ECE 444 / ECE 544 / CS 444 / CS 544
Supervisory Control and Critical Infrastructure Systems

Session 20

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CS & ECE 444/544 Class Project Deliverables

Outline for Report or Presentation

- Introduction with overview of your project and your objectives.
- Provide a little background.
- Describe your project. Show how you modeled, simulated, and/or built your project.
- Present results, demonstrating how your project met the following aspects of ICS systems:
  - Data Acquisition,
  - Data Transmission,
  - Data Processing plus display of processed data or action taken based on the results and
  - Use of a standard communication protocol.
- End with a summary and conclusions,
  - Finish with a description of any further work you or someone could do to (especially for projects where you were limited by

Presentation Format:

- Presentations: Can last up to 10 minutes
  - Include at least slides/graphics of some sort.
  - Show a demonstration if appropriate.
- Students in on campus sections should present in class on either ~~May 2~~ or ~~May 4~~. April 30 May 2
- Off campus students should record presentations and get them to me. We can schedule a Zoom session where I record if needed. These will be shared with the class through a UI managed process.
- Presentations should be completed by **5:00pm** on Friday May ~~3.~~ 3

Report Format:

- Reports: Should be single column, font size of 12 points or higher with a common font (Times, Arial, Calibri, etc.).
- Approximately 5-7 pages with few/small figures, longer if have more figures or larger size figures.
- Due by 5:00pm on Friday May ~~3.~~ 3

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Availability Comparison

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Table 3: Availabilities of Systems to Retrieve all Line Data and Operate Any Breaker

Ethernet LAN	Availability %	Predicted Annual Hours Out of Service
Switches	99.6079	34.3
Shared Hubs	99.7725	19.9
Redundant Switches	99.8932	9.3
Redundant Shared Hubs	99.8945	9.2
Redundant Servers, Routers, Switches	99.9850	1.3

Figure from: G.W. Scheer and D.J. Dolezilek "Comparing the Reliability of Ethernet Network Topologies in Substation Control and Monitoring Networks," 2nd *Annual Western Power Delivery Automation Conference, 2000*

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Relay-to-relay communication

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Table 6: Relay-to-Relay Communications in a Substation

Network	Availability %	Predicted Annual Hours Out of Service
Switches	99.7138	25
Shared Hubs	99.8778	10.7
Redundant Switches	99.9991	.07
Redundant Servers, Routers, Switches	99.9995	.04
Redundant Shared Hubs	99.9998	.01
Direct	99.9999	.00014

no network

Figure from: G.W. Scheer and D.J. Dolezilek "Comparing the Reliability of Ethernet Network Topologies in Substation Control and Monitoring Networks," 2nd *Annual Western Power Delivery Automation Conference, 2000*

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Availability Comparison

Table 3: Availabilities of Systems to Retrieve all Line Data and Operate Any Breaker

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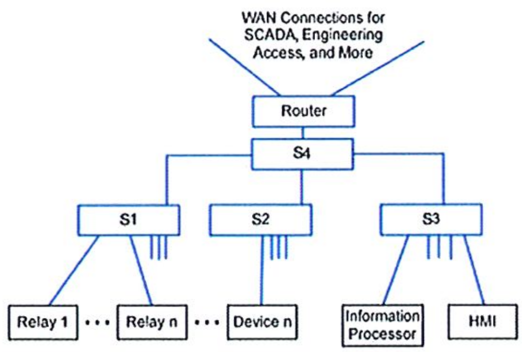
Network Redundancy: Single Network



RTU + other functions

Figure from: V. Skendzic and G.W. Scheer "Performance of Redundant Ethernet Networks for Electric Substation Instrumentation and Control," 11nd *Annual Western Power Delivery Automation Conference, 2000*

Spanning Tree Protocols

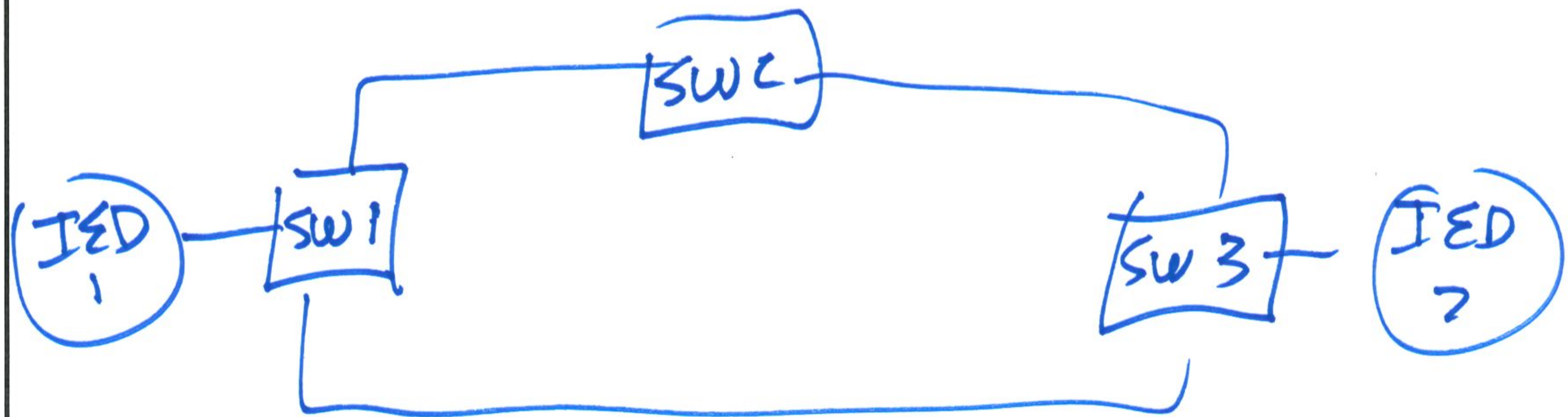
→ Developed originally in enterprise system

- some are fairly slow at identifying problem & rerouting

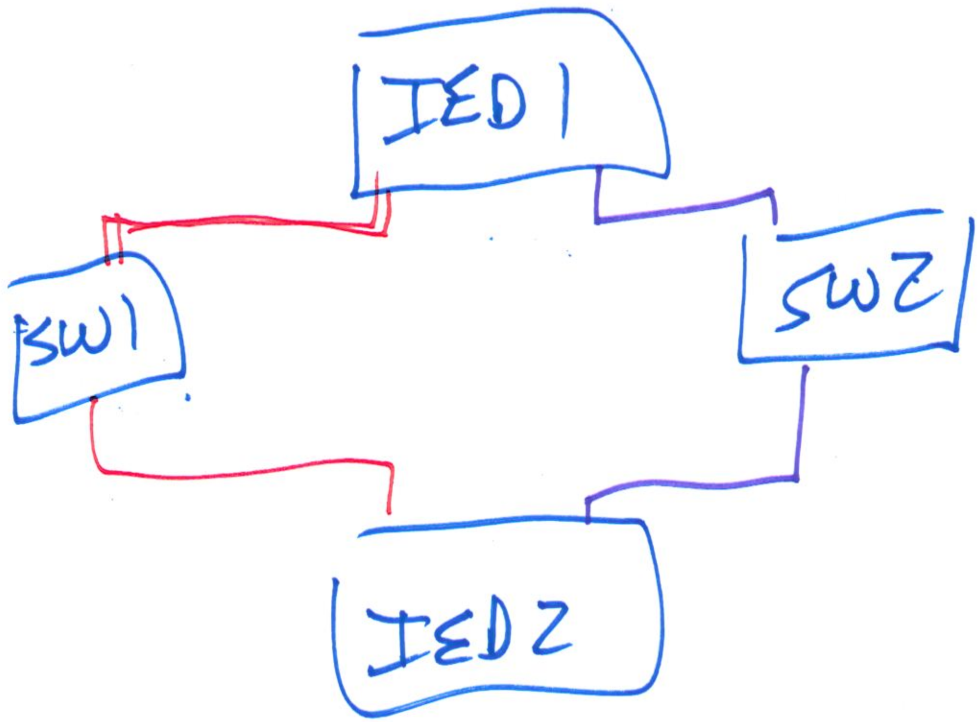
→ Rapid spanning tree protocol

- server monitors state of network
  - dynamic traversing checks
    - sever/reroute - open paths
- can still have problems in time critical cases

High Availability Seamless Redundancy (HSR)



Parallel Redundancy Protocol (PRP)



IEDs connected to two independent networks

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Network Topology: Loop

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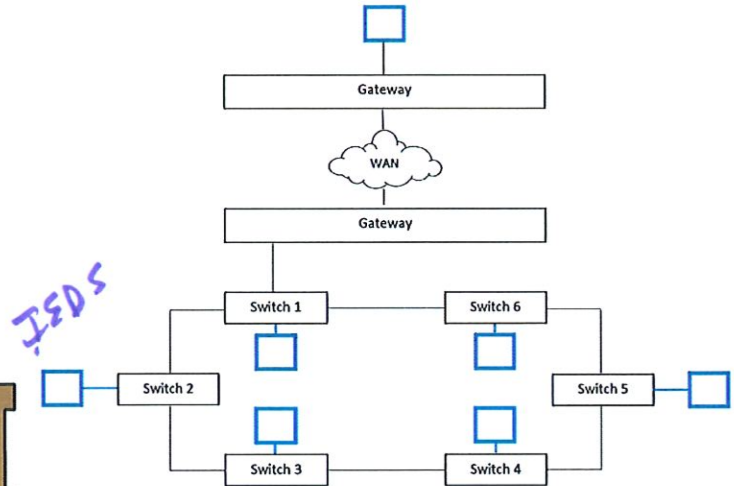

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Network Topology: Ladder

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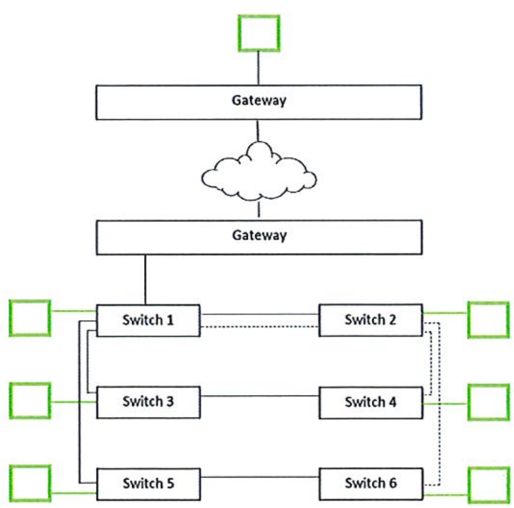

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Industrial Control Systems: From Control Point of View

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- Working down in scale…
  - » Supervisory control
    - communication to distributed devices → measurements & commands
  - » Digital Implementation
    - → Analog system
      - → digitizing (sampling)
        - signal processing
      - system designed using LaPlace domain
    - → digital system → Z-transform

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Industrial Control Systems: From Control Point of View

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- Analog control - what are we controlling
  - options: on/off, classical control (LaPlace), modern control
    - state variable
    - model predictive control
- The actual process
  - ↳ typically physical system - power system
    - mechanical sys
    - chemical process
    - etc...

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Control Example: Cruise Control

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- What is the Process Variable? - what we're controlling
  - speed of a car
- What are the inputs?
  - measured speed
  - throttle position
  - time
  - setpoint
- Forces? (disturbance inputs)
  rolling friction, wind drag, weight/gravity

Feedback diagram

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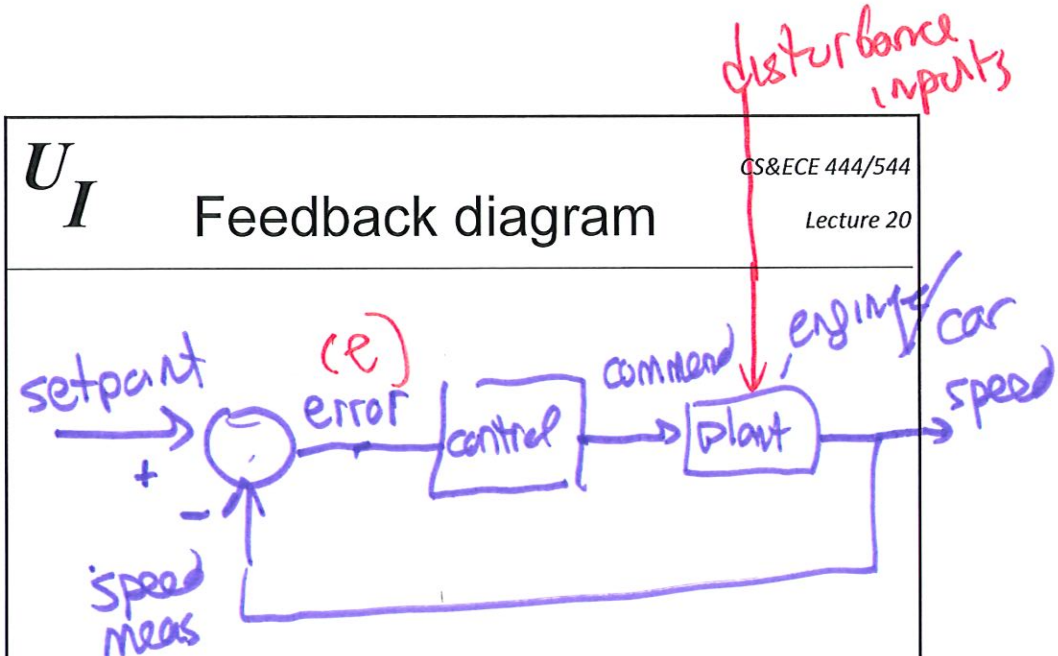

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Control Loop

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- Proportional Control
  - » V (control output) = K_p*e + m_0 (error)
    - – Nominal control position: m_0
    - – Proportional gain: K_p
    - – Error between: e = $vel_{desired}$ – vel_{actual}
  - » Control output changes throttle
    - – A human drive would push down on gas pedal

Response on steep hill?

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up hill
→ slow down → error increases
- proportional control
$Kp \cdot e + m_0$
- control design?
- increase Kp - unstable unless add limits

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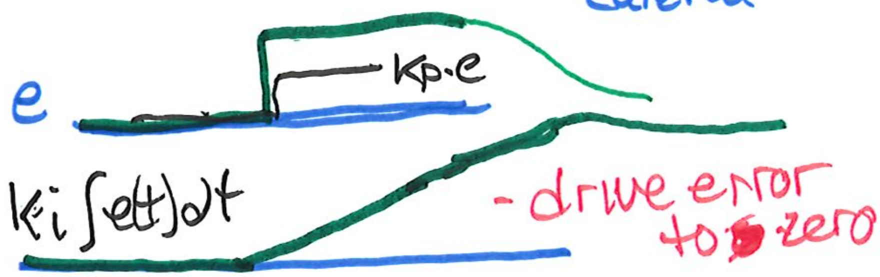
Change control system design

Add integral & derivative terms ..
↑ careful



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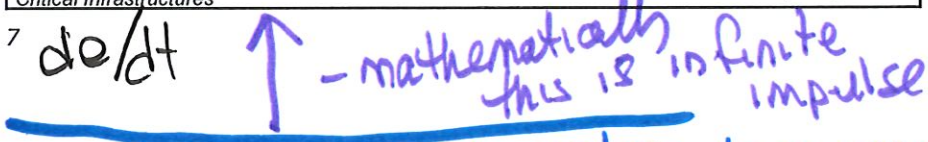
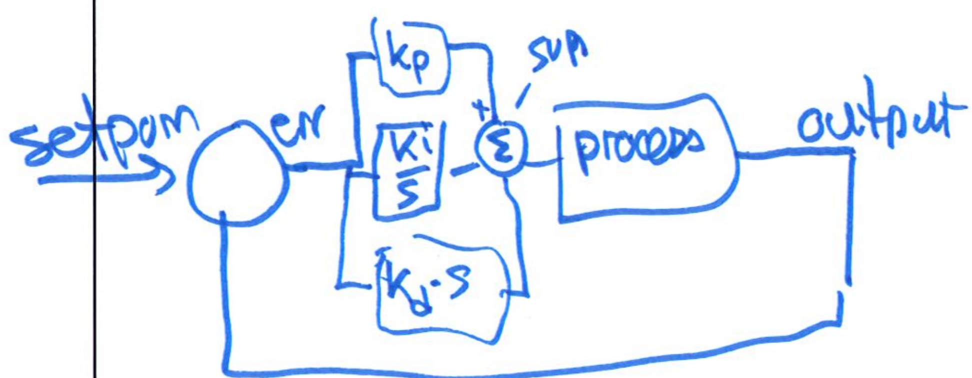


derivative term can damp the system if set right but it can hurt stability if done poorly

proportional integral derivative

PID Control diagram

- Tuning challenges→ widely used



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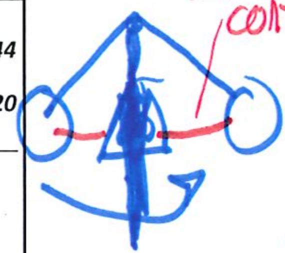
Implementation?

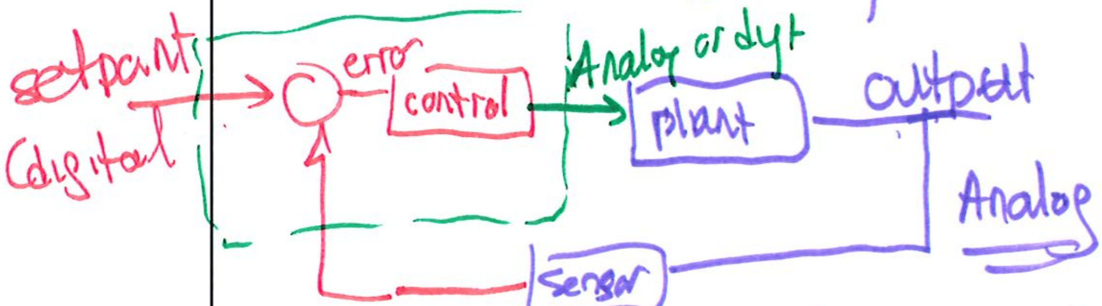
- Mechanical designs: old steam engine governor
- Analog electronics



operational amplifiers
- transistors – capacitors, resistors, inductors
- Difficult to modify in place
- Stability: temperature, tolerances, aging
- poor noise immunity

Digital Implementation

measurements – digitizing



digital (digital filter (or Analog) to remove noise

Advantages
1. Noise immunity
2. flexible
3. Low cost (maintenance)