university of groningen

faculty of science and engineering

Mechatronics

Week 1 Day 1

Course Info

- **Teachers**:
  - Dr. Saeed Ahmed, Assistant Professor ENTEG
  - **Office Hours**: Mondays 13:30-14:30 (5111.0151 NB4)
  - A number of teaching assistants (Melvyn Wildeboer, Cole Onorati, Riccardo Roscigno, Candela Arrieta Bartolome)
- **Important course information** can be seen on **Brightspace** in the folder **"All about Mechatronics"**.
- Books:
  - Textbook 1: Bohdan T. Kulakowski, John F. Gardner, J. Lowen Shearer, Dynamic Modeling and Control of Engineering Systems, Cambridge University Press, ISBN: 978-0-521-86435-0.
  - Textbook 2: Yang, Bingen and Inna Abramova, Dynamic Systems: Modeling, Simulation, and Analysis, Cambridge University Press, ISBN: 978-1-107-17979-0.
- Books will not be treated chronologically! Also **additional course material** will appear on **Brightspace**!

Pre-requisites

- Check a lists of pre-requisites on Brightspace (**calculus, linear algebra, signals and systems, control engineering**, etc.)

- Those topics will not be discussed in the Lectures or in the Tutorials! However, we will **refresh some concepts** on control engineering during the first tutorial.

- Questions regarding the course can be asked at

rug.mechatronics.fall2024@gmail.com

Course Info – Lecture Recordings

- Lecture recordings from previous years will be uploaded regularly on Brightspace
- **Purpose**: You can take help from them if you miss some concept in the lecture
- They are not indicative of the lectures this year and not a binding on us of what is happening in the lectures of this year

Course Info – Guest lecture

- There will be a guest lecture during the course
  - Mandatory
  - Announced soon
  - Please note that the content of this lecture is part of the exam material.

Course Info – Tutorials

- The tutorial lectures are part of the practical
  - Mandatory attendance
  - We accept up to 80% attendance

- **Teaching method from second tutorial on:**
  - "Flipping the class"
  - Tutorial questions will be divided into two groups of four questions each
    - First group of questions: solved by the students before coming to the tutorial by following the solutions to these questions.
    - Second group of questions: solved by the students in the classroom during their assigned tutorial following the instructions of the teaching assistants

Course Info – Tutorials

- Every week, three tutorial classes are held, one for each group. Please stay in your group!
- Check Rooster for locations

Groups	
Wednesdays (17:00-19:00)	BME MSc yr 1 MDD gr 1, AM yr3, As I&I,
Thursdays (15:00-17:00)	BME MSc yr 1 MDD gr 2
Fridays (11:00-13:00)	PTL 1, PTL 2, PTL 3, PTL 4

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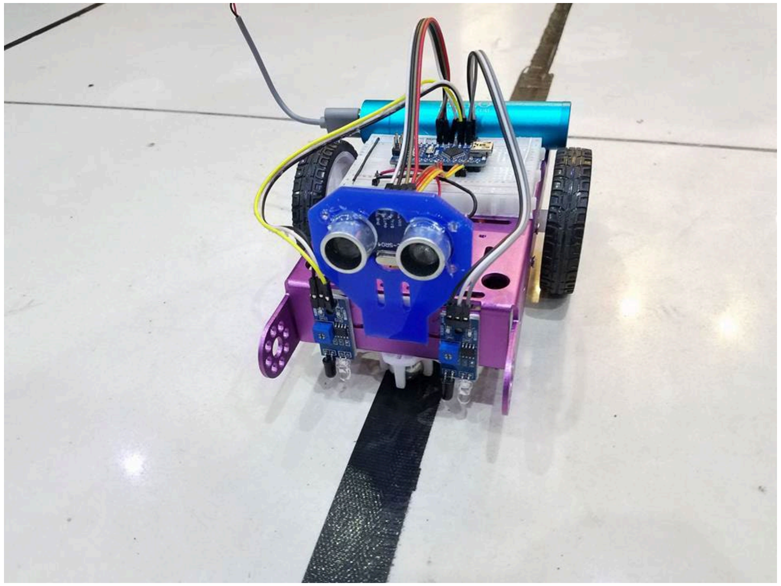
Course Info – Practical

- Line Following and Obstacle Avoidance using Arduino

Course Info – Practical

- Practical obligatory



  - Practical in groups of 3
  - Line Following and Obstacle Avoidance using Arduino
  - The practical of last year is still valid, not from the years before.
  - Practical should be completed sufficiently (practicals are not graded)

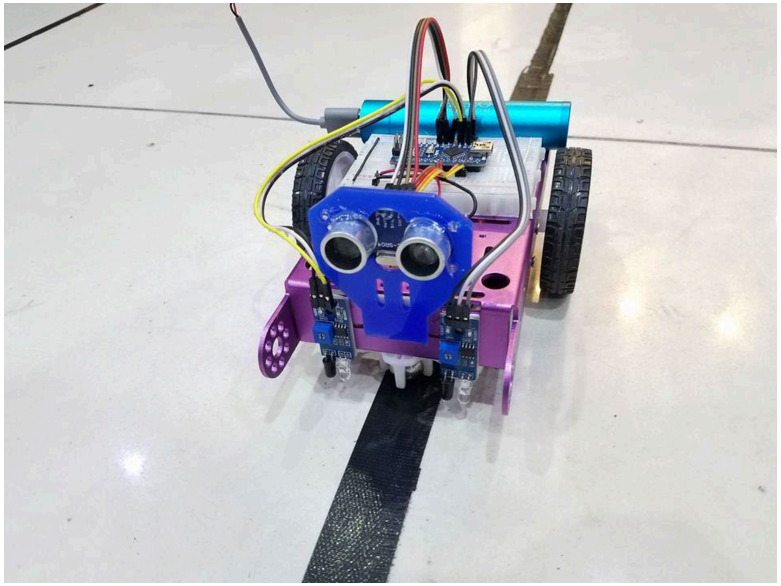
Group student names: **Group student numbers:** **Name assessor:** **Date of assessment:**	

Assignment	Areas of improvement (insufficient)	Sufficient	Additional feedback or suggestions
1. Understanding of the system		Each student of the group is able to explain the influence of the gains of the controller on the behavior of the robot.	
2. Hardware understanding		Each student of the group is able to answer theoretical questions related to the hardware of the rover (actuator, sensors, controller)	
3. Algorithm understanding		Each student of the group is able to explain the basic concept of the algorithm of the code for the controller part and gains, line following part and obstacle avoidance part	
4. Rover		The rover is able to follow the line and at least attempt obstacle avoidance (it does not need to continue following the line after the obstacle) within two attempts	

Note: Bad performance of one student of the group will not result in failing the group but only that specific student.

Course Info – Practical

- Practical in weeks 50 (2 hours) and 51 (4 hours). No general lectures and tutorials in week 51
- 19 to 24 December have been kept free!
- Enrollment in the practical groups will be done soon through Brightspace.



Course Info - Examination

- Exams:
  - Final exam: Wednesday, 22 January 2025, 18:15-21:15, Exam Hall 3 A1 - B11 Blauwborgje 4
  - Re-examination: Friday 11 April 2025, 18:15-21:15, Exam Hall 2 L1 - M16 Blauwborgje 4

- The final exam and re-examination are three hours long.
- One A4-size (both sides) handwritten cheat sheet is allowed.
- Previous exams are available on Brightspace.

- Assessment
  - The final grade only depends on the final exam
  - The weighted of the final exam must be > 5.5
  - Both the lab sessions are attended and the lab is passed with a sufficient
  - The attendance in the tutorial is 80%
  - The first lecture and the guest lecture should be attended.

Topic of today

- Introduction to Mechatronics
  - Example 1: Advanced cars
  - Example 2: Cochlear implant
- The Current Trends in Mechatronics
- Mechatronics design cycle
  - Axiomatic design
    - Example 1: Design of an artificial limb
    - Example 2: Design of a prosthetic arm
    - Example 3: Automated Guided Vehicle design
  - V-diagram
    - Example: Design of an artificial limb

Introduction to Mechatronics

Definitions

From **IFAC** (International Federation of Automatic Control) Technical Committee in Mechatronics:

"Many technical processes and products in the area of aerospace, mechanical and electrical engineering show an increasing integration of mechanics with electronics and information processing. This integration is between the components (hardware) and the information-driven functions (software), resulting in integrated systems called mechatronic systems."

From **Mechatronics journal** (a journal of IFAC):

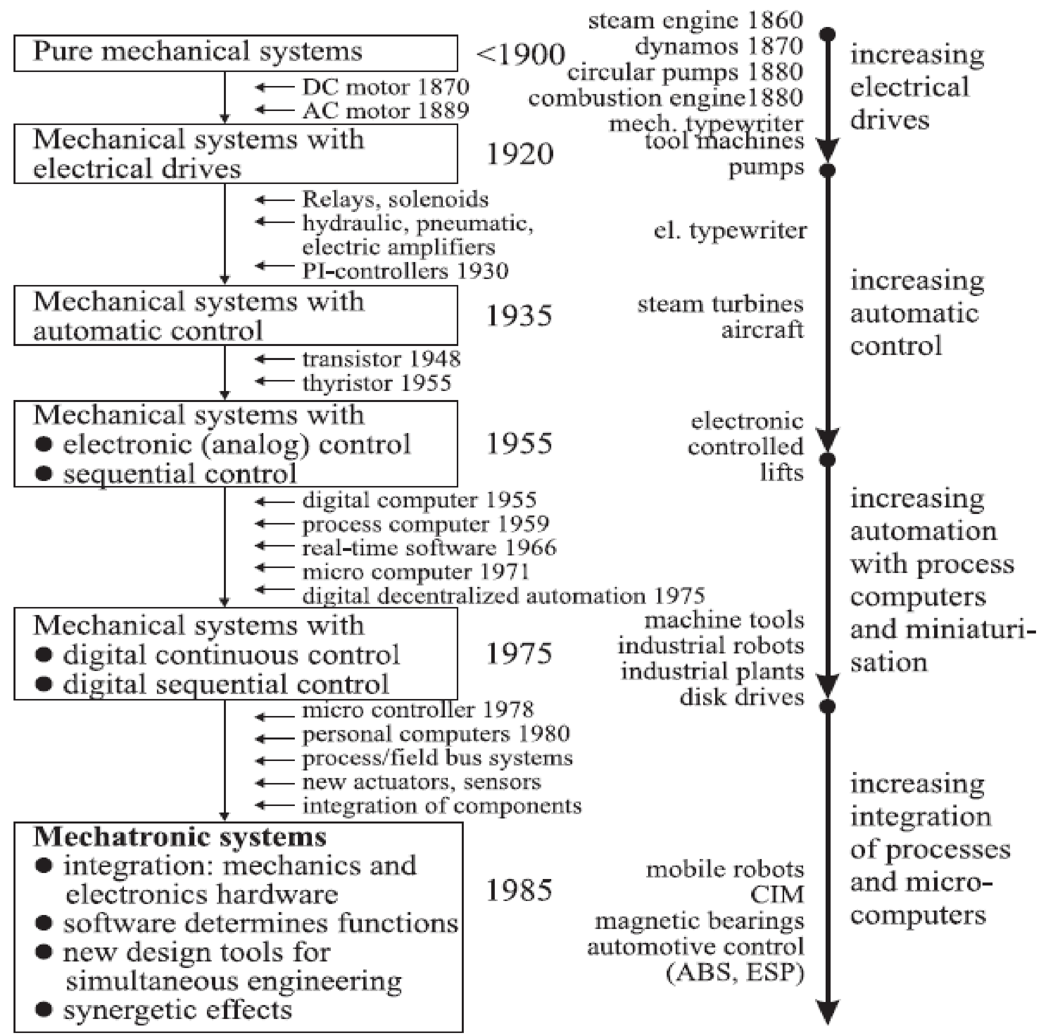
"Mechatronics is the synergistic combination of precision mechanical engineering, electronic control and systems thinking in the design of products and manufacturing processes. It relates to the design of systems, devices and products aimed at achieving an optimal balance between basic mechanical structure and its overall control."

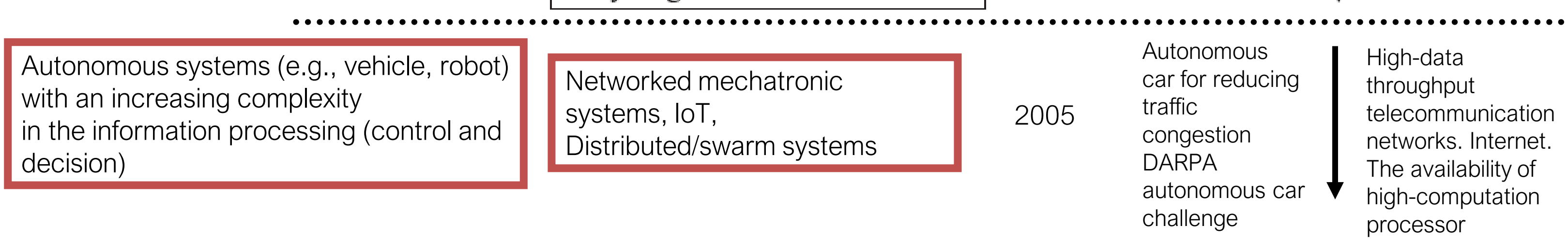
From **IEEE/ASME Transactions on Mechatronics**:

"Its scope encompasses all practical aspects of the theory and methods of mechatronics, the synergetic integration of mechanical engineering with electronic and intelligent computer control in the design and manufacture of industrial products and processes."

History

- The timeline on the right is taken from (Isermann, 2008).
- The year is indicative.
- The bottom description is added by me.



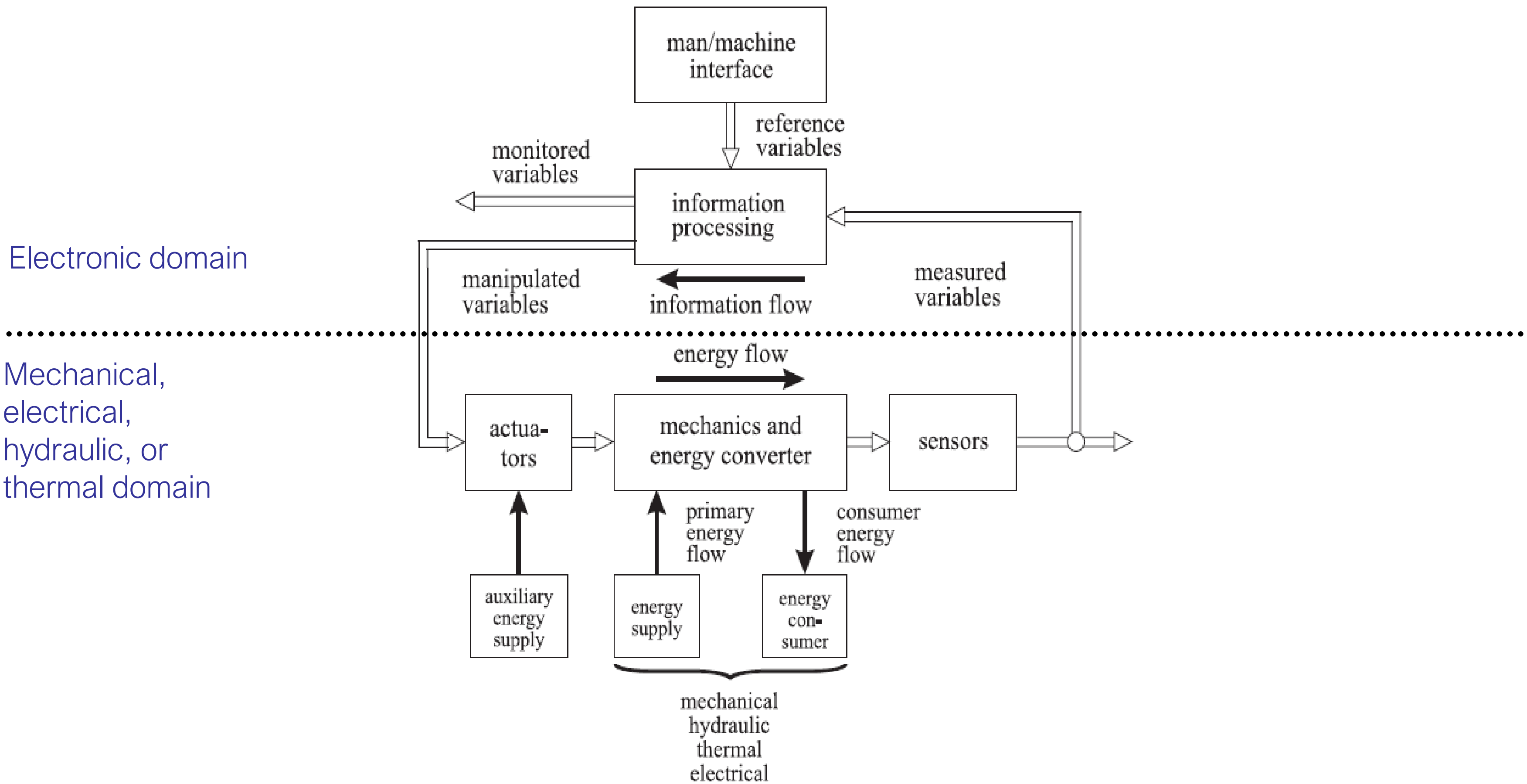


Mechatronics diagram

The figure is taken from (Isermann, 2008).

Electronic domain

Mechanical, electrical, hydraulic, or thermal domain



Example 1: Advanced cars

According to IEEE Spectrum 15 years ago:

- For a premium-class car, it can contain of up to 100 million lines of software code.

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- It is estimated that 400 – 500 million lines of software code is embedded in current cars.

Example 1: Advanced cars

According to IEEE Spectrum 15 years ago:

- For a premium-class car, it can contain of up to 100 million lines of software code.
- Executed on 70-100 electronic control units distributed in a car.
- It is estimated that 400 – 500 million lines of software code is embedded in current cars.
- Low-end cars have 30 to 50 electronic control units.

Example 1: Advanced cars

The electronics controllers are used to control the following (from IEEE Spectrum, 2009):

Air-bag system	Antilock brakes	Automatic transmission
Alarm system	Climate control	Collision-avoidance system
Cruise control	Communication system	Dashboard instrumentation
Electronic stability control	Engine ignition	Engine control
Electronic-seat control	Entertainment system	Navigation system
Power steering	Tire-pressure monitoring	Windshield-wiper control

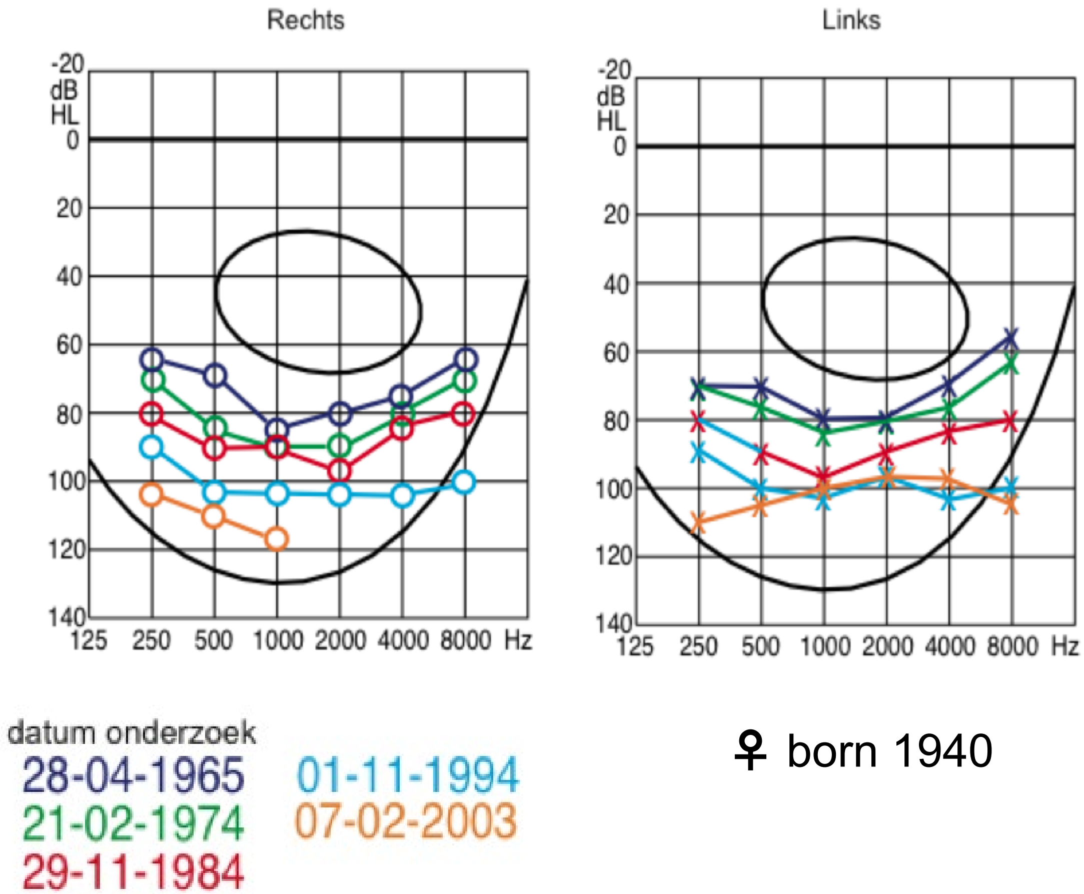
Nowadays also:

- automatic parking system
- adaptive cruise control
- cooperative adaptive cruise control, …

Autonomous vehicles

- Autonomous car (http://www.youtube.com/watch?v=cdgQpa1pUUE) (2012)
- Ideal situation https://www.youtube.com/watch?v=MRPK1rBI_rI
- Smart inventory systems in warehouse – KIVA systems, Amazon robots and Alibaba robots https://www.youtube.com/watch?v=HYjc9h8oSsY
- Quadcopters (http://www.youtube.com/watch?v=w2itwFJCgFQ)

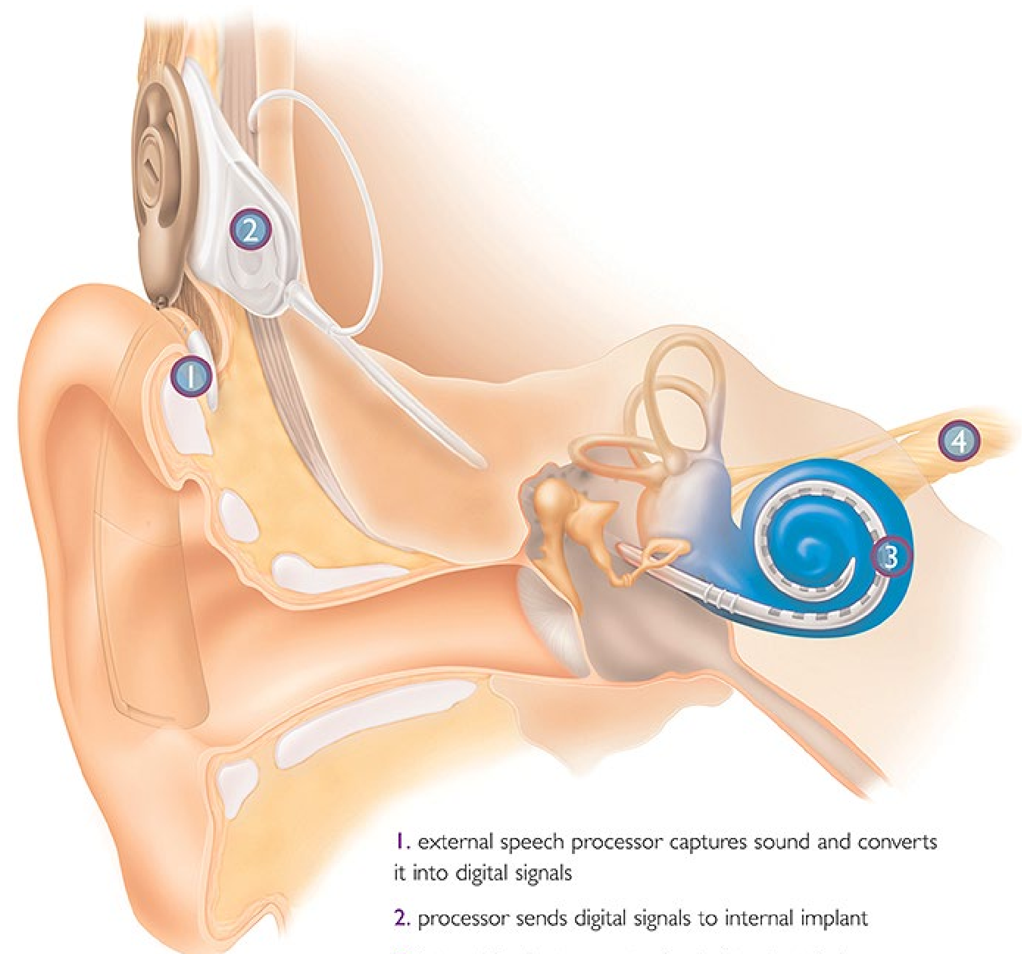
Example 2: Cochlear implant



♀ born 1940

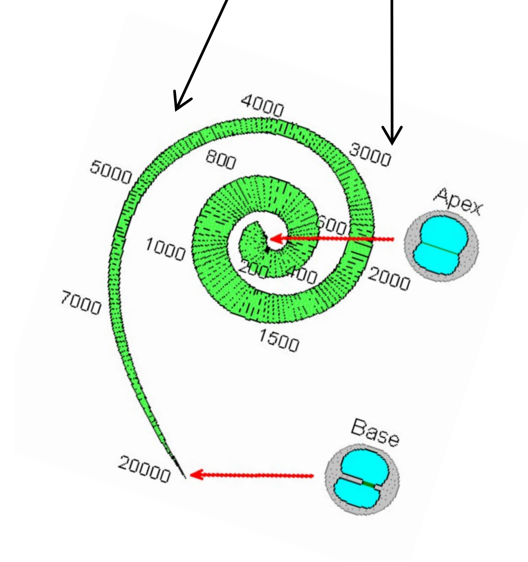
Conductive hearing loss with ageing

The cochlear implant

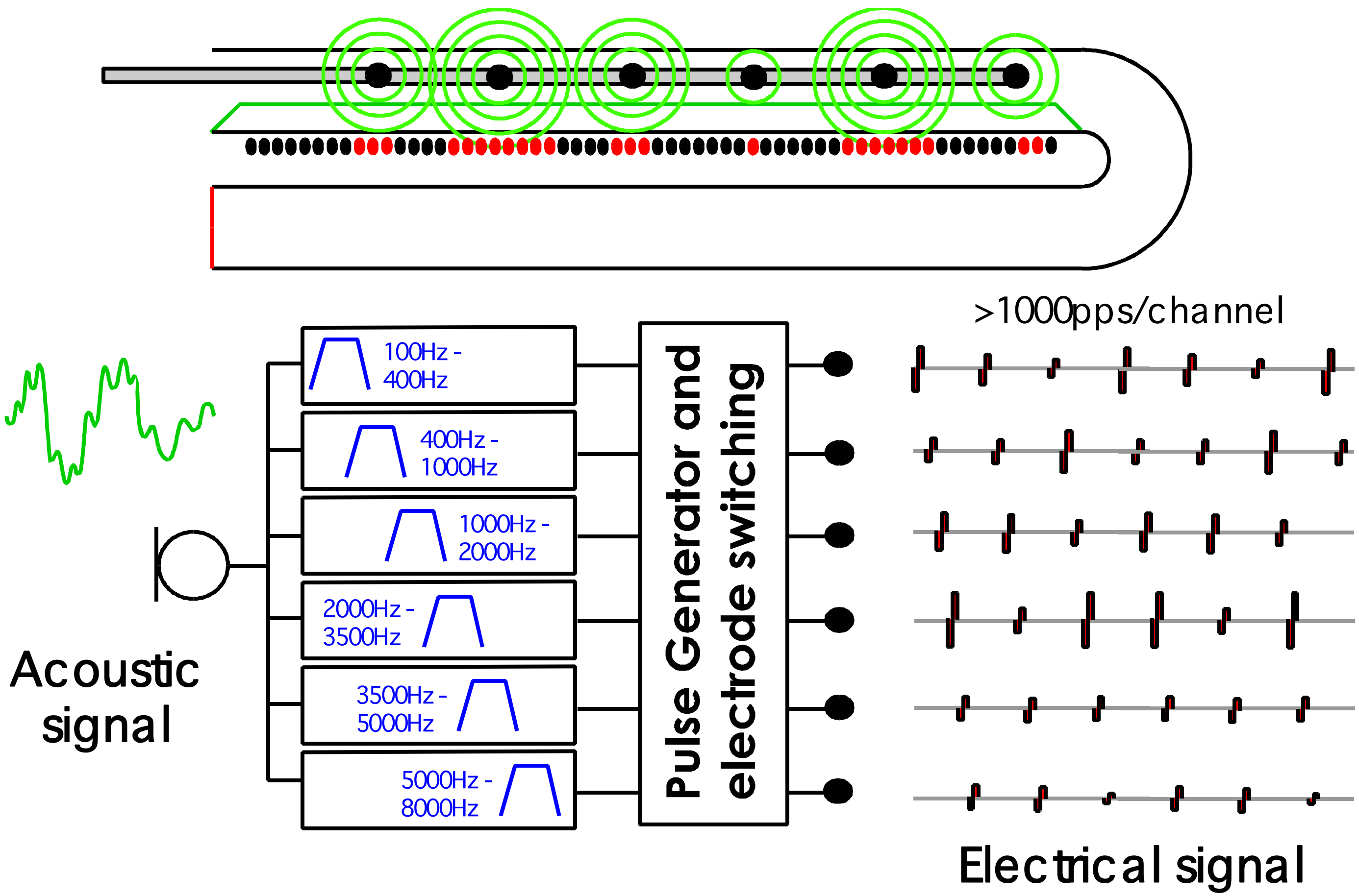


1. external speech processor captures sound and converts it into digital signals
2. processor sends digital signals to internal implant
3. internal implant converts signals into electrical energy, sending it to an electrode array inside the cochlea
4. electrodes stimulate hearing nerve, bypassing damaged hair cells, and the brain perceives signals; you hear sound

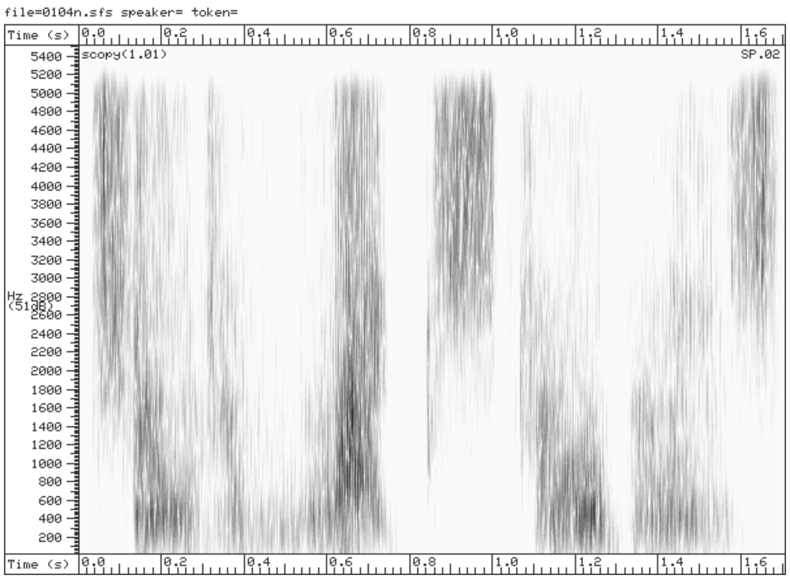
Spatial distribution of auditory nerves with different sensitivity to specific sound frequencies

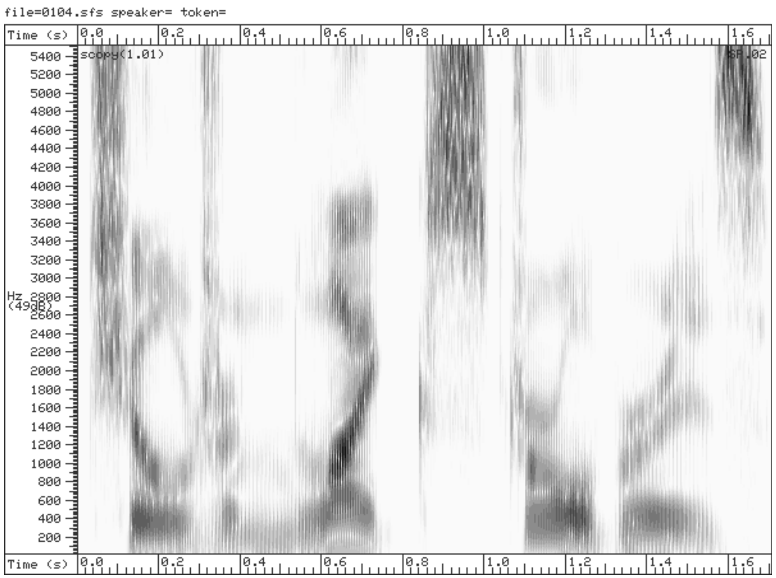


Stimulation of the auditory nerve by electrical pulses



Demo with 6 audio channels





Why mechatronics systems?

- Achieving **high-precision systems**
- **Distributing mechanical tasks**/functions
- **Miniaturization**
- Offering **more functionality**:
  - fault-tolerant systems
  - remote control
  - providing estimation of the systems' states, etc.
- Reconfigurable for **optimal performance** or for having **additional functionality**

The current trends in Mechatronics

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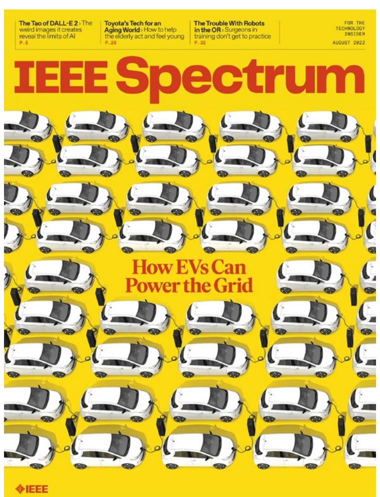
Trends (IEEE Spectrum)

December 2022

November 2022

October 2022

September 2022



August 2022

June 2022

February 2023

March 2023

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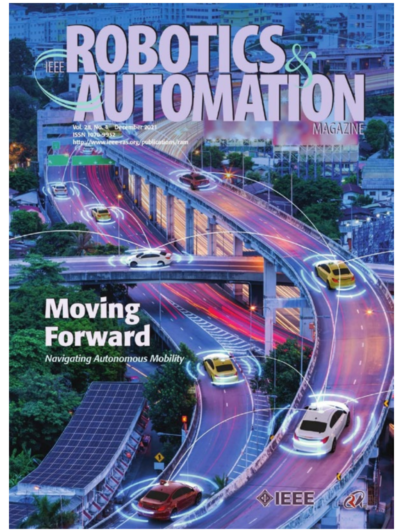
Trends (IEEE RAS)

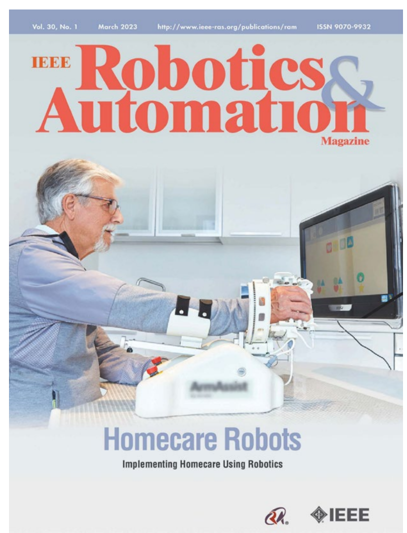
March 2021



December 2021

March 2022

December 2022



March 2023

June 2023

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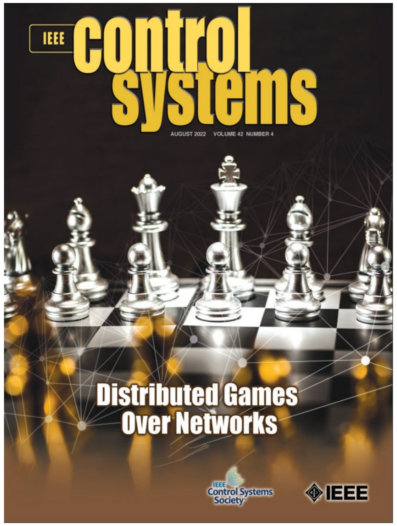
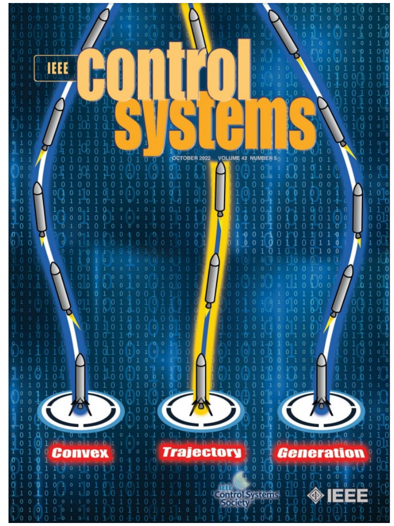
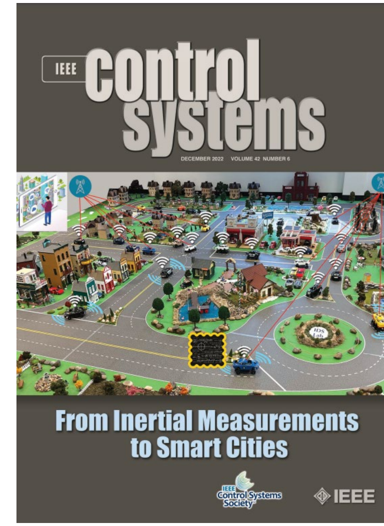
Trends (IEEE CSM)



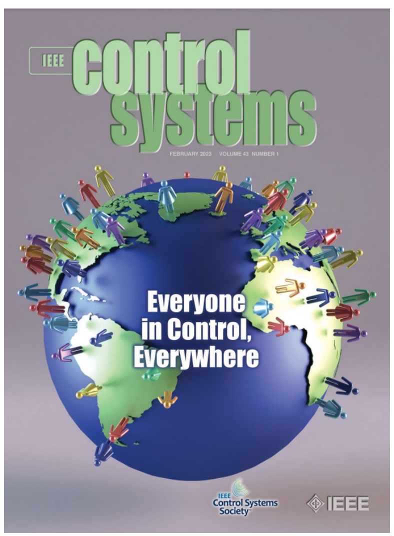
August 2022



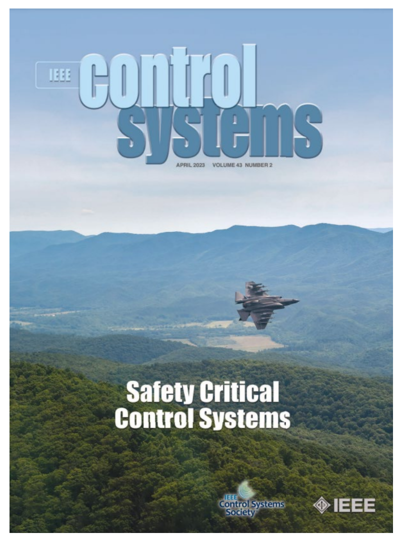
October 2022



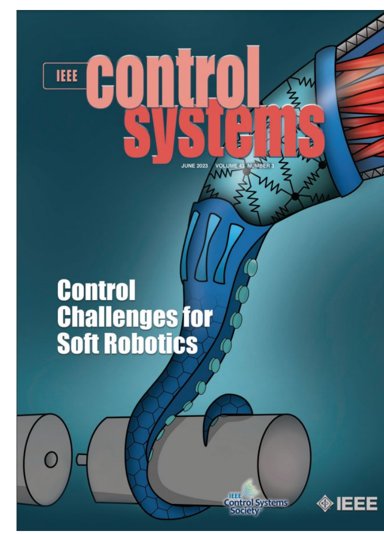
December 2022



February 2023



April 2023



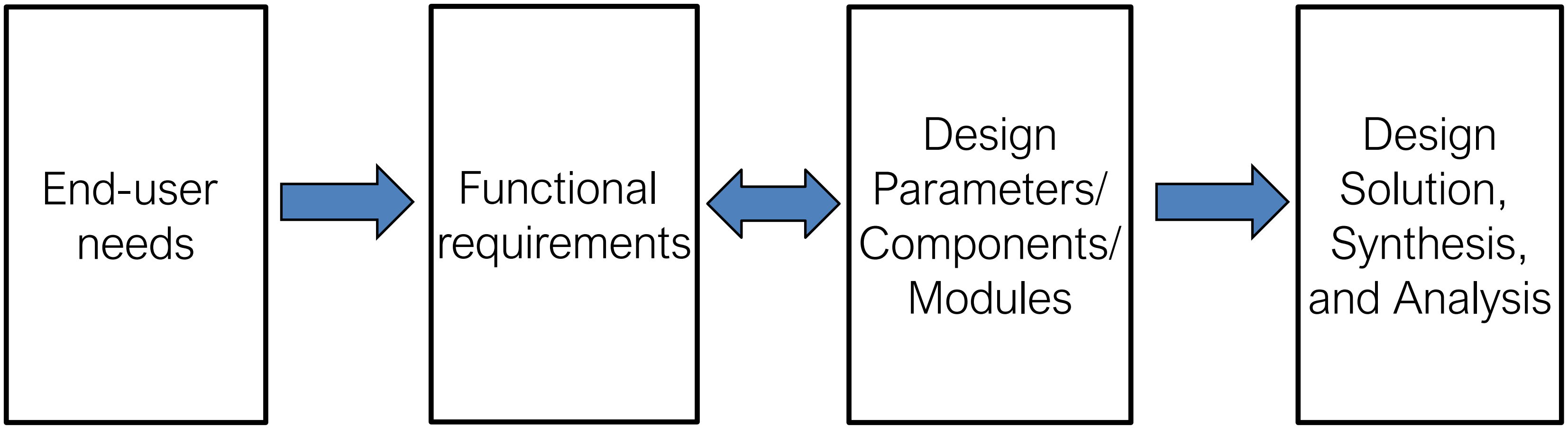
June 2023

Recurrent themes

- Exploration (space, deep-sea)
- Healthcare (prosthetic, artificial organs, MEMS for drug delivery)
- Automotive industry (advanced car, hybrid car, electric car, autonomous car)
- Robots for societal tasks (mail delivery, social therapy)
- Autonomous robots/mechatronics systems (unmanned aerial vehicle (UAV), swarm robots, humanoids)
- Algorithms and AI are important

Mechatronics Design Cycle

Axiomatic design



What is the purpose?
What do they want?
Where will it be used?
Will it be used in conjunction with something else?
Will it depend on other systems?

What do we want to achieve (to meet the demand)?
Any design/physical constraint?
How to quantify the needs?

How do we achieve it?
What components are needed?
What are the possibilities for meeting the requirements?

How do we integrate it?
How to analyze the solution?
How to optimize the design?

Example 1: Design of an artificial limb

Requirements

Requirements include **user demands** and **functional requirements**:

User Demands:

- Walking on two legs possible
- No pain
- Comfortable walking
- Flexible as a human leg

Functional requirements:

- Nervous system steers the leg movements
- The lifetime of all elements should be ‘x’ number of years
- Joints in knee and ankle with maximally ‘x’ damping/friction
- The limb should be able to carry a weight of ‘x’ kg

Specifications

Specifications include the **design parameters**:

- The material of the limb is stiff enough, i.e., >x and <y
- Flexibility of the joint is between x and y
- Sensors to determine signals from the nervous system
- The accuracy of the sensors is between x and y

Example 2: Design of a Prosthetic Arm

Figure 1: Prosthetic hand designed by Zhe Xu and Emanuel Todorov at the University of Washington.

Design of a Prosthetic Arm

End-user needs:
Everything that the user may ask.

→

Functional Requirements:
How do we translate user demands into technical and measurable requirements?

↔

Design Parameters/ Components/ Modules:
How do we achieve it?
What components are needed?

→

Design Solution, Synthesis and Analysis:
How do we integrate it?
How to optimize the design?

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Design of a Prosthetic Arm

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Design Solution, Synthesis and Analysis:
How do we integrate it?
How to optimize the design?

- Be light
- Be cheap
- Look like a real hand
- Be durable

Design of a Prosthetic Arm

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Design Solution, Synthesis and Analysis:
How do we integrate it?
How to optimize the design?

- Be light
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- Lifespan ~ 5 years
- Weight = 1 kg
- Must be able to open and close in less than 0.5 sec
- The power source must have an autonomy of 3 days

Design of a Prosthetic Arm

End-user needs:	Functional Requirements:	Design Parameters/ Components/ Modules:	Design Solution, Synthesis and Analysis:
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- High-precision servomotors to move the fingers and the wrist.
- The use of a lithium-ion polymer battery as a power source.
- Force sensors in the fingers joints to avoid squashing objects.

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Design Solution, Synthesis and Analysis:
How do we integrate it?
How to optimize the design?

- Controller design
- Modeling and simulation
- Systems integration

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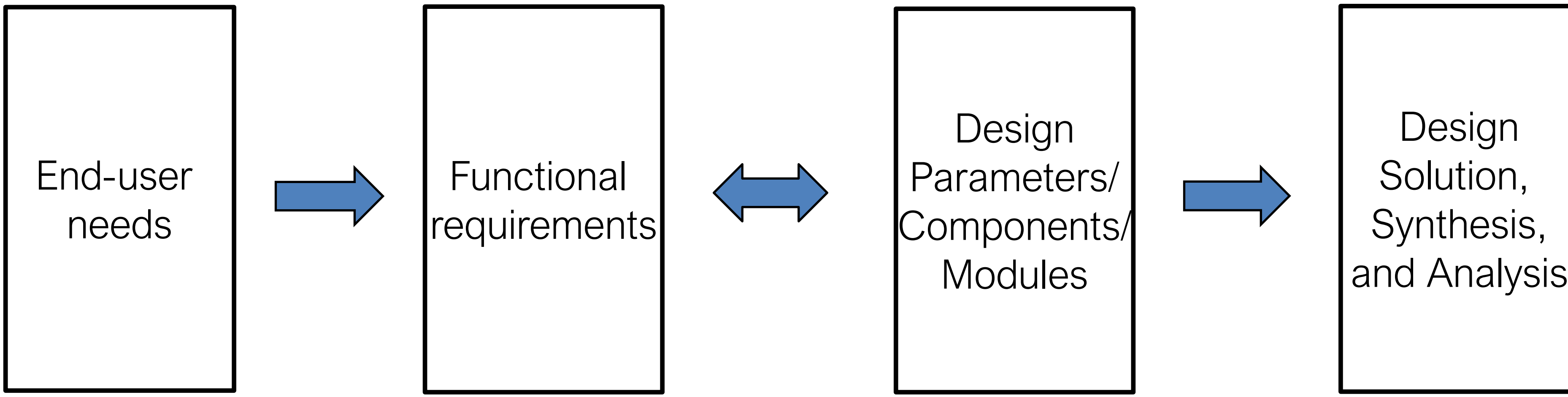
Example 3: Automated Guided Vehicle design

Automated Guided Vehicle design

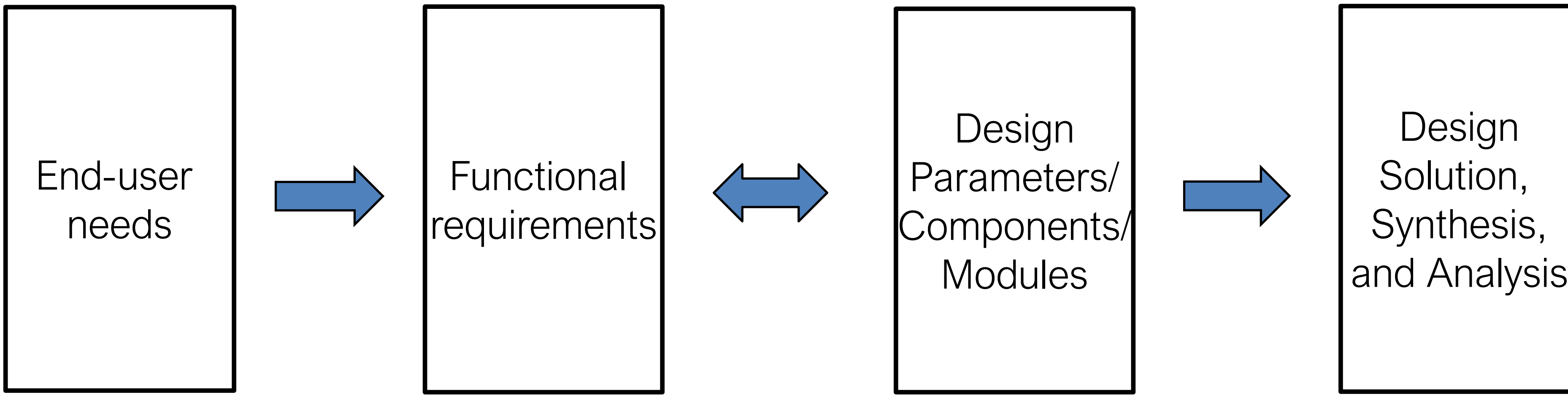


Automated Guided Vehicle design

End-user needs → Functional requirements ↔ Design Parameters/ Components/ Modules → Design Solution, Synthesis, and Analysis

The AGV can follow a marked line.
It can identify stop and start sign.
It can carry loads of up to 1kg.
It can reach and maintain constant speed within 0.1s.
Low power consumption.

Automated Guided Vehicle design



The AGV can follow a marked line.
It can identify stop and start sign.
It can carry loads of up to 1kg.
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Low power consumption.

Stabilize/maintain the AGV within 1cm from its centerline.
It is robust/adaptive to the variation on the weight up to 2kg.
Settling time (the speed control) of 0.05s.
Total power consumption < 10W.

Automated Guided Vehicle design

End-user needs → Functional requirements ↔ Design Parameters/ Components/ Modules → Design Solution, Synthesis, and Analysis

End-user needs

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Design Parameters/ Components/ Modules

Position control using camera with resolution of 1mm.
The mechanical design has to accommodate for mass of up to 2kg.
Velocity sensor (tacho, encoder) or stepper motor (without velocity feedback).
Low friction in mechanism, choice of motors.

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Automated Guided Vehicle design

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Design Solution, Synthesis, and Analysis

Controller design.
Modeling and simulation.
Systems integration

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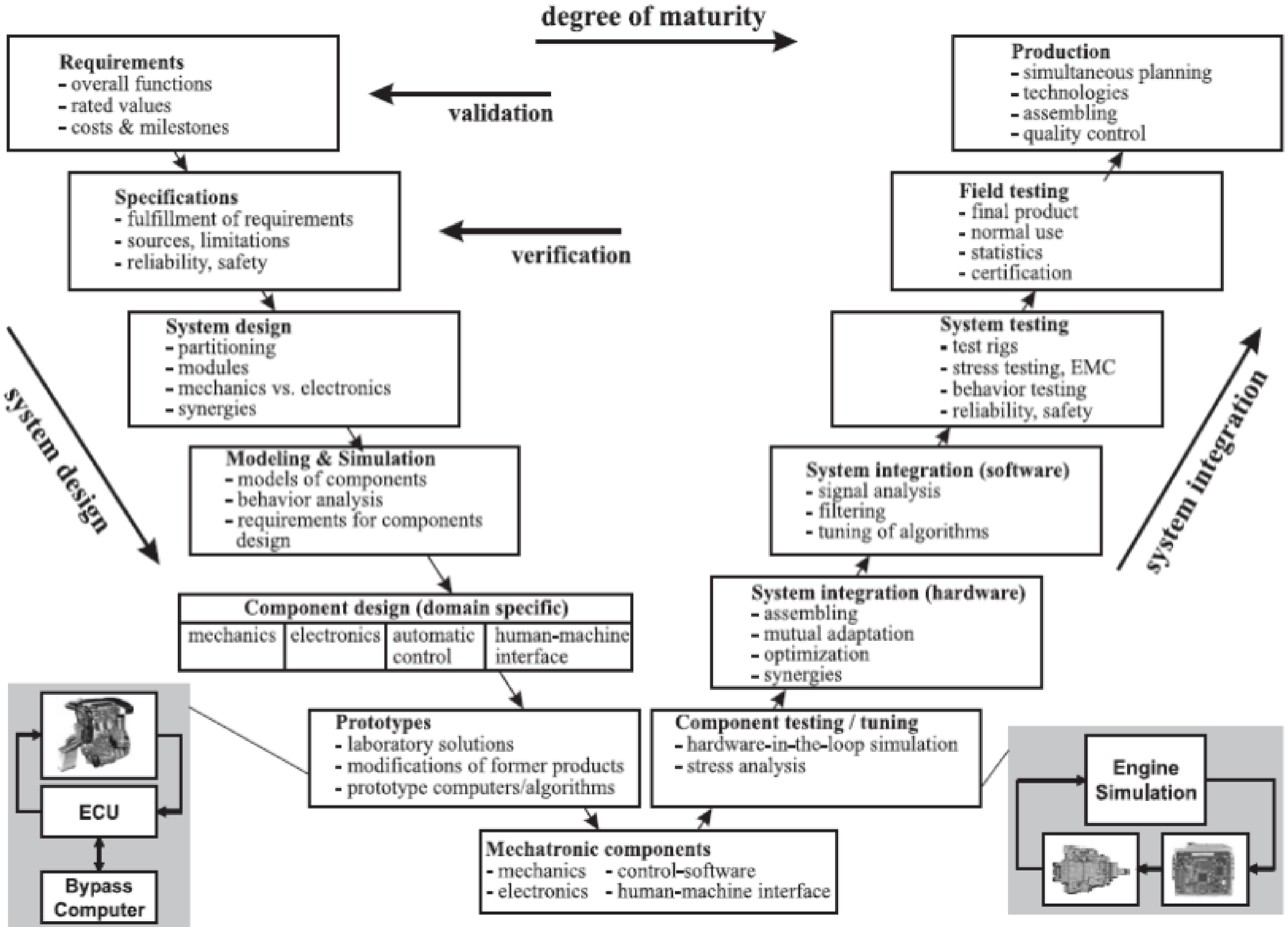
V-diagram



Example: Design of an artificial limb

System Design:
overall design with
all specifications

System Design:
overall design with all specifications

→

Modeling and Simulation:
CAD/CAM or other design to model and simulate

→

System Design: overall design with all specifications

→

Modeling and Simulation: CAD/CAM or other design to model and simulate

→

Component Design: zoom in on the details of the limb and joints, etc.

→

System Design: overall design with all specifications

→

Modeling and Simulation: CAD/CAM or other design to model and simulate

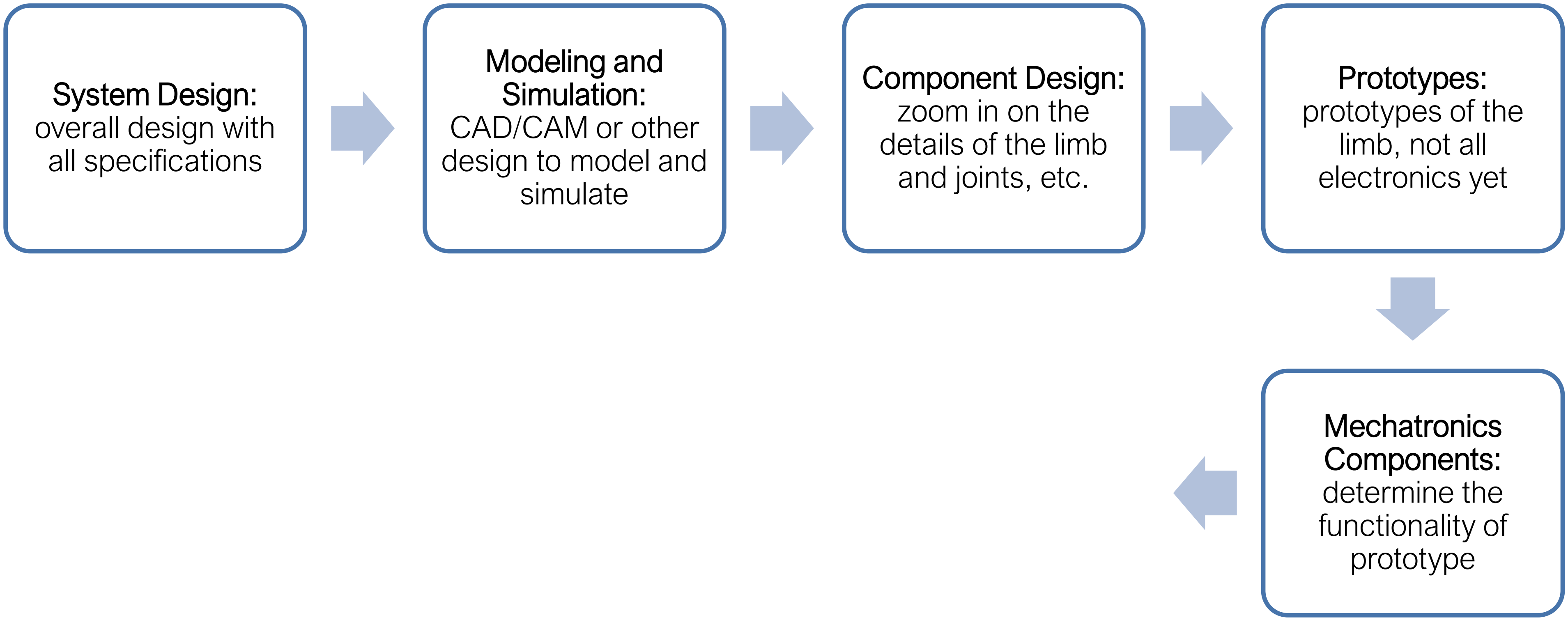
→

Component Design: zoom in on the details of the limb and joints, etc.

→

Prototypes: prototypes of the limb, not all electronics yet

↓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Modeling and Simulation: CAD/CAM or other design to model and simulate
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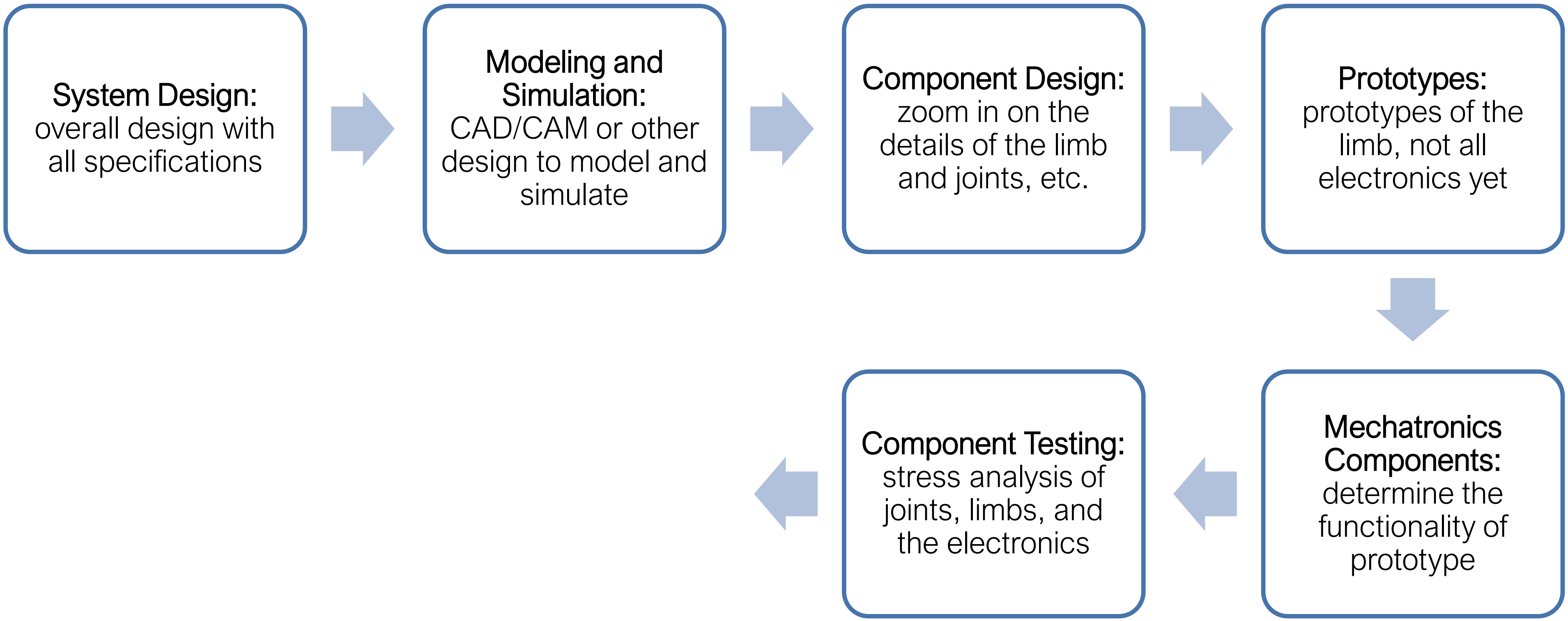
Prototypes: prototypes of the limb, not all electronics yet
Mechatronics Components: determine the functionality of prototype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Modeling and Simulation: CAD/CAM or other design to model and simulate
Component Design: zoom in on the details of the limb and joints, etc.
Prototypes: prototypes of the limb, not all electronics yet
Mechatronics Components: determine the functionality of prototype
Component Testing: stress analysis of joints, limbs, and the electronics

System Design: overall design with all specifications

Modeling and Simulation: CAD/CAM or other design to model and simulate

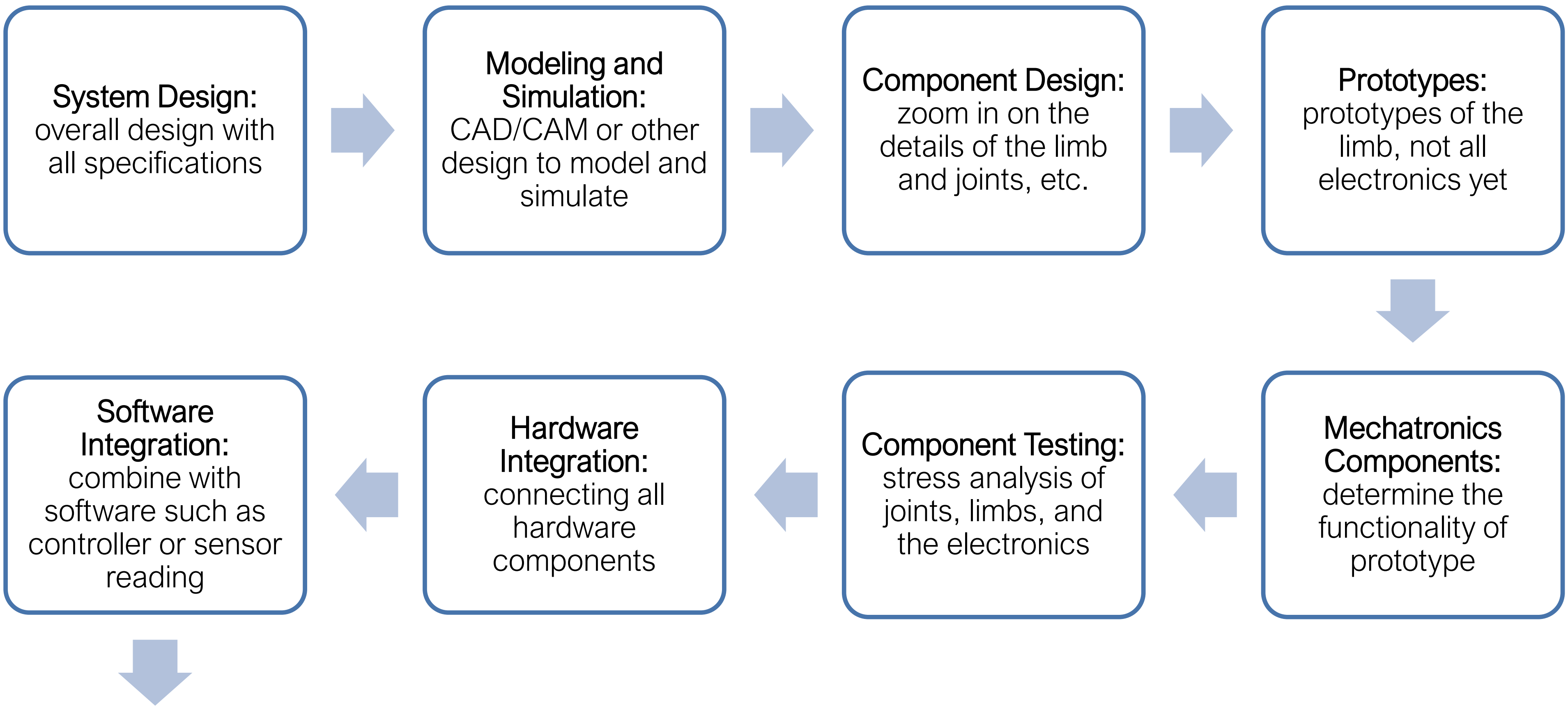
Component Design: zoom in on the details of the limb and joints, etc.

Prototypes: prototypes of the limb, not all electronics yet

Mechatronics Components: determine the functionality of prototype

Component Testing: stress analysis of joints, limbs, and the electronics

Hardware Integration: connecting all hardware components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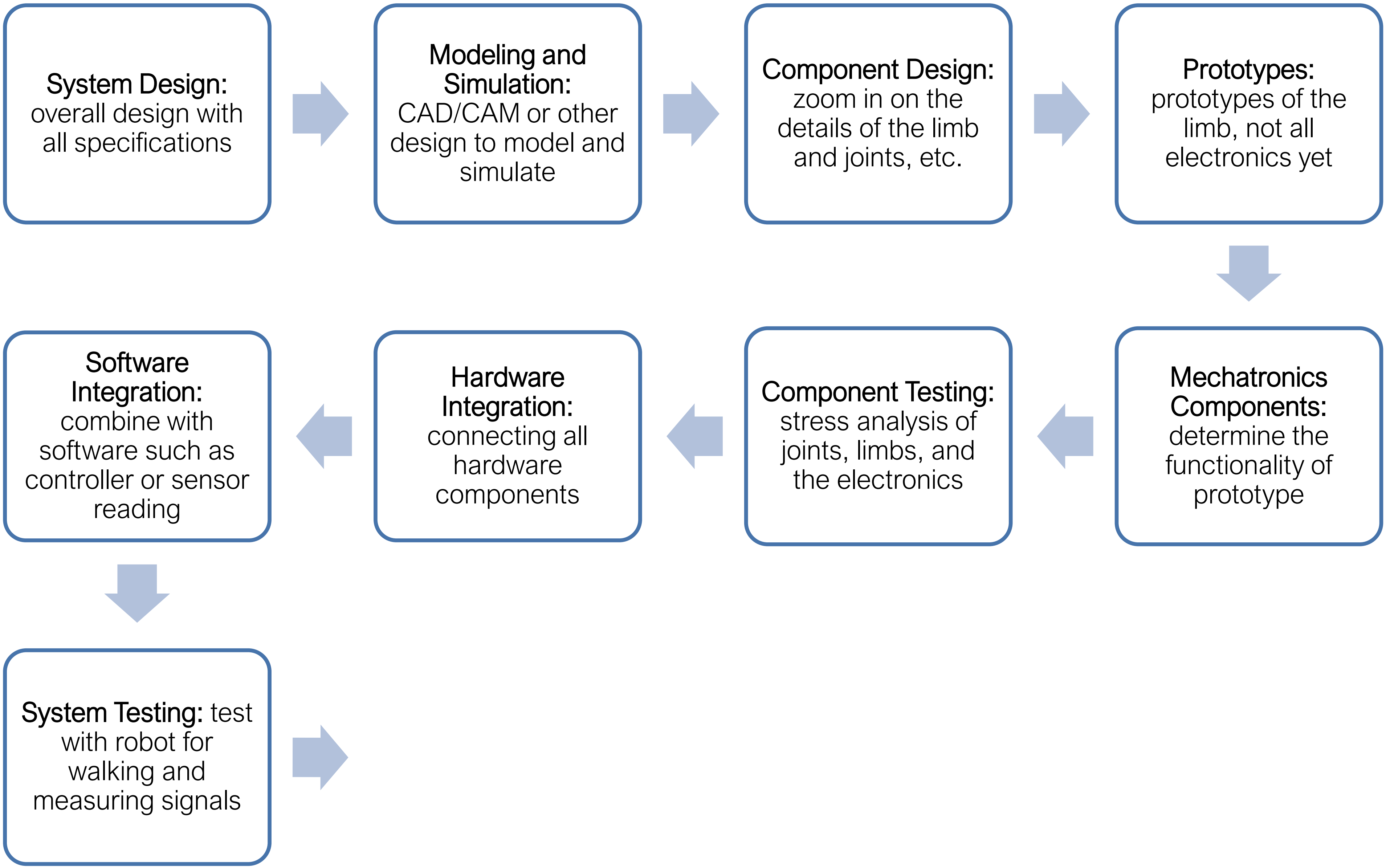
Modeling and Simulation: CAD/CAM or other design to model and simulate
Component Design: zoom in on the details of the limb and joints, etc.
Prototypes: prototypes of the limb, not all electronics yet
Mechatronics Components: determine the functionality of prototype
Component Testing: stress analysis of joints, limbs, and the electronics
Hardware Integration: connecting all hardware components
Software Integration: combine with software such as controller or sensor reading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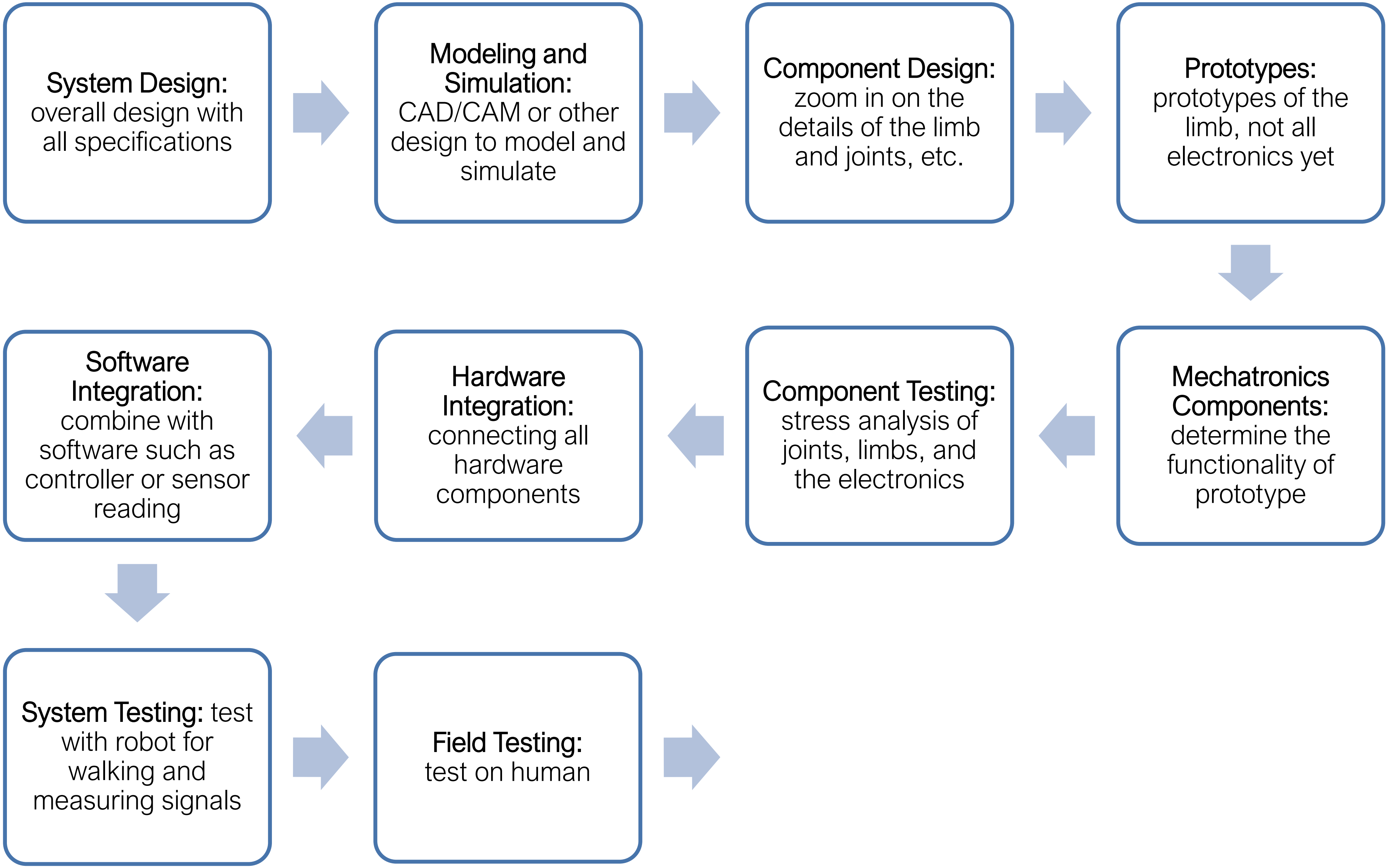
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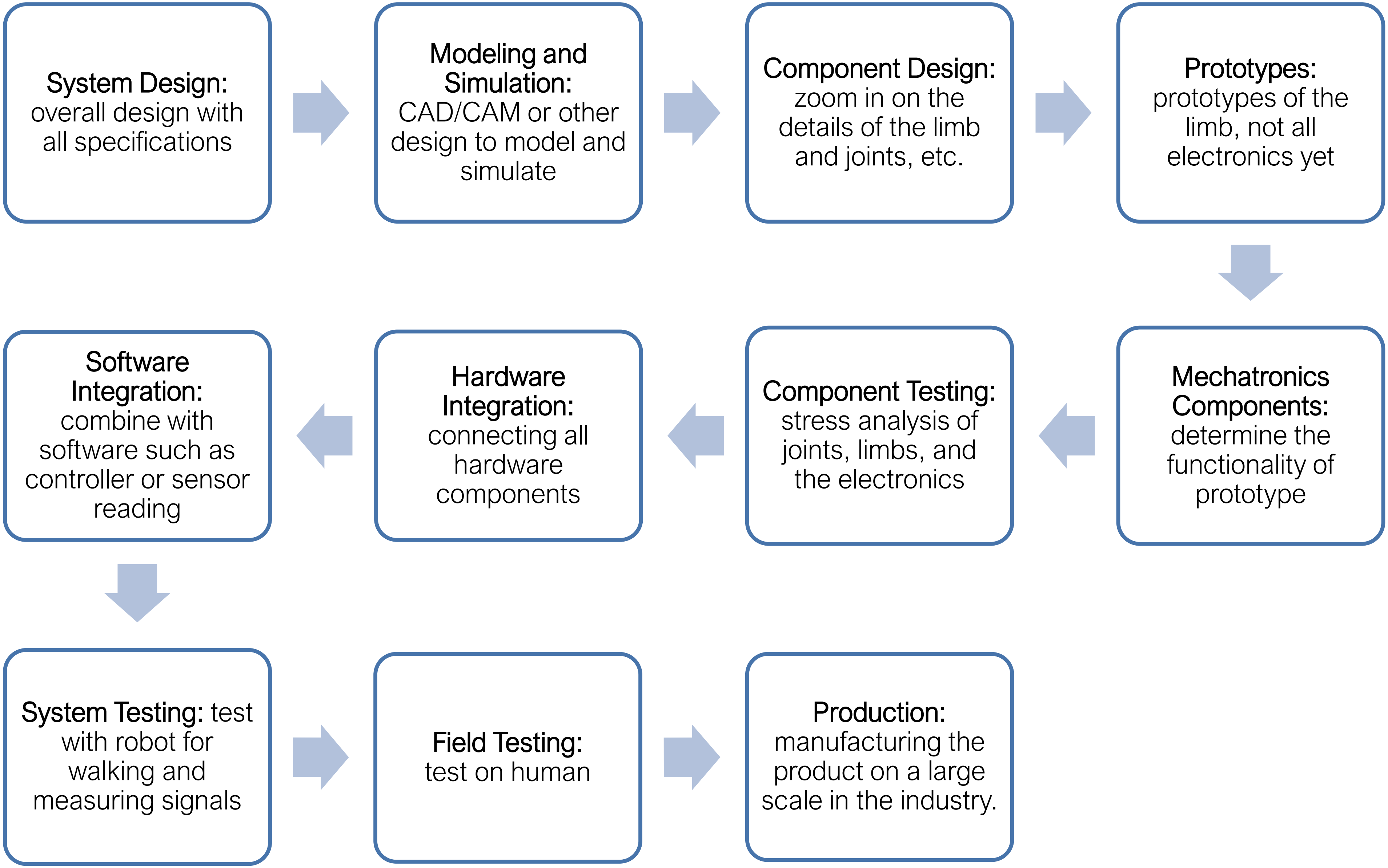
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System Testing: test with robot for walking and measuring signals
Field Testing: test on human
Production: manufacturing the product on a large scale in the industry.

Next

- Sensors, actuators, and systems engineering

Next week:

- Lectures on modeling of dynamical systems