Lecture 1: **Intro; Kinematic Foundations**
Reading: Hartenberg and Denavit Chapter 2
Mason section 2.1
Sciavicco and Siciliano section 1.3.

- Course goals, syllabus, logistics.
- Basic kinematic concepts.
- Kinematic mechanisms.

Lecture 2: **Differential Geometry**
Reading: handouts

- Groups
- Manifolds
- Tangent vectors, tangent spaces, vector fields
- Cotangent vectors, cotangent spaces, one-forms

Lecture 3: **Rotations I**
Reading: Sciavicco and Siciliano sections 2.1–2.6
Salamin

- Rotation matrices
- Lie groups and SO(n)
- Euler angles; Angle axis

Lecture 4: **Rotations II**
*Reading:*Sciavicco and Siciliano sections 2.1–2.6.

- Unit quaternion
- Matrix exponential; so(n)

Lecture 5: **Displacements**
Reading: Sciavicco and Siciliano section 2.7

- Homogeneous coordinates
- Special Euclidean group SE(n); se(n)
- metrics
- Screw (that's not a verb) theory

Lecture 6: **Forward Kinematics I**
Reading: Sciavicco and Siciliano sections 2.8, 2.9.

- Joint space, operational space, special frames

- Denavit-Hartenberg conventions
- Kinematics of planar arm

Lecture 7: **Forward Kinematics II**
Reading: Sciavicco and Siciliano sections 2.8, 2.9

- Kinematics of anthropomorphic arm
- Beyond Denavit-Hartenberg
- Kinematics of mobile robots

Lecture 8: **Reverse Kinematics I**
Reading: Sciavicco and Siciliano sections 2.10–2.12

- Workspace and redundancy
- Geometrical solution of planar arm

Lecture 9: **Reverse Kinematics II**
Reading: Sciavicco and Siciliano sections 2.10–2.12

- Solution of anthropomorphic arm
- Theorems

Lecture 10: **Differential Kinematics I**
Reading: Sciavicco and Siciliano sections 3.1–3.7

- Jacobian matrix
- Coordinate charts
- Singularity and redundancy

Lecture 11: **Differential Kinematics II**
Reading: Sciavicco and Siciliano sections 3.1–3.7

- Anthropomorphic arm
- Nonholonomic systems
- Mobile robots

Lecture 12: **Statics**
Reading: Sciavicco and Siciliano sections 3.8, 3.9

- The Virtual Work argument
- Duality of force and motion
- Velocity and force transformations

Lecture 13: **Trajectory planning**
Reading: Sciavicco and Siciliano chapter 5

- Paths and trajectories
- Interpolating splines
- Interpolation in the tangent space

Lecture 14: **Planning**
Reading: Handouts

- Configuration space
- Potential fields
- Search in tangent space
- Random graphs in configuration space
- Grasp planning

Lecture 15: **Differential Equations**
Reading: Handouts (Luenberger)

- Existence and uniqueness of solutions
- The general solution to linear ordinary differential equations
- The exponential
- Eigenvectors and eigenvalues
- Equilibria
- Stability (classic)

Lecture 16: **Linear Control by Example**
Reading: Handouts
Sciavicco and Siciliano Appendix C

- System modelling
- State space representation
- Control design
- Stability analysis (Lyapunov)

Lecture 17: **Transform Theory I**
Reading: Handouts

- The Laplace-Transform

- Block Diagram Manipulation
- System equivalence
- Feedback
- Stability analysis (Routh and Lyapunov)

Lecture 18: **Transform Theory II**
Reading: Handouts

- Discrete time systems
- General solution to ordinary linear difference equations
- The Z-Transform
- Stability analysis (discrete time classic)

Lecture 19: **Linear Systems I**
Reading: Handouts (Chen)

- The State-Transition Function
- The Matrix Exponential
- Cayley-Hamilton theorem
- Similarity transforms
- Canonical forms

Lecture 20: **Linear Systems II – controllability**
Reading: Handouts (Chen and Brogan)

- What is controllability
- The controllable subspace
- Testing for controllability

Lecture 21: **Linear Systems III – observability**
Reading: Handouts (Chen and Brogan)

- What is observability
- The observable subspace
- Testing for observability

Lecture 22: **Linear Systems IV – realization**
Reading: Handouts (Chen)

- System equivalence

- Normal forms
  - input
  - output
  - balanced
  - minimal
- Canonical decomposition of LTI systems

Lecture 23: **Linear Systems – Pole Placement**
Reading: Handouts (Chen)

- Pole-Placement theorem
- Design of state-feedback controllers
- Full-dimensional state estimator

Lecture 24: **Linear Systems – Pole Placement**
Reading: Handouts (Chen and Kalman)

- Reduced-order state estimator
- Integrated estimation and control
- The Kalman filter

Lecture 25: **Dynamics of Mechanisms I**
Reading: Sciavicco and Siciliano Chpt. 4

- Lagrangian formulation
- Newton-Euler formulation

Lecture 26: **Dynamics of Mechanisms II**
Reading: Sciavicco and Siciliano Chpt. 4

- Models of simple manipulators
- Computational issues
- Stability

Lecture 27: **Control of Mechanisms I**
Reading: Sciavicco and Siciliano Chpt. 6

- Joint space control
- Independent joint control
  - Structure
  - Stability

  - Performance

- Computed torque control
  - Structure
  - Stability
  - Performance

Lecture 28: **Control of Mechanisms II**
Reading: Sciavicco and Siciliano Chpt. 6
Whitcomb, Rizzi, and Koditschek TRA 93

- Inverse dynamics control
  - Structure
  - Stability
  - Performance
- Adaptive techniques

Lecture 29: **Control of Mechanisms III – Workspace Control**
Reading: Sciavicco and Siciliano Chpt. 6
Hutchinson, Hager, and Corke
Khatib
Raibert and Craig

- Visually guided control
- Operational space control
- Hybrid force-position control