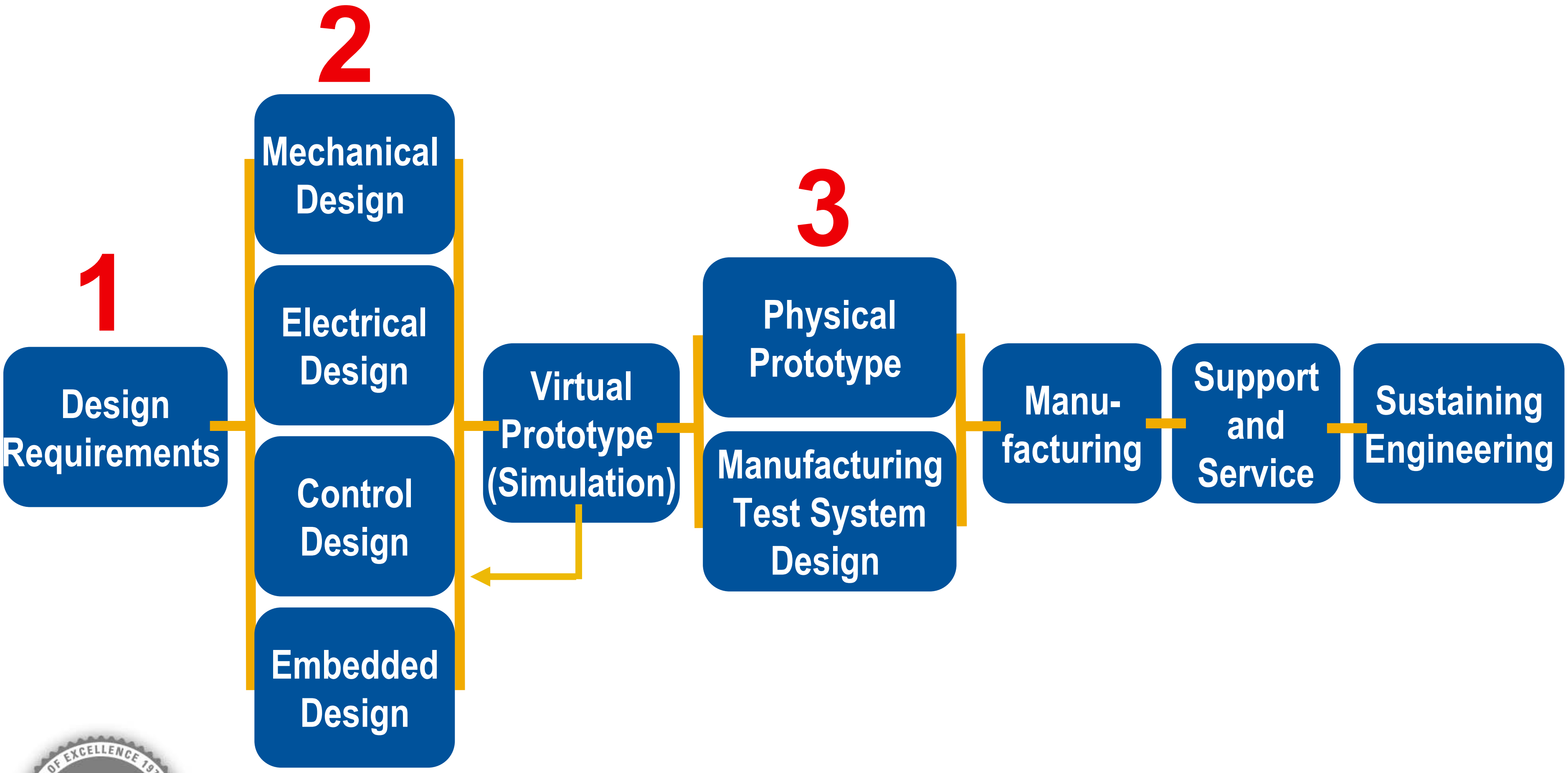
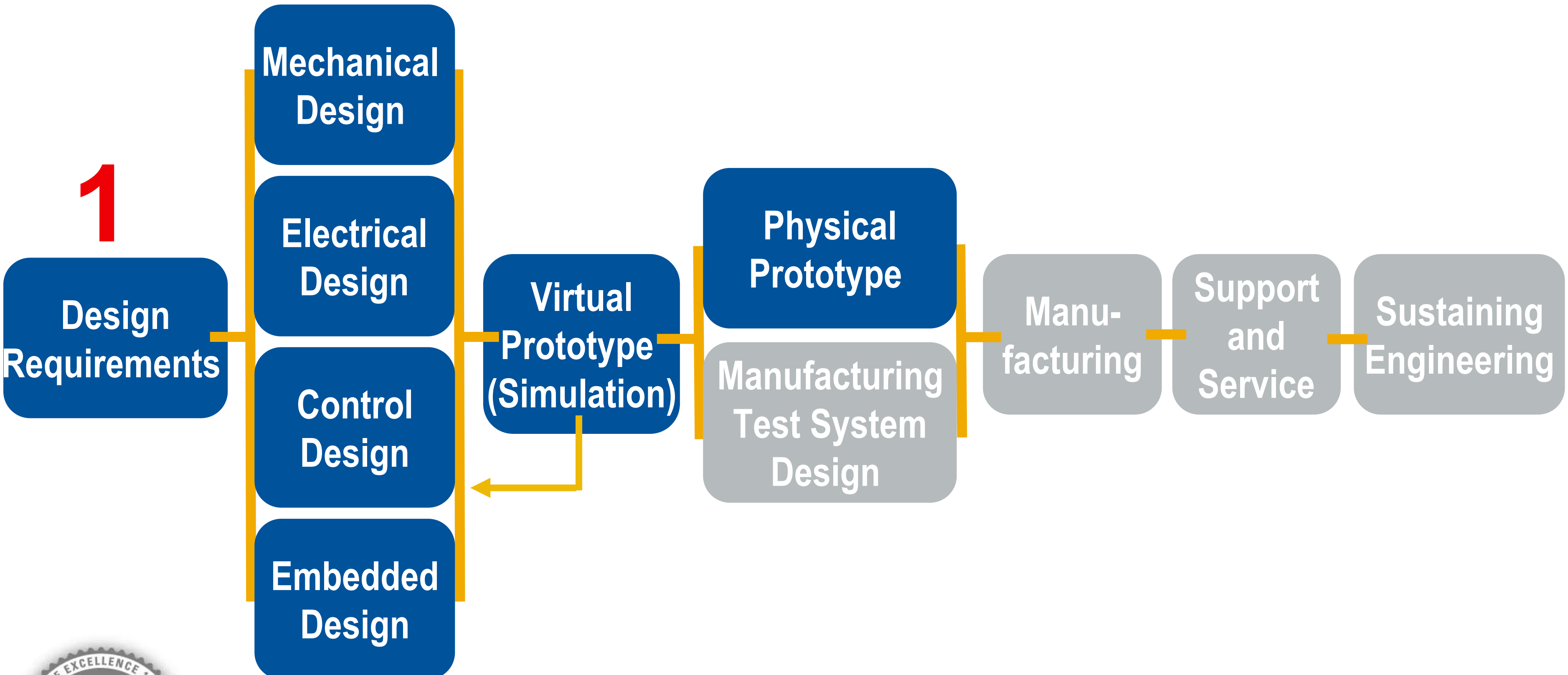
Essential Technologies for Industrial Machine Design and Prototyping

Mechatronics: Streamlined Approach to Machine Design



Design Requirements



Design Requirements

- Functionality: *Milling aluminum parts*
- Part size: *Up to 10 by 15 cm*
- Throughput: *3 parts per minute*
- Precision: *5 µm*
- Safety: *Light curtains, emergency stop*
- Cost: <*$50,000*

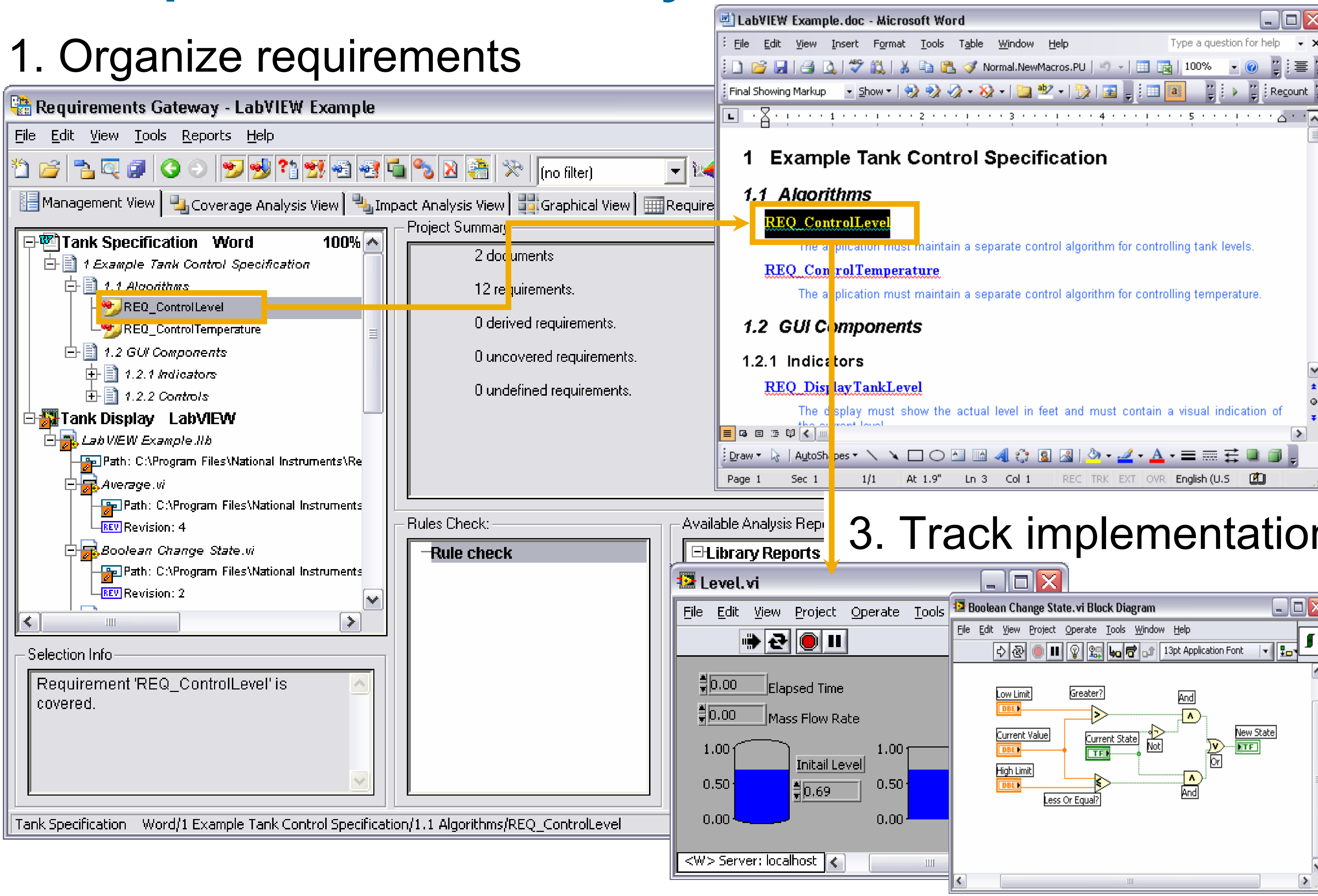
Automotive Part

NI Requirements Gateway

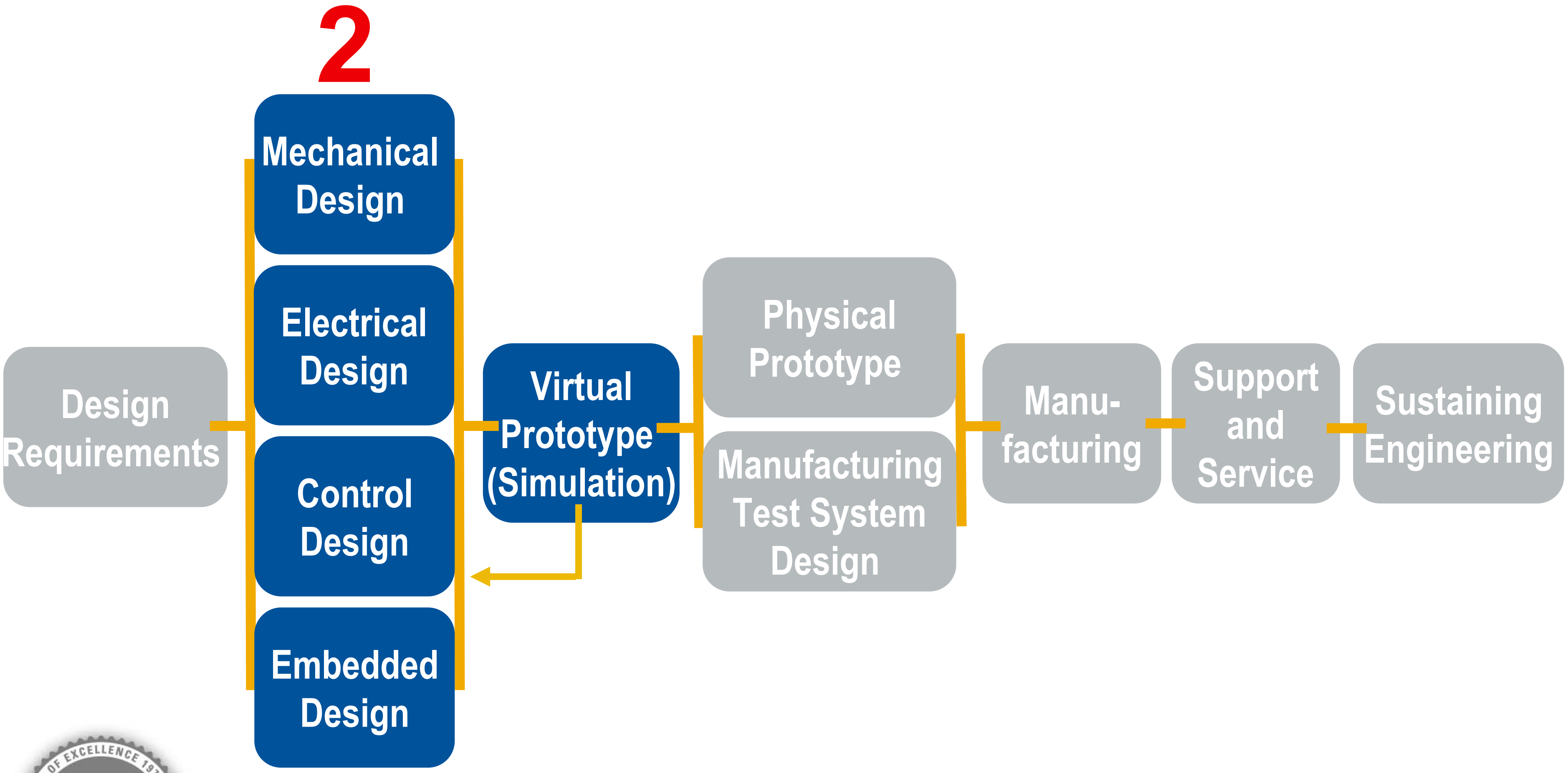
1. Organize requirements

2. Associate details

3. Track implementation



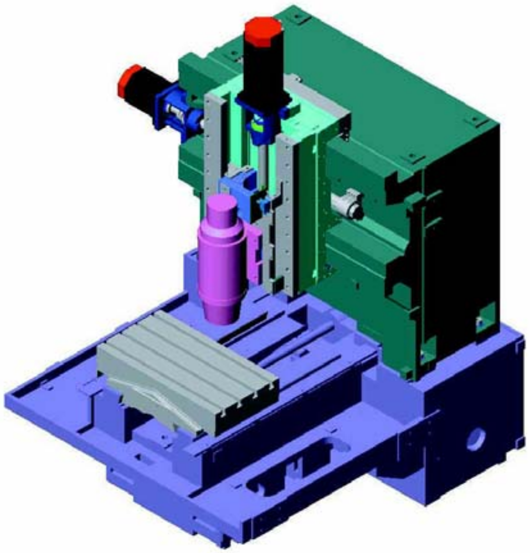
Mechatronics Concurrent Design



Traditional Approach: Design Requirements to Mechanical Concept

Design Requirements → **Mechanical Conceptual Design**

- *Milling aluminum*
- *Up to 10 by 15 cm*
- *3 parts per minute*
- *5 µm*
- *Light curtains, emergency stop*
- *<$50,000*



3D CAD Model

Mechatronics Approach: Concurrent Development (Design Tool Integration)

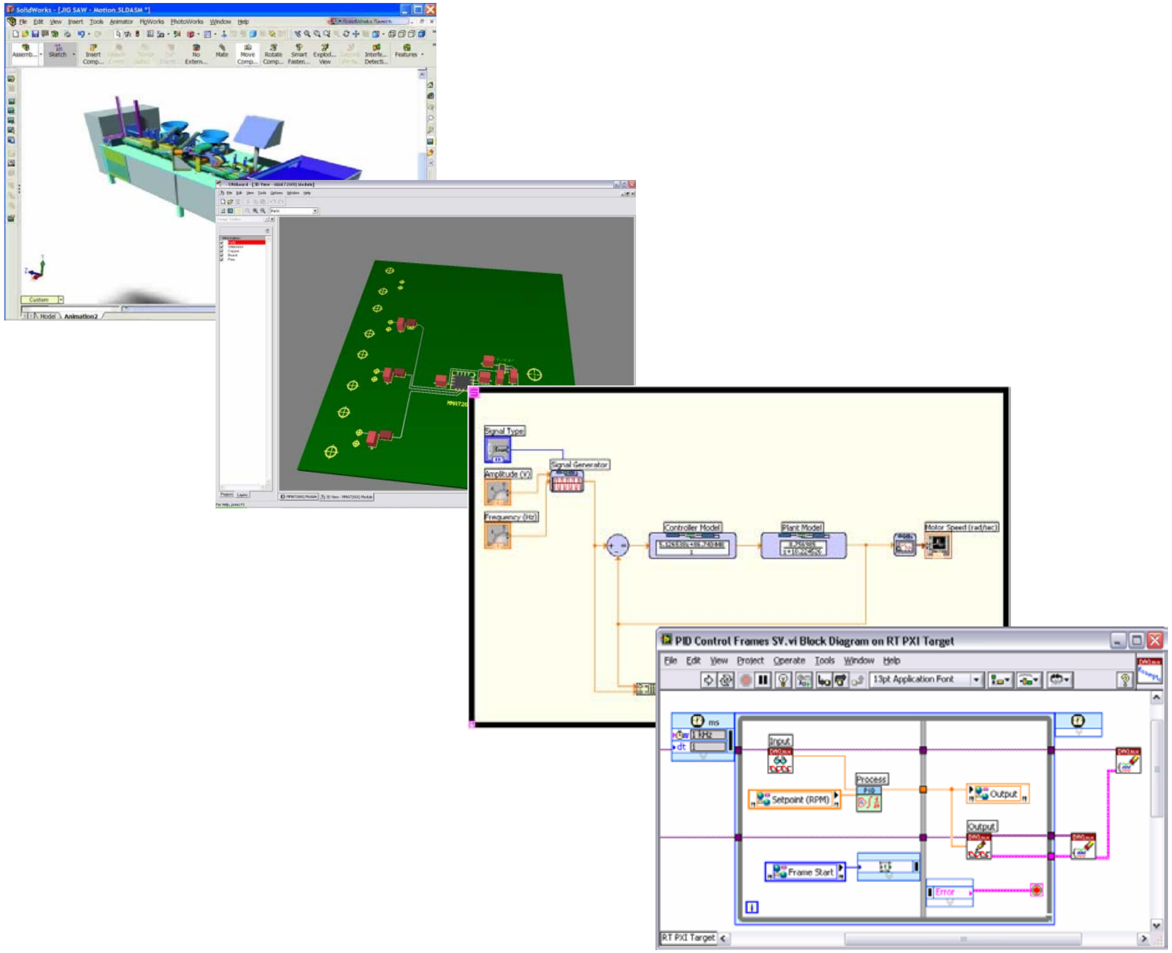
Mechanical Design

Electrical Design

Control Design

Embedded Design

Virtual Prototype (Simulation)



Level of Design Tool Integration

- *Ultimate – One design tool for all disciplines*
- Manual – Manually pass data between tools
- Basic – Data transferred via standard file formats
  - Motion profile data as CSV file to CAD
- Advanced – Complete tool automation
  - NI LabVIEW automating SolidWorks through ActiveX

Open Connectivity to Design Tools

Mathematics
NI **LabVIEW** Math
The MathWorks, Inc. **MATLAB®**
Maplesoft **Maple**
MathSoft **Mathcad**

Electrical Design
NI LabVIEW (Motor Sizing)
NI **Multisim**
ORCAD **PSpice**
Ansoft **Designer**

Control Design
NI **LabVIEW Control Design**
The MathWorks, Inc. **Simulink®**
Dynasim **Dymola**
Plexim **PLECS**

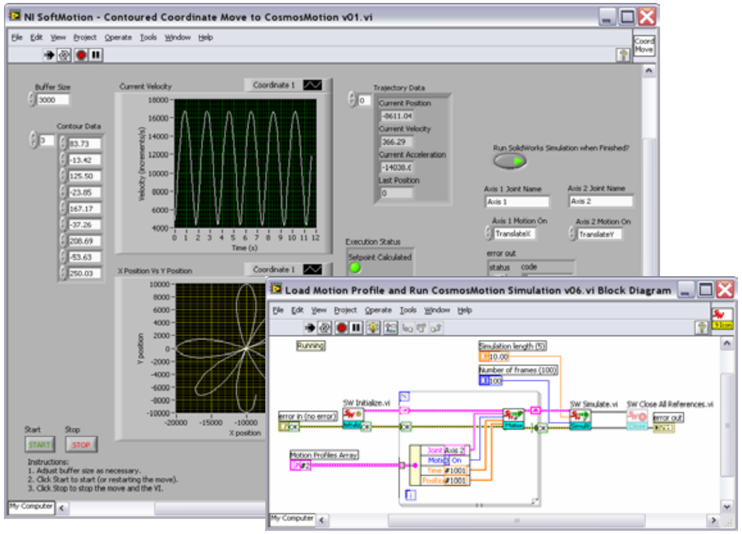
Embedded Software
NI LabVIEW Real-Time/Embedded
Wind River **Workbench**
Analog Devices **VisualDSP++**
Freescale **Code Warrior**
Xilinx **System Generator**

Mechanical Design
SolidWorks **SolidWorks**
PTC **Pro/Engineer**
MSC **Nastran** and **Adams**
Autodesk **AutoCAD**

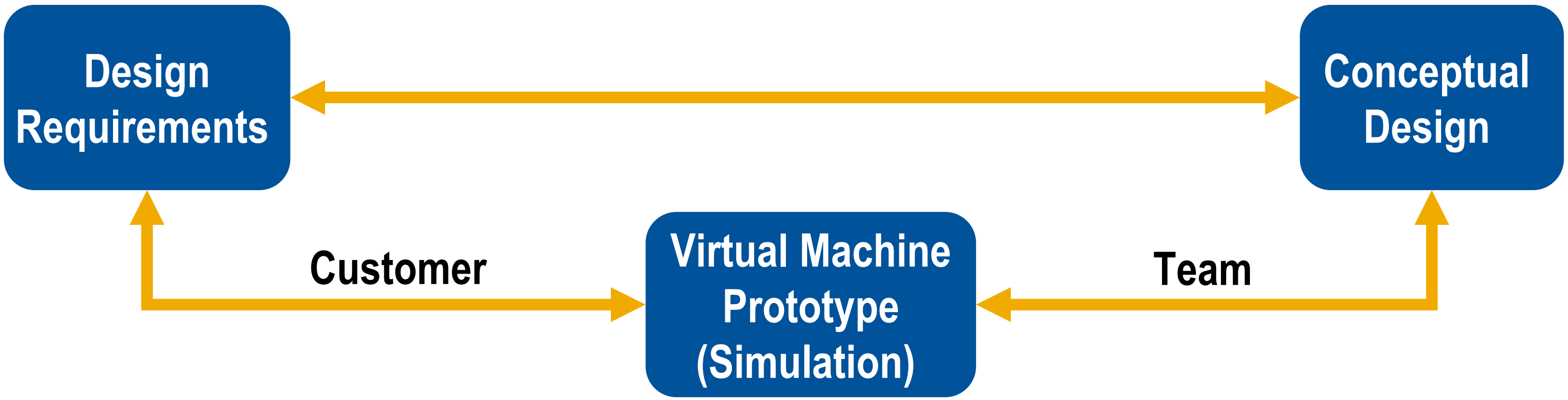
NATIONAL INSTRUMENTS LabVIEW

LabVIEW: Virtual Prototyping Platform

- Intuitive graphical tools for domain experts
- Built-in control design and simulation
- Design tool integration
- Flexible, open architecture
- Ability to target multiple industrial hardware platforms



Virtual Machine Prototyping



Mechanical: *Design visualization*

Electrical: *Motor sizing*

Control: *Verify control logic*

Embedded Software: *Easy implementation*

Mechanical Design Challenges

Challenge: Understanding the requirements

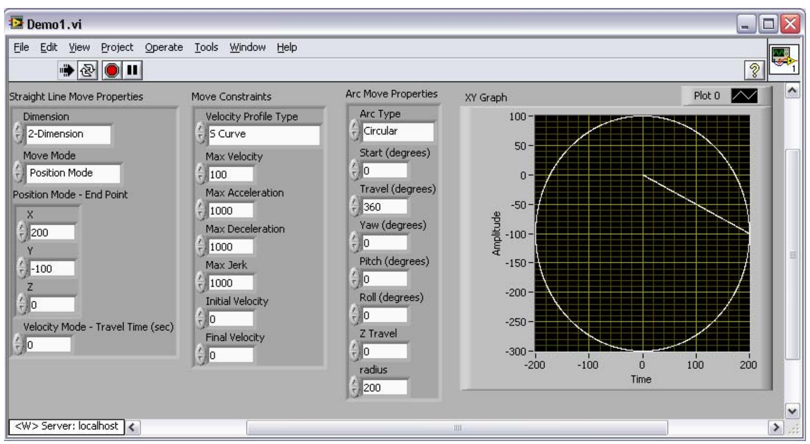
Solution: Electromechanical simulation

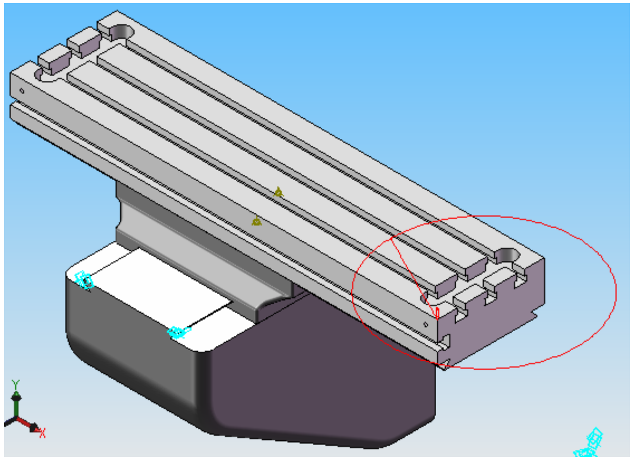
Benefits:

- ✓ Improved customer communication
  - Confidence builder: showing proof of concept
  - Competitive advantage in the bidding process
- ✓ Improved design team communication
  - Refining design specifications
  - Evaluating high-level architectural design

Electromechanical Simulation Steps

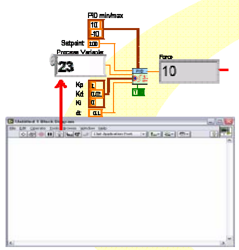
1. Determine machine logic
2. Generate profile data with virtual prototyping software
3. Send to 3D design tool
4. Use CAD tool to animate machine functionality

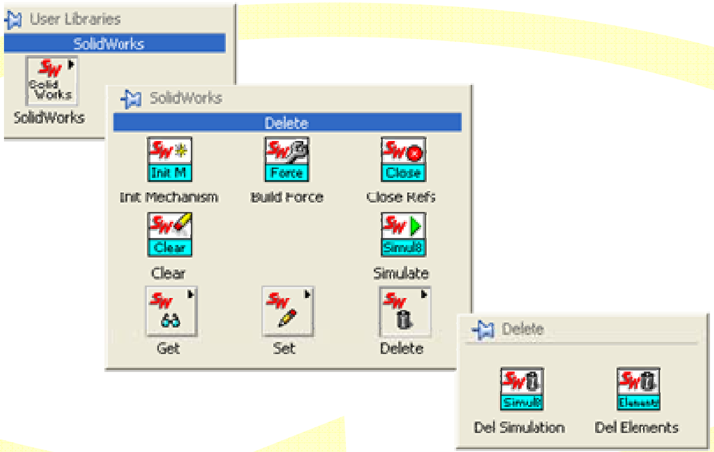




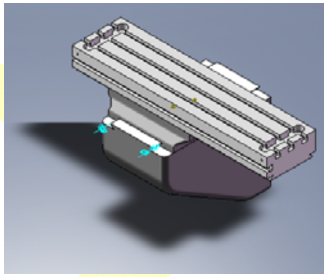
Software Tools

- SolidWorks Professional
  - COSMOSMotion
- LabVIEW Professional
  - Free SolidWorks/LabVIEW ActiveX Interface
  - NI Motion Assistant



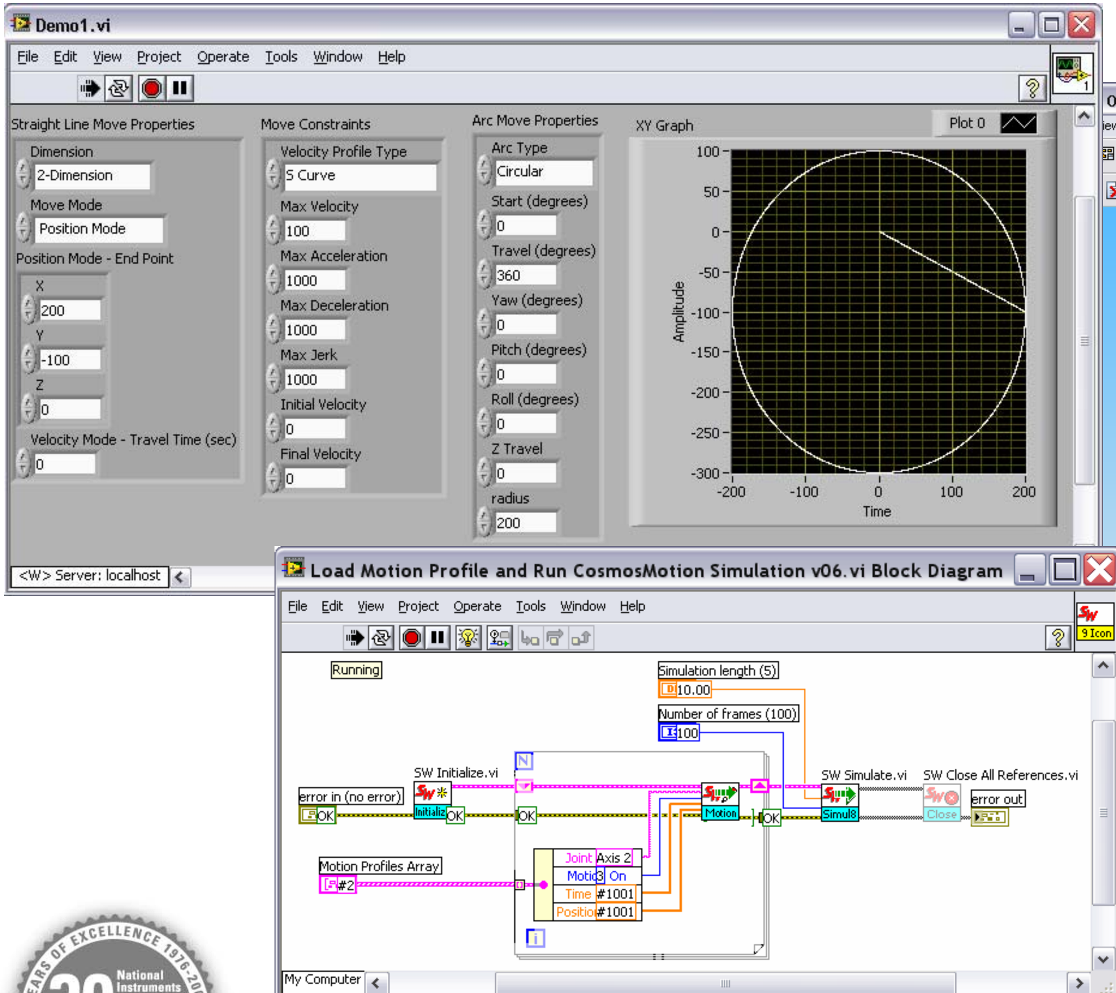


SolidWorks – LabVIEW Interface Functions

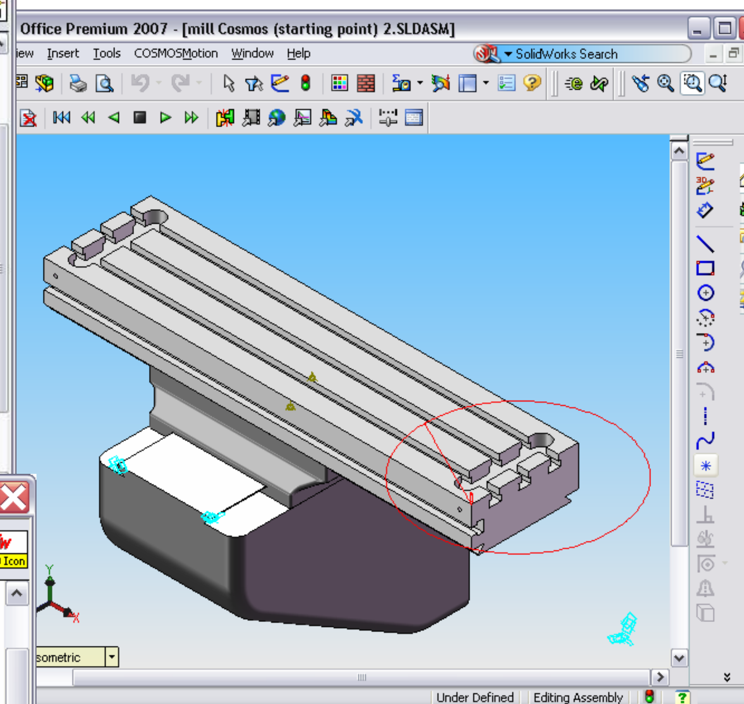


Demo: LabVIEW Automates Design Visualization

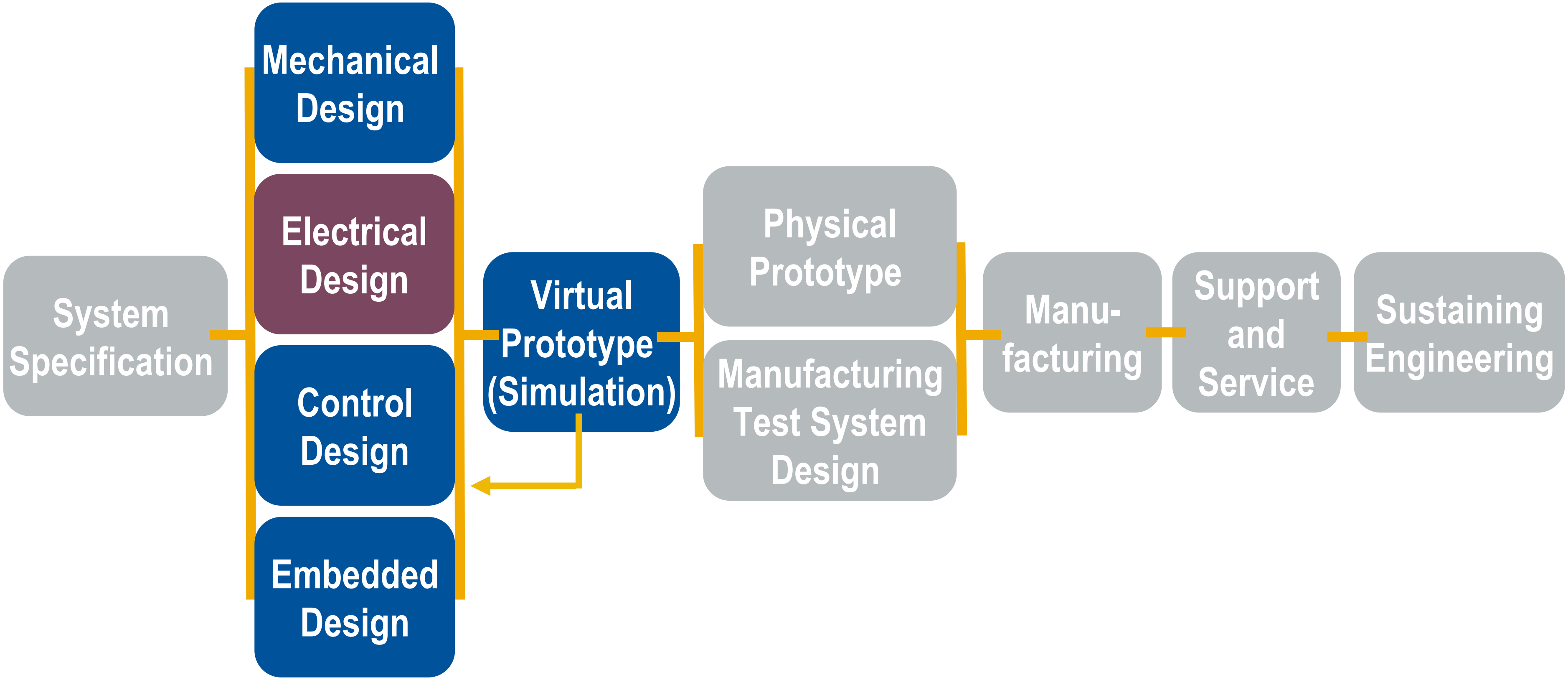
2. Control



1. Mechanical Design



Electrical Design



Electrical Design Challenges

Challenge: Specifying correct motor size

Solution: Sizing virtual motors

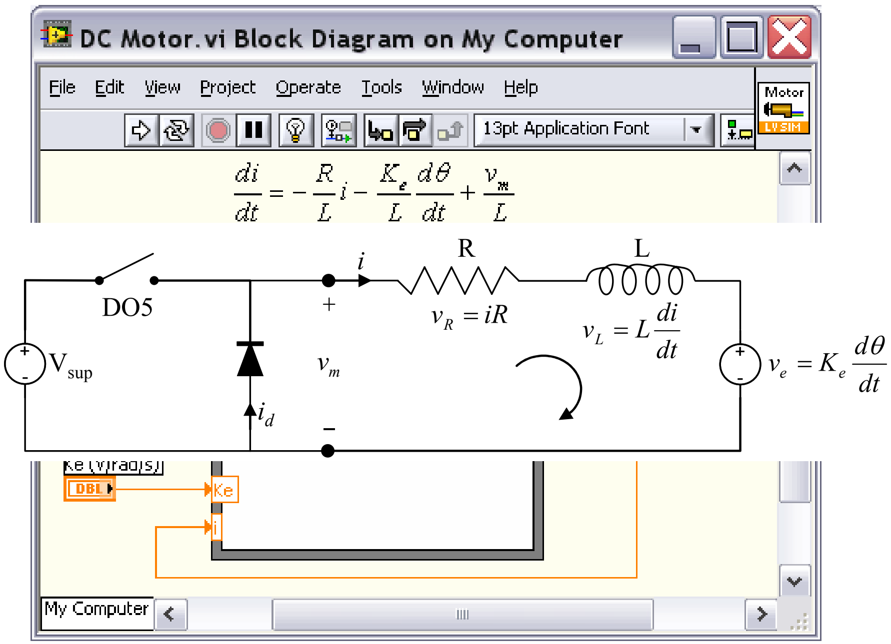
Benefits:

- ✓ Apply motor sizing principles interactively
- ✓ Virtually test various motors
- ✓ Estimate control tuning parameter before physical prototype

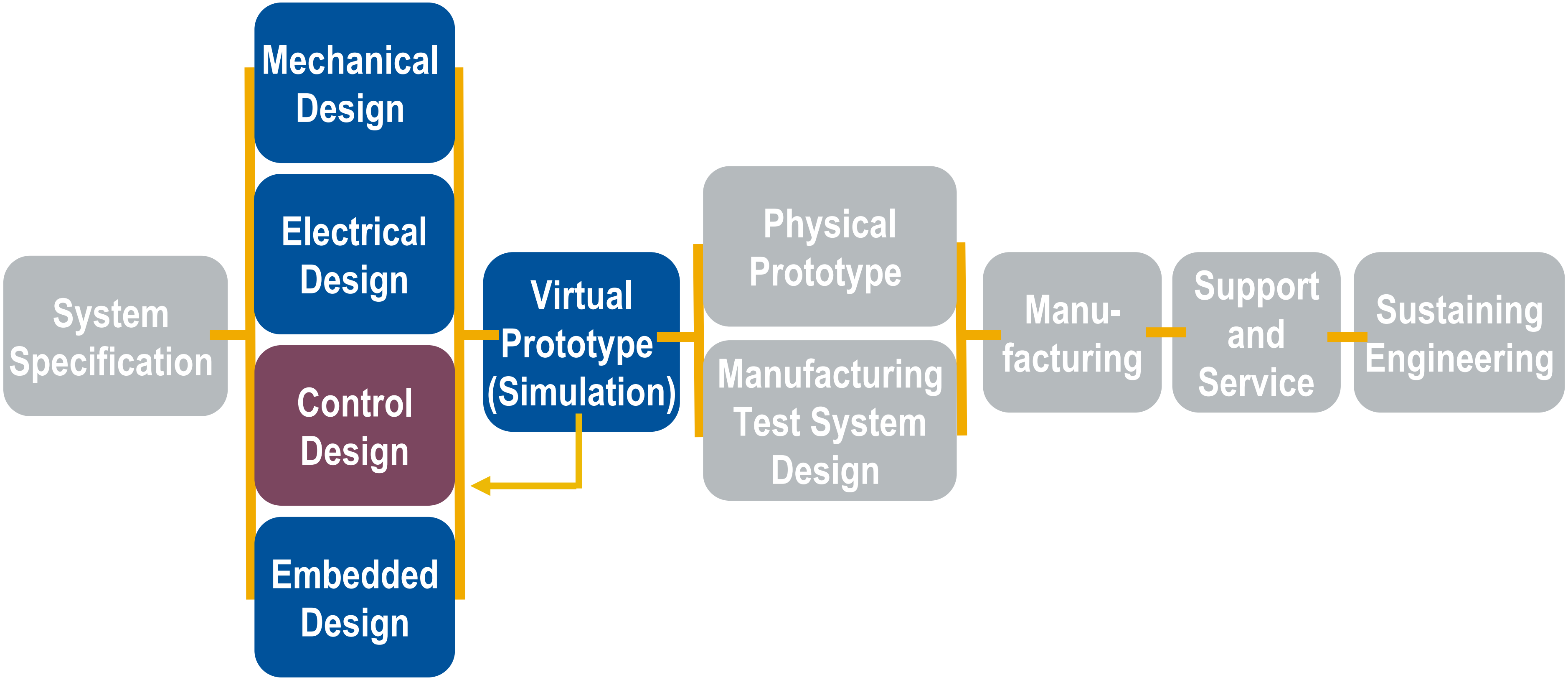
Virtual DC Motor Sizing

1. Acquire motor specifications from data sheet
2. Simulate motor response to velocity and torque profile from CAD

		1219 N		4,5 G	006 G	012 G	015 G	
1	Nominal voltage	U_N		4,5	6	12	15	Volt
2	Terminal resistance	R		10,7	17,6	69,0	131	Ω
3	Output power	$P_{2\,max.}$		0,46	0,49	0,50	0,41	W
4	Efficiency	$\eta_{max.}$		74	73	72	70	%
5	No-load speed	n_o		15 300	16 000	16 000	16 200	rpm
6	No-load current (with shaft ø 0,8 mm)	I_o		0,008	0,007	0,004	0,003	A
7	Stall torque	M_H		1,14	1,17	1,19	0,96	mNm
8	Friction torque	M_R		0,02	0,02	0,03	0,03	mNm
9	Speed constant	k_n		3 460	2 721	1 364	1 109	rpm/V
10	Back-EMF constant	k_E		0,289	0,368	0,733	0,902	mV/rpm
11	Torque constant	k_M		2,76	3,51	7,00	8,61	mNm/A
12	Current constant	k_I		0,362	0,285	0,143	0,116	A/mNm
13	Slope of n-M curve	Δn/ΔM		13 413	13 642	13 447	16 875	rpm/mNm
14	Rotor inductance	L		150	300	1 200	1 600	µH
15	Mechanical time constant	τ_m		20	20	18	19	ms
16	Rotor inertia	J		0,14	0,14	0,13	0,11	gcm²
17	Angular acceleration	$\alpha_{max.}$		81	84	92	87	·10³rad/s²
18	Thermal resistance	R_{th1} / R_{th2}	17 / 48					K/W
19	Thermal time constant	τ_{w1} / τ_{w2}	3,5 / 386					s
20	Operating temperature range:							
	– motor		– 30 ... + 85 (optional – 30 ... + 125)					°C
	– rotor, max. permissible		+ 85 (optional + 125)					°C
21	Shaft bearings		sintered bronze sleeves	ball bearings				
22	Shaft load max.:		(standard)	(optional)				
	– with shaft diameter		0,8	1,0				mm
	– radial at 3 000 rpm (1,5 mm from bearing)		0,5	5				N
	– axial at 3 000 rpm		0,1	0,5				N
	– axial at standstill		20	5				N
23	Shaft play:							
	– radial	≤	0,03	0,02				mm
	– axial	≤	0,2	0,2				mm
24	Housing material		steel, nickel plated					
25	Weight		11					g
26	Direction of rotation		clockwise, viewed from the front face					
	Recommended values - mathematically independent of each other							
27	Speed up to	$n_{e\,max.}$		12 000	12 000	12 000	12 000	rpm
28	Torque up to	$M_{e\,max.}$		0,60	0,60	0,60	0,60	mNm
29	Current up to (thermal limits)	$I_{e\,max.}$		0,260	0,200	0,100	0,070	A



Control Design



Control Design Challenges

Challenges:

- Software development in critical path
- Physical prototype needed to test control algorithm

Solution: Develop and test control algorithm on virtual model

Benefits:

✓ Get head start on control development

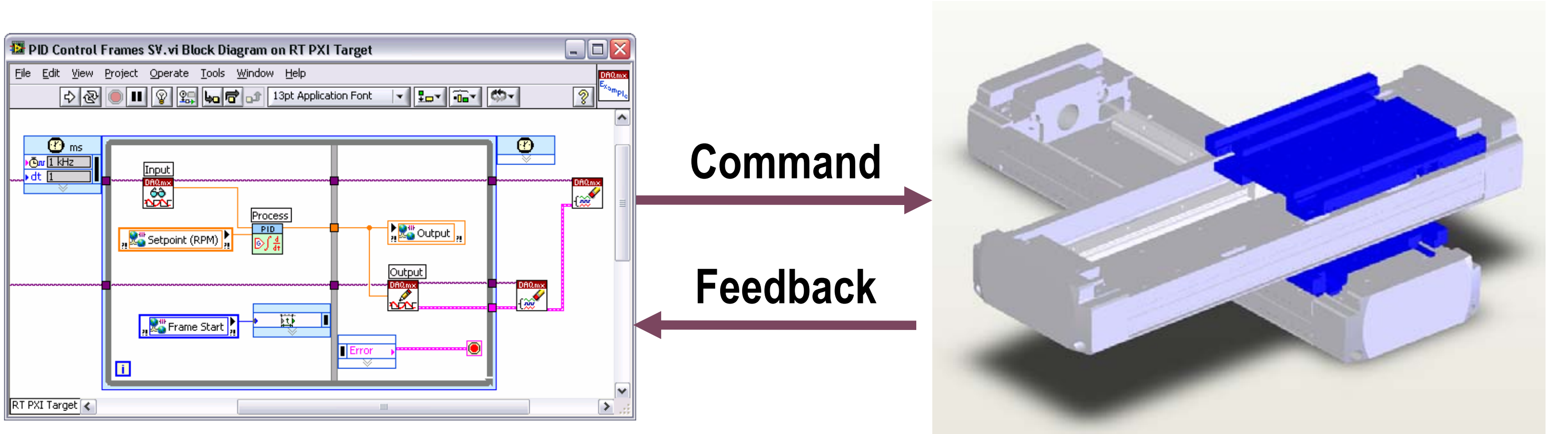
✓ Refine control strategy before physical prototyping

✓ Detect interferences and resonance

Integrating Control and Mechanical Design

Control Software

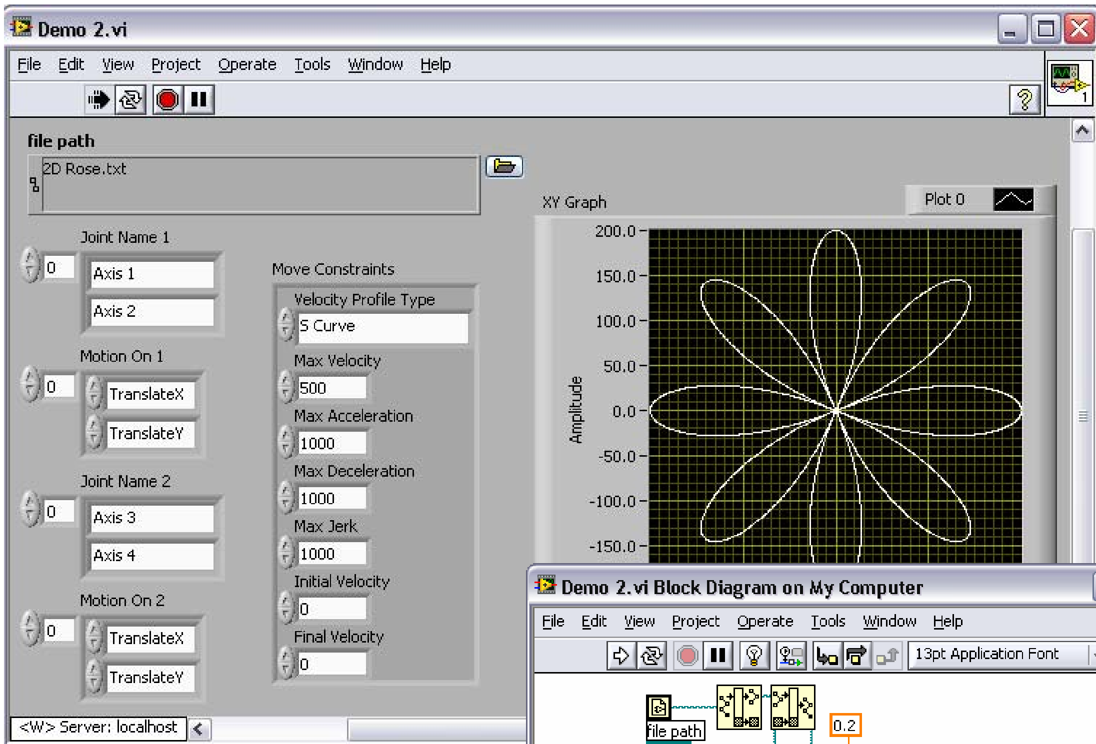
Simulation

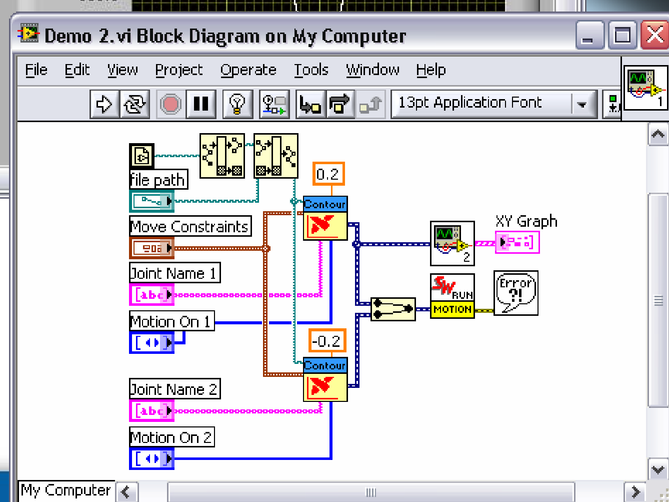


1. Develop machine control logic
2. Animate model and identify potential issues

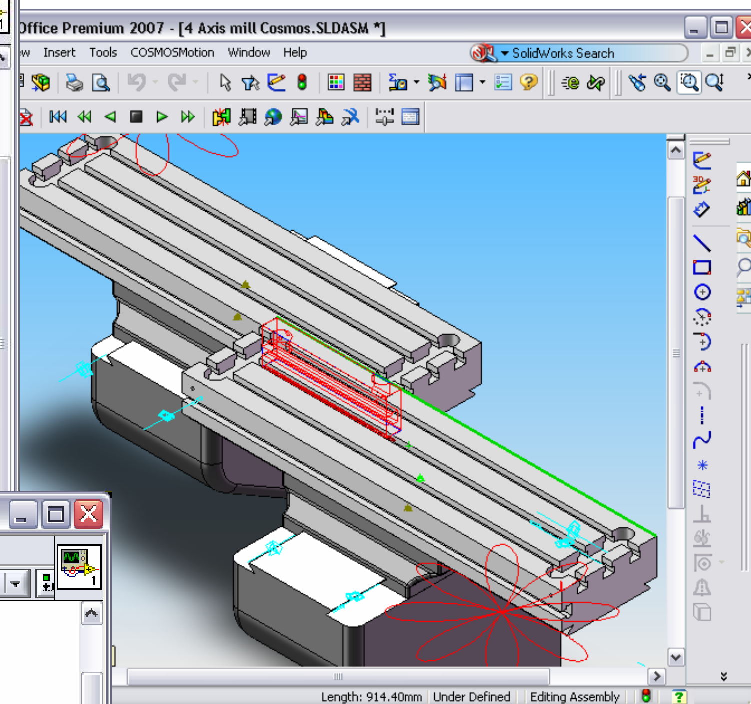
Demo: Interference Detection

1. Motion Profile





2. Interference Detection



Control Design Challenges

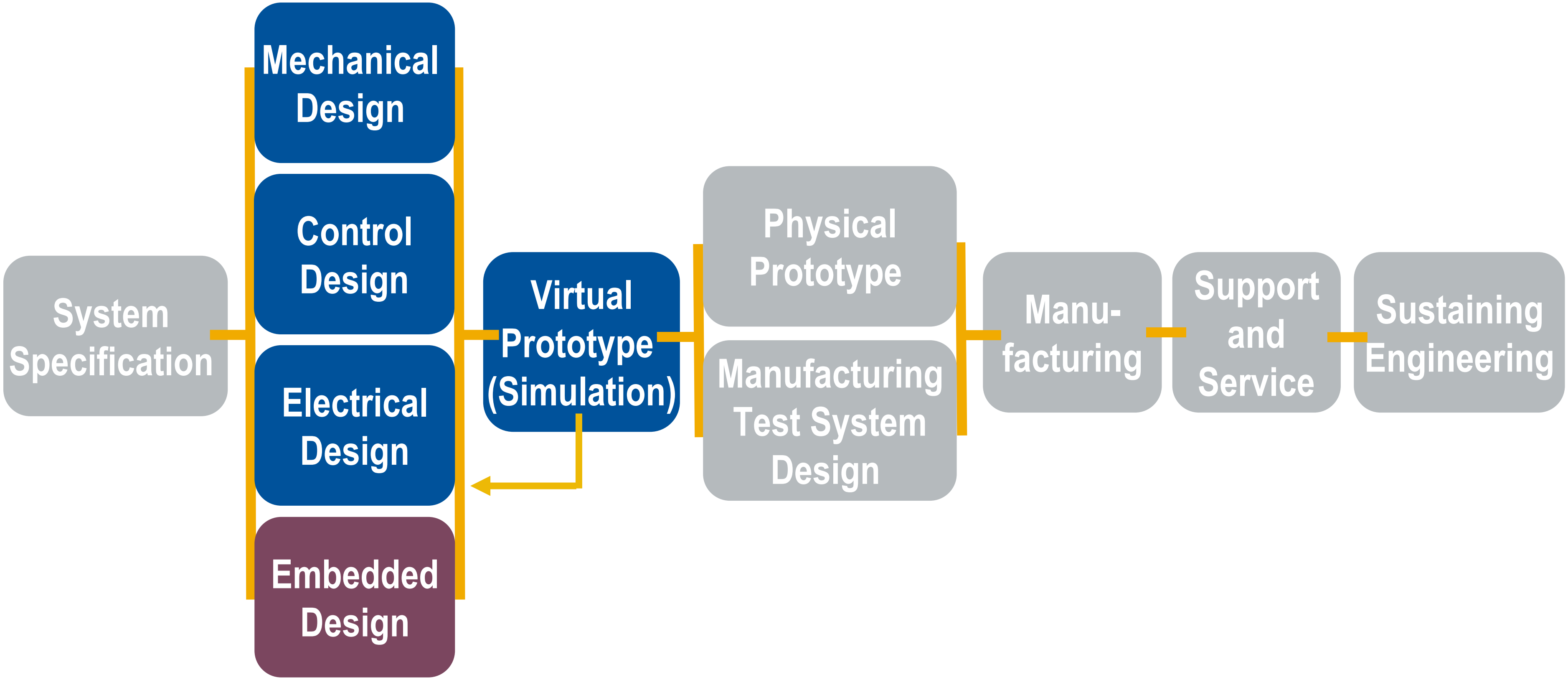
Challenge: Finding an alternative for conventional PID, which is not tuned for all machine states

Solution: Using advanced PID or other control algorithms

Benefits:

- ✓ Achieve more precise control
- ✓ Choose from PID, advanced PID, and model-based and model-predictive control
- ✓ Reduce wear and tear on machine parts

Embedded Software Design



Embedded Software Design Challenges

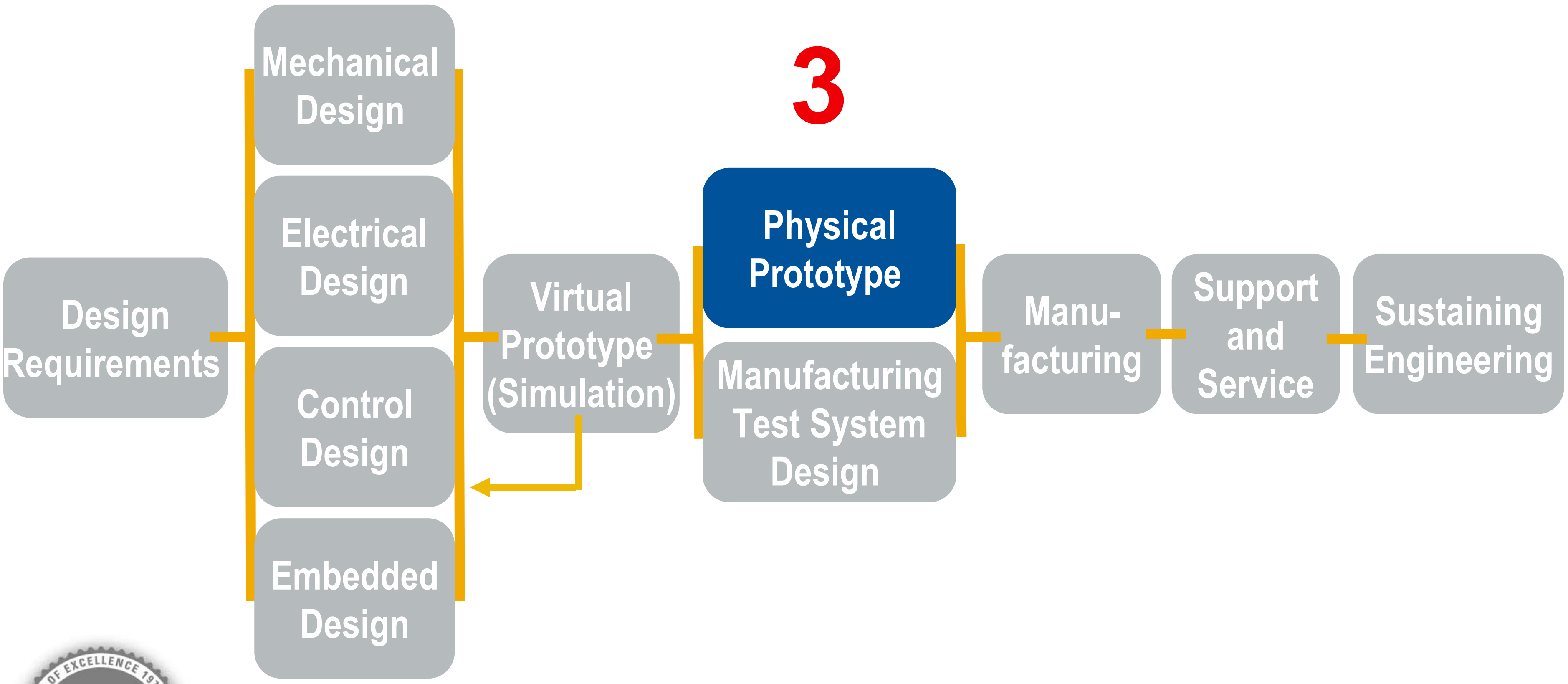
Challenge: Implementing embedded algorithms

Solution: Using control design software that runs natively on embedded hardware

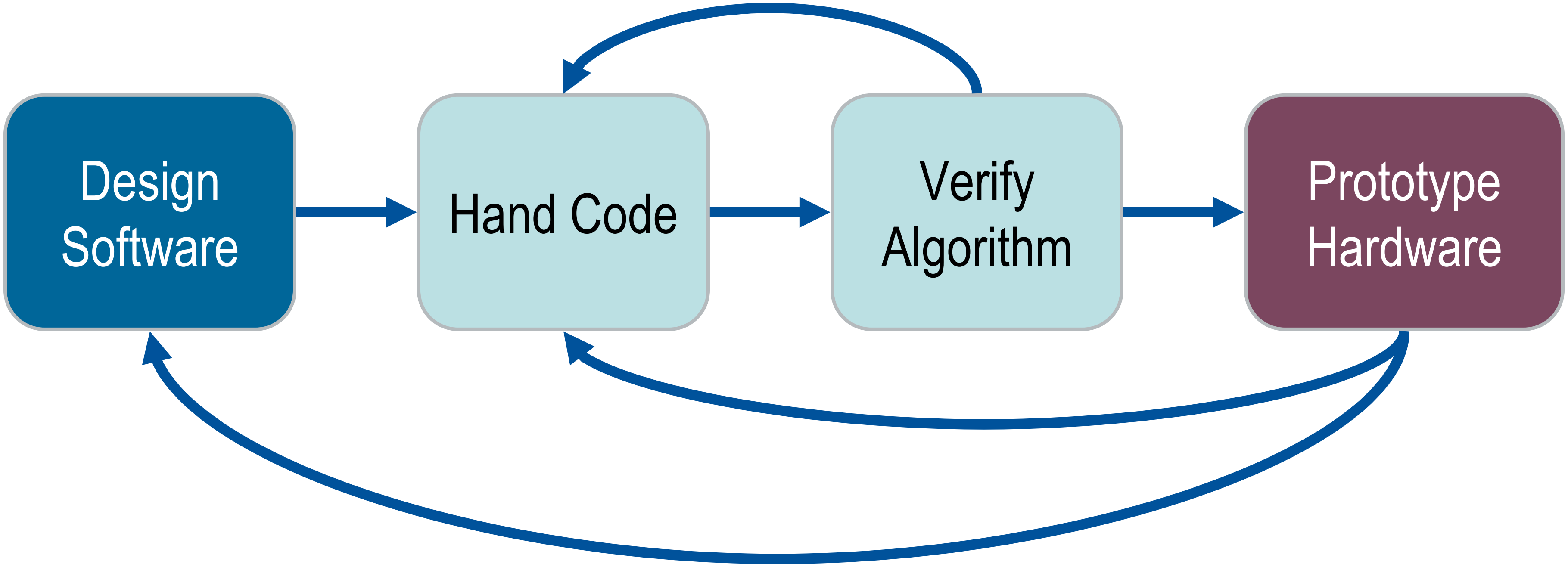
Benefits:

- ✓ Reduced development time and cost
- ✓ Less chance for translation errors

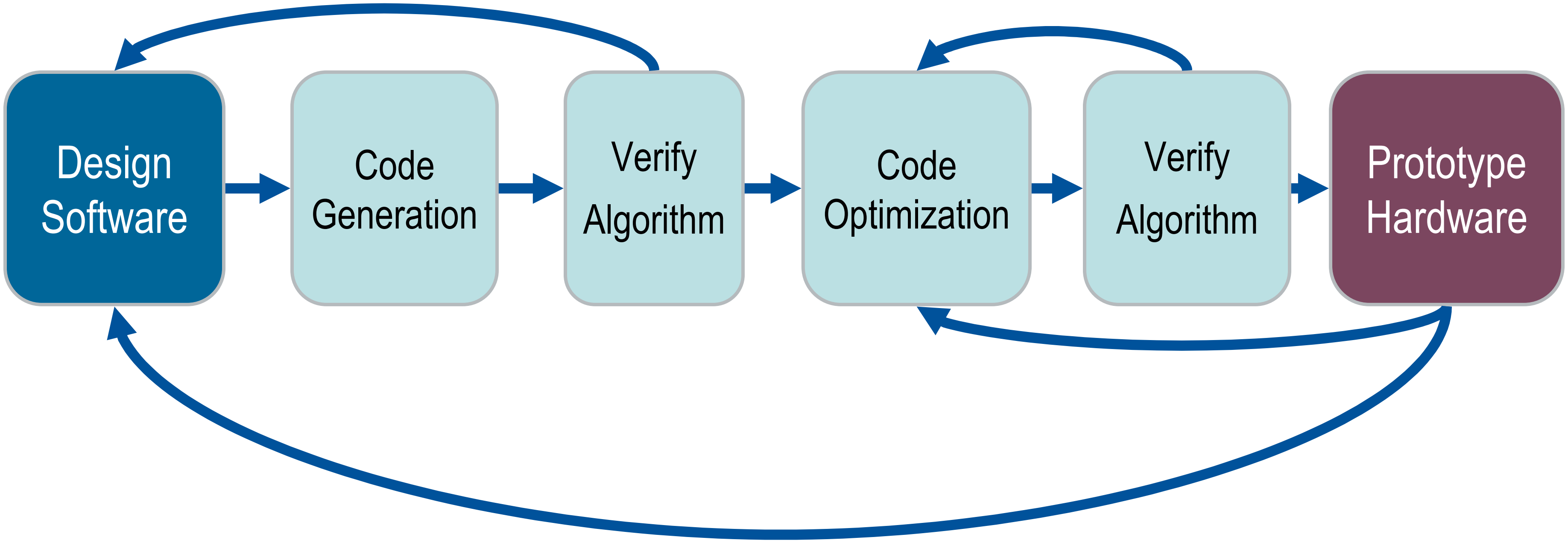
Physical Prototyping



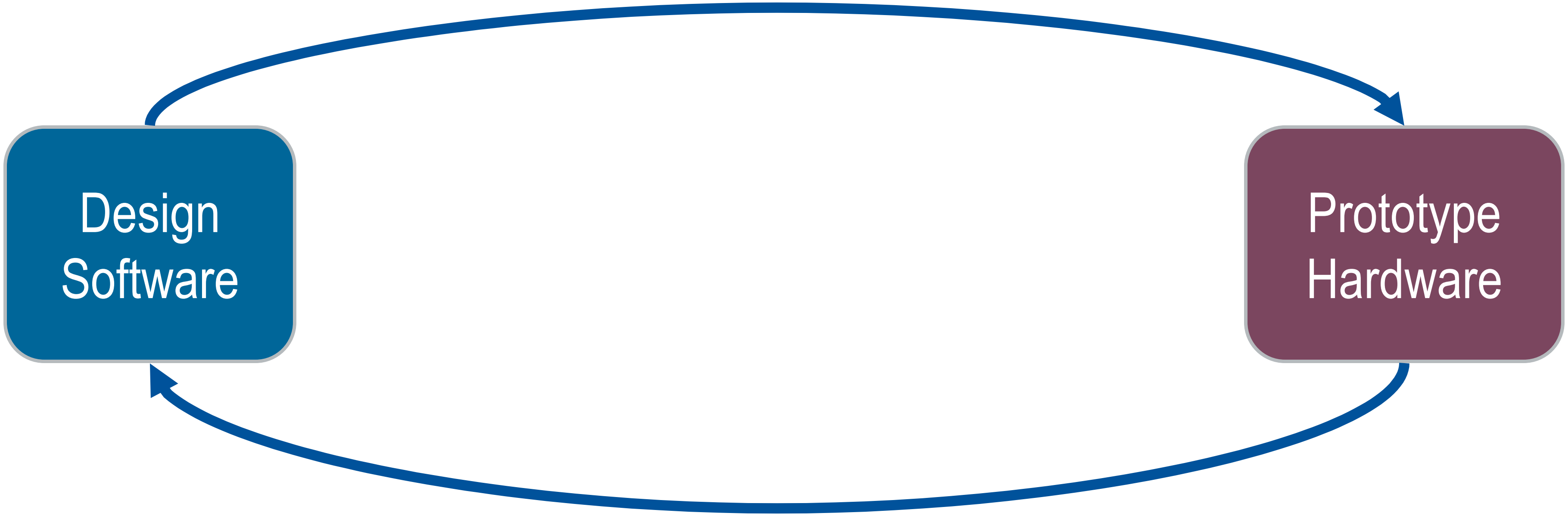
Algorithm Engineering



Algorithm Engineering



Algorithm Engineering



Prototyping Challenges

Challenge: Choosing the right prototyping platform

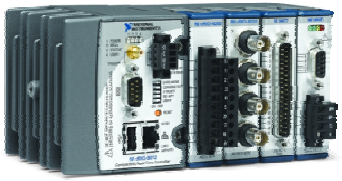
- Controller speed and memory
- I/O from specialty signals
- Ability to implement advanced control algorithms

✓Reliably run custom control algorithms

✓Integrate any I/O including machine condition monitoring and vision

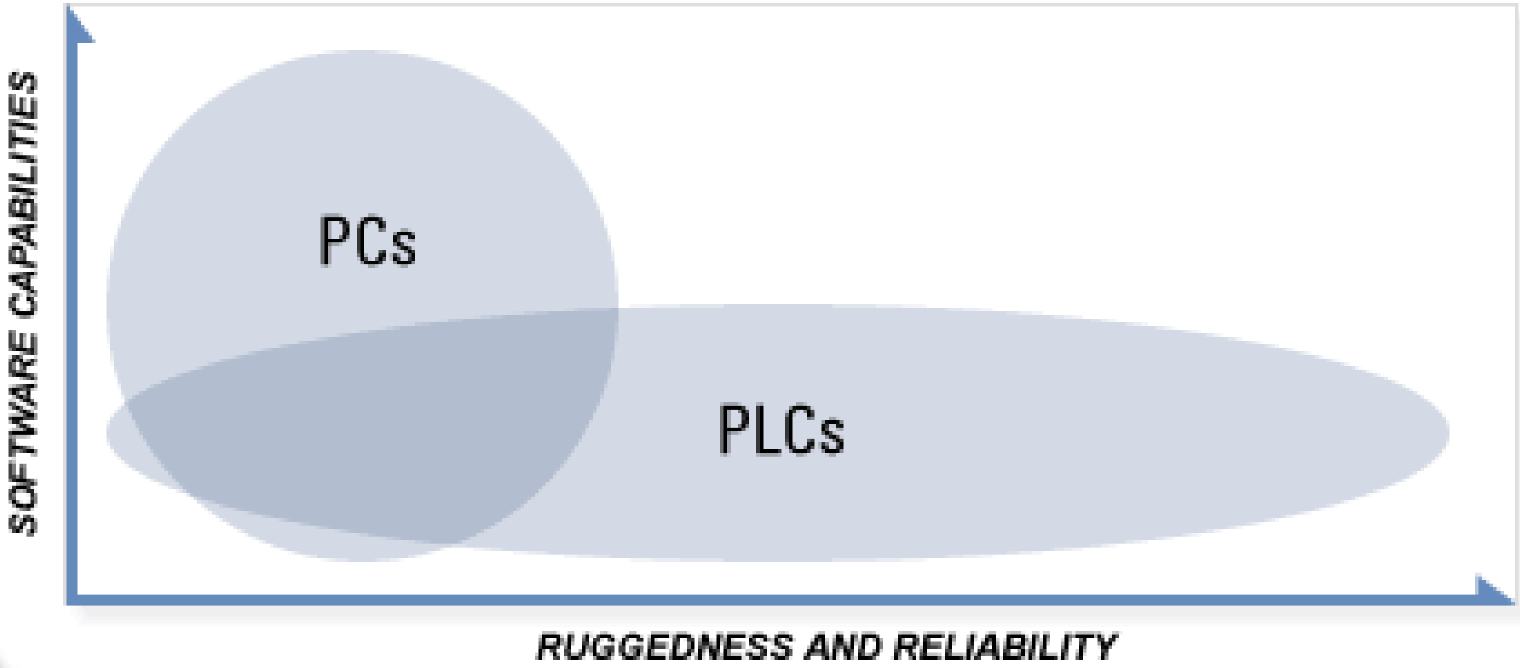
Prototyping Hardware

- Desktop PCs
- Industrial PCs
- Programmable automation controllers (PACs)
- Programmable logic controllers (PLCs)
- Custom boards

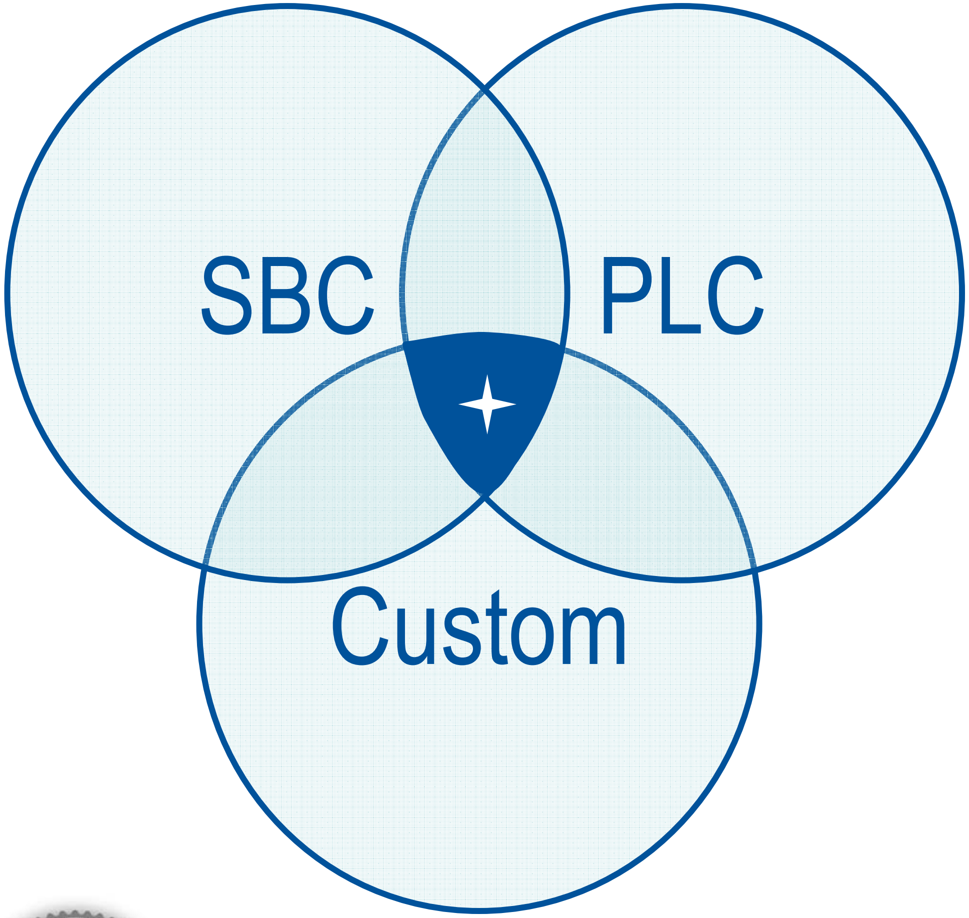


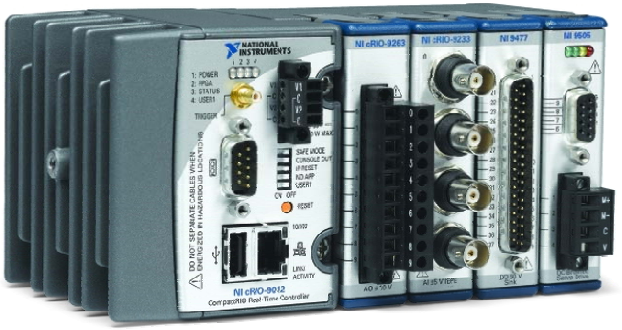
Programmable Automation Controller (PAC)

- Ruggedness and reliability of PLC
- Software capabilities of PC
- Modular and diverse I/O



FPGA-Based Programmable Automation Controller

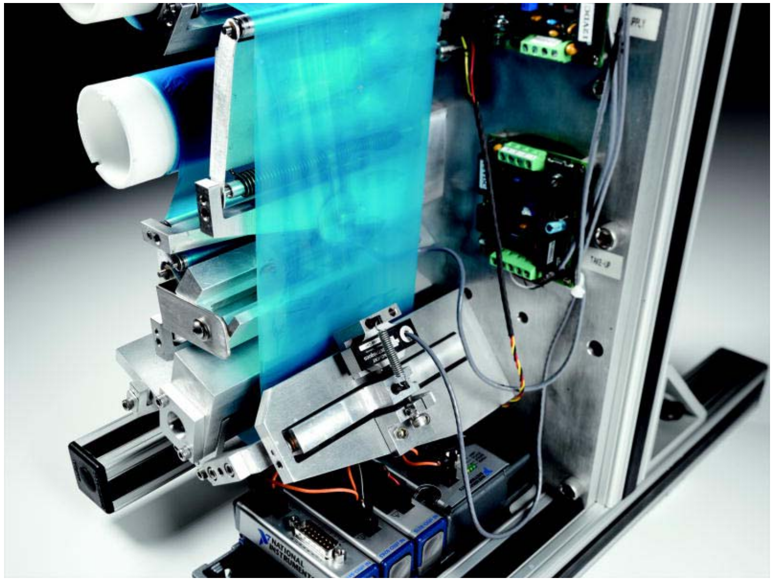




NI CompactRIO

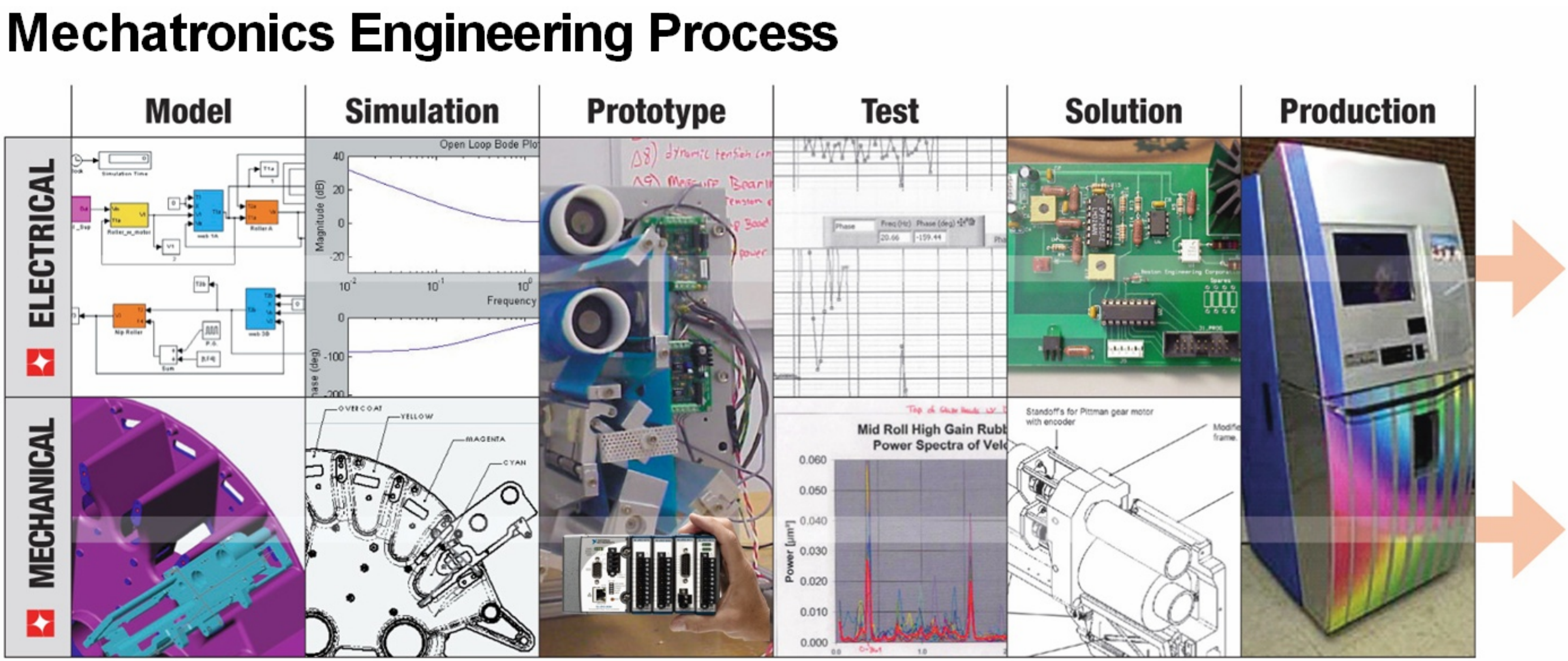
Use Case: Digital Photo Kiosk Design

- Design Challenges
  - Precise web tensioning
  - Vibrations from cutter head
  - Varying motor speed
- Solution Mechatronics
  - Mechanical and control simulation
  - Sixth-order control algorithm
  - Two-motor axis dancer system
  - Prototyping with LabVIEW and CompactRIO
- Result
  - ***10X faster than competition***



BOSTON ENGINEERING

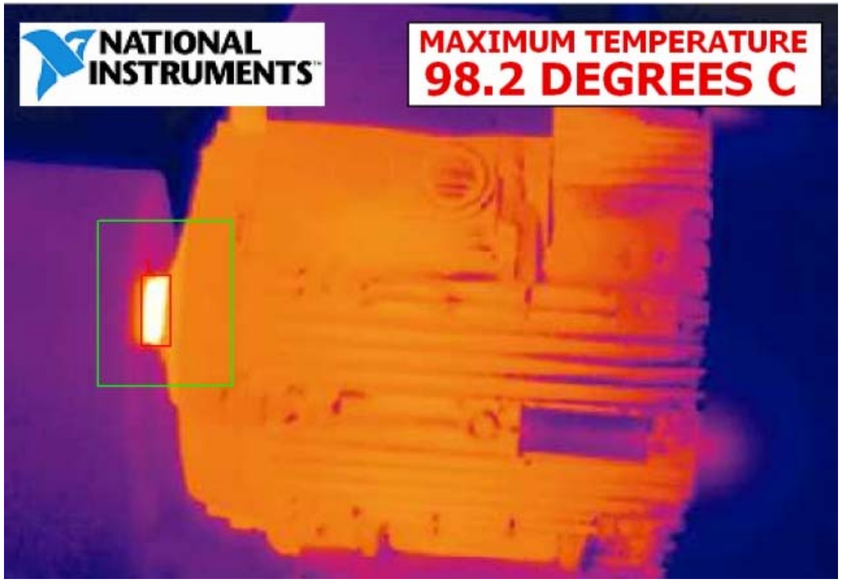
Use Case: Digital Photo Kiosk Design



Demo: Physical Prototype

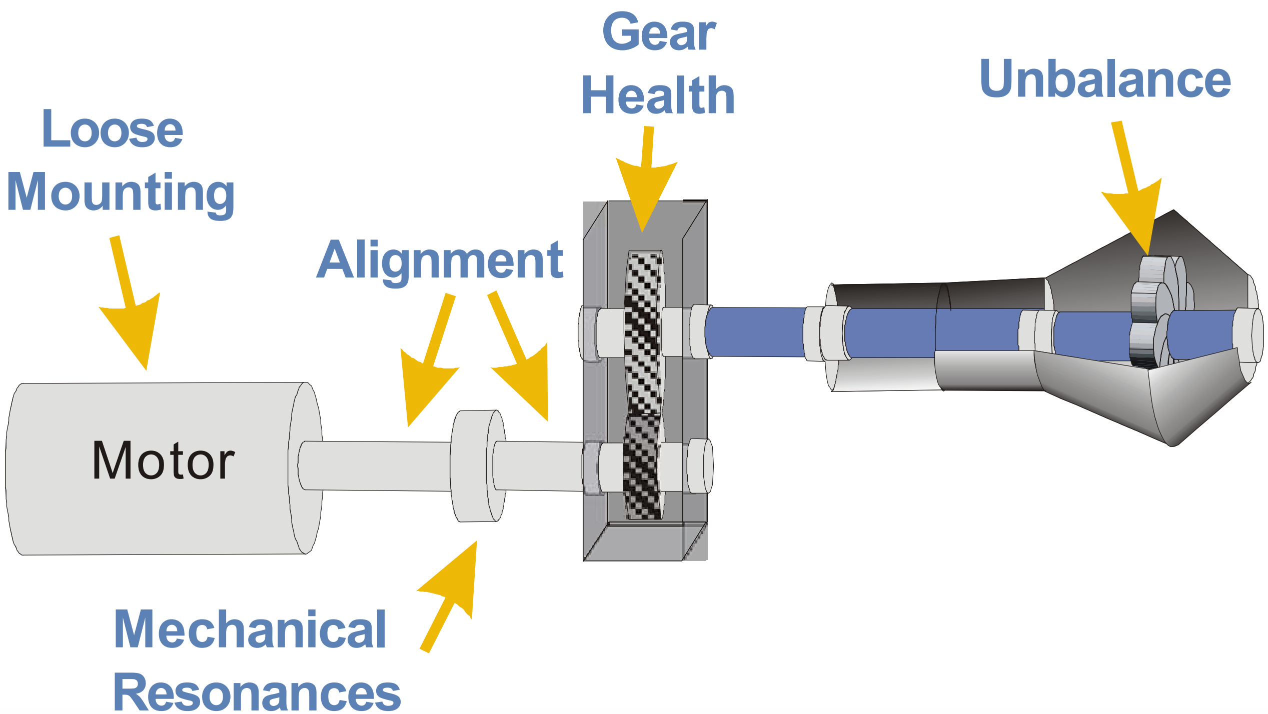
Additional Design Considerations: Machine Condition Monitoring

- Why use machine vision?
  - Increase product throughput
  - Reduce product inspection cost
  - Use infrared, X-ray
- Applications
  - Manufacturing
  - Product testing
  - Product packaging
  - Robot guidance



Additional Design Considerations: Machine Condition Monitoring

Data Acquisition → Data Analysis → Diagnosis and Control



Conclusion

Mechatronics concurrent development:

- Reduces development time and risk
- Requires design tool integration

NATIONAL INSTRUMENTS LabVIEW