MASSACHUSETTS INSTITUTE OF TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

2.671 Measurement and Instrumentation

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Course Contents

- Background, History and Future
  - The development of measurement standards and units
  - Modern measurement standards, units and approaches
  - The rise of the instrumentation company
  - Linking measurements with control
  - The future: automating the scientific method
- Basic Instrumentation
  - Cables and Connectors
    - Coaxial cables (50 ohm instrument vs 75 ohm video)
    - BNCs and banana plugs
  - Digital Power Supplies
    - Voltage and current control
  - Digital Multimeters
    - DC and AC voltage
    - DC and AC current
    - Ohms (2 and 4 wire measurement)
    - Temperature (thermister, thermocouple, RDT)
    - Capacitance
  - Digital Oscilloscopes
    - DC and AC coupling
    - Averaging
    - Triggering
    - YT vs XY modes
    - Power spectrum
  - Function Generators
    - Sinusoids
    - Square waves (variable high low times)
    - Triangular waves
    - Arbitrary waveforms
  - Pulse Generators
  - Filters
    - Lowpass
    - Highpass
    - Bandpass and notch
  - Input output impedance and instrument loading

- Basic Electronics
  - Resistors
    - Fixed (1% and better, carbon, metal film and wire wound)
    - Variable (potentiometers)
    - Power resistors
  - Capacitors
    - Nonpolarized (silver mica, polycarbonate, polyester, ceramic)
    - Polarized (tantalum, electrolytic)
    - Super-capacitors
  - Inductors (fixed and variable)
  - Batteries
    - Rechargeable (Lithium ion, lead acid)
    - Single use (alkaline)
  - Diodes
  - LEDs
  - Relays (AC and DC)
  - Transformers (fixed and variable)
  - Passive resistor, capacitor & inductor circuits (low & high pass filters)
    - Impedance transfer function analysis via Laplace transforms
    - Voltage transfer function analysis via Laplace transforms
  - Voltage regulators, voltage references
  - Operational Amplifiers
    - 741 type
    - Input and output impedance
    - Offset voltage and bias currents
    - Open and closed loop bandwidth
    - Buffers
    - Inverting and noninverting with gain
    - Summing, subtraction. differentiation and integration
    - Lowpass and highpass filters
    - Rectification (half and full wave (absolute value))
  - Power Amplifiers
    - Current vs voltage output
  - Instrumentation Amplifiers
    - Common mode rejection ratio
    - Sensor bridge configurations
  - Digital Electronics
    - Logic elements and families
    - Counters and oscillators
- Computer Basics
  - Computer processors, memory and operating systems
  - Screen resolution and color representation
  - Computer i/o
    - Serial ports (RS 232) and parallel ports
    - Universal serial bus (USB and USB-2)
    - Firewire ports (IEEE 1394, iLink) and digital video
    - Wireless : WiFi (802.11a/b,g,n), Bluetooth, ZigBee
    - Audio i/o (resolution and sampling rates)
  - Languages and Environments
    - Visual Basic and Visual C#
    - Matlab and Mathcad, Excel, LabView
  - Analog i/o (ADC and DAC resolution and speed)

- Signal Processing, System Identification and Parameter Estimation
  - Analog to Digital Conversion (ADCs)
  - Digital to Analog Conversion (DACs)
  - Aliasing and Nyquist frequency (in time and space)
  - Means, standard deviation, RMS and variance
  - Probability Density and Distribution Functions
    - Central limit theorem
  - Digital Signal Generation
    - Sinusoids
    - Binary white noise
    - Gaussian white noise
    - Non-Gaussian non-white noise
  - Least-squares Function Fitting and Assumptions
    - Linear functions
    - Linearizing transformations
    - Nonlinear function fitting
    - Singular value decomposition (SVD)
  - Estimation Error and Parameter Sensitivity Functions
    - Error in both axes
  - Statistical Significance Testing
    - Hypothesis testing
  - Linear Dynamic Signal Analysis
    - Auto-correlation function
    - Power spectral analysis
    - Fourier transforms and FFTs
  - Linear Dynamic System Analysis (System Identification)
    - Cross-correlation functions
    - Impulse response functions (Toeplitz matrix inversion)
    - Convolution and System Output Prediction
    - Frequency response measurements
      - Bode plots
      - Nyquist plots
    - Laplace transforms
    - Transfer function fitting
    - Hankel matrix decomposition
  - Experimental Techniques
    - Impulse inputs
    - Step response and square wave testing
    - Ramp inputs
    - Sinusoidal testing and swept sine testing
    - Stochastic testing
      - Pseudo-random binary inputs (PRBS)
      - Gaussian white noise inputs
      - Optimal input design
  - Nonlinear System Identification
    - Weiner series
    - Volterra series
    - Wiener and Hammerstein systems
    - Parallel cascades

(Note: in places the following sequence follows the chapter organization of
The CRC Measurement, Instrumentation and Sensors Handbook,
CRC & IEEE Press, (J.G. Webster, ed.), 1999. (copies in 2.671 Lab.)

- Spatial Variables Measurement
  - Displacement Measurement (Linear and Angular)
    - Resistive Sensors (e.g. linear and rotary potentiometers)
    - Optical Encoders (e.g. rotary encoders, linear stage encoders)
    - Inductive Displacement Sensors (e.g. LVDTs, Fastar, proximity)
    - Capacitive Sensors (e.g. differential capacitance)
    - Piezoelectric Transducers and Sensors
    - Magnetic Sensors (e.g. Hall effect sensors)
    - Lateral Effect Photodiodes
    - Synchro/Resolver Sensors (e.g. motors)
    - Time of Flight Ultrasonic Sensors
    - Laser Interferometers
    - Confocal Optical Sensors
    - Imaging Systems (e.g. CCD tracking of IR photodiodes)
  - Thickness Measurement
    - Micrometers
    - Laser scanners
  - Distance Measurement
    - Acoustic Time of Flight (e.g. camera focus, room dimensions)
    - Radar
    - Laser Time of Flight
  - Position, Location and Altitude Measurement
    - Altitude Measurement
    - Inertial Navigation
      - MEMS devices
    - Global Positioning System (GPS)
  - Level Measurement
  - Area Measurement
  - Volume Measurement
  - Angle Measurement
  - Tilt Measurement
  - Velocity Measurement (linear and angular)
    - Coil induction
    - Magneto-dynamic
  - Acceleration, Vibration and Shock Measurement
    - Strain gage based accelerometers
    - Quartz accelerometers
    - MEMS accelerometers

- Time and Frequency Measurement

- Solid Mechanical Variables Measurement
  - Mass and Weight Measurement
    - Strain gage
    - Quartz resonant beam
  - Density Measurement
  - Strain Measurement
    - Strain gages
    - Laser speckle interferometry
  - Force Measurement
    - Strain gage force sensors
      - Metal foil
      - Semi-conductor
    - Quartz force sensors
  - Torque and Power Measurement
  - Tactile Sensing

- Fluid Mechanical Variables Measurement
  - Pressure Measurement
    - Barometers and barographs
    - Bourdon tubes, Vidie capsules, MEMS diaphragms
  - Sound Pressure/Level Measurement
    - Human ear response
    - Microphones
      - Moving coil
      - Quartz
      - Piezoelectric
      - Electret
      - Capacitance
  - Flow Measurement
    - Differential Pressure Flow meters
    - Variable Area Flow meters
    - Positive Displacement Flow meters
    - Turbine and Vane Flow meters
    - Impeller Flow meters
    - Electromagnetic Flow meters
    - Ultrasonic Flow meters
    - Vortex Shedding Flow meters
    - Thermal Mass Flow meters
    - Carioles Effect Mass Flow meters
    - Drag Force Flow meters
  - Point Velocity Measurement
    - Pitot Probe Anemometry
    - Thermal Anemometry
    - Laser Anemometry
  - Viscosity Measurement
  - Surface Tension Measurement

- Thermal Variables Measurement
  - Temperature Measurement
    - Solid differential thermal expansion (e.g. bimetallic strips)
    - Liquid expansion (e.g. glass bulb-capillary)
    - Gas/vapor expansion (e.g. refrigerator sensor)
    - Resistivity change (e.g. platinum resistance (RDT))
    - Thermocouples (e.g. Type K and J)
    - Thermistors
    - Semiconductor diodes
    - Infrared sensors
    - Pyroelectric sensors
    - Temperature indicating materials (e.g. battery tester strip)
    - Resonating crystal sensors (e.g. quartz resonant)
  - Thermal Conductivity Measurement
  - Heat Flux Measurement
  - Calorimetry (e.g. differential scanning calorimeter (DSC))
  - Thermal Imaging

- Electrical/Electronic Variables Measurement
  - Voltage Measurement
  - Current Measurement
  - Resistance Measurement
    - 2 wire and 4 wire ohms measurements
  - Charge Measurement
  - Capacitance Measurement
  - Inductance Measurement
  - Magnetic Field Measurement
  - Electrical Impedance Measurement
    - Impedance transfer functions

- Optical Variables Measurement
  - Photometry and Radiometry
    - Photoconductive sensors
    - Photojunction sensors
    - Charge coupled devices (CCD cameras)
    - Photomultipliers
    - Avalanche photodiodes (APDs)
  - Optical Spectrometers
    - UV-VIS spectrometers
    - Fiber spectrometers
  - Polarization Measurement
  - Refractive Index Measurement
  - Imaging Sensors (e.g. CCDs)
    - Charged coupled devices (CCDs)
    - CMOS and Foveon
    - 2D lateral effect photodiodes
    - Bayer masks, frame sequential and lens arrays
- Radiation Measurement

- Chemical Variables Measurement
  - Composition Measurement
  - pH Measurement
  - Humidity and Moisture Measurement
  - Environmental Measurement
    - CO_2, O_2, CO

- Biomedical Variables Measurement
  - Biopotentials and Electrophysiology Measurement
    - Skeletal muscle potentials (electro-myograms (EMG))
    - Heart muscle potentials (electro-cardiograms (ECG,EKG))
    - Eye position potentials (electro-oculargrams (EOG))
    - Brain activity potentials (electro-encephalograms (EEG))
  - Blood Pressure Measurement
    - Pressure cuff (sphygmomanometer)
  - Blood Flow Measurements
  - Respiration Measurements
  - Biomechanics Measurements
  - Blood Chemistry Measurements
    - Blood O_2, Blood glucose
  - Medical Imaging
    - X-Ray Imaging
    - Computerized Axial Tomography (CAT scan)
    - Magnetic Resonance Imaging (MRI)
    - Positron Emission Tomography (PET)
    - Ultrasound Imaging
  - Genomic Measurements
  - Proteomic Measurements

- Actuators/Motors
  - Muscle (actin myosin engine)
  - Linear and rotary solenoids
  - Electric motors
    - DC and AC motors
    - Stepping motors (micro stepping, linear)
  - Voice coil motors (loud speakers, linear actuators)
  - Ribbon (Lorentz force) drivers
  - Galvanometers
  - Faraday motors
  - Linear commutated motors
  - Hydraulic actuators
  - Pneumatic actuators
  - Thermal bimorph actuators
  - Piezoelectric actuators
    - piezo ceramics, piezo polymers
    - piezo bimorphs
  - Magneto strictive actuators
  - Shape memory alloy actuators
  - Photo strictive actuators
  - Contractile polymers (conducting polymers)