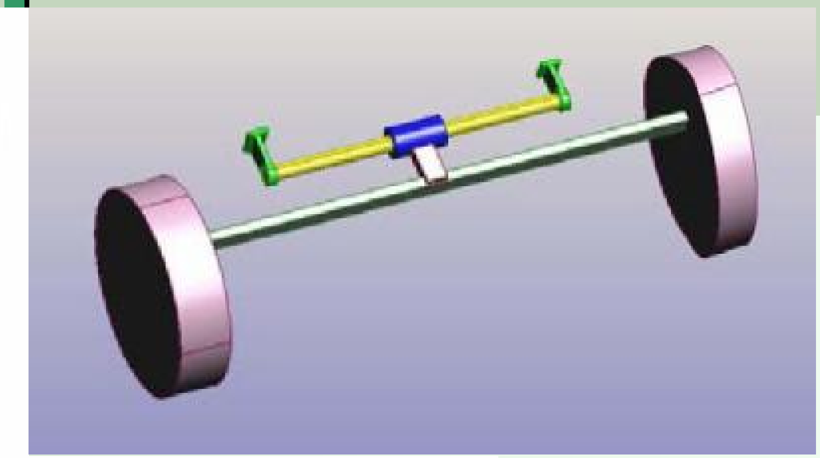


Parameter Optimization

		Req. Steering velocity	Req. Steering Torque	Energy efficency	Total mass
CAD	*Linkage geometry*	X	X	O	O
	Linkage mass, m	X	X	O	X
Motor geometry	*Mover mass*	X	X	O	X
	Stator geometry	O	O	O	X
	Number of Windings	O	O	O	O
Elektro-mechanics	*Max current, Im*	O	X	O	O
	Motor Resistance	O	O	X	O
	Force constant, C_f	O	X		O
	Voltage constant, C_v	X	O		O
	Controller design	X	X	X	

Parameters Optimization





	w	h	l	ml	dm	lm	mm	R	L	Cf	Cv	Im
Linkage width	w			X								
Linkage hight		h		X								
Linkage length			l	X								
Linkage mass				ml								O
Mover diameter					dm		X	X	X	X	X	X
Mover length						lm	X	X	X	X	X	X
Mover mass							mm					O
Motor Resitance								R				X
Motor Inductance									L			X
Motor Force Const.										Cf		O
Motor Voltage Const.											Cv	
Rated Motor Current										X	X	Im

Depend →

X – direct relation
O – inderect relation (e.g. sets requirments on)