SFWR ENG 4AA4

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Note: information from the pre-requisite, SFWR ENG 3DX4 will not be included in this summary (although corrections will be).

Contents

Real-Time Systems

Classifications

What happens upon failure to meet deadlines:

- **Soft**: performance is degraded but not destroyed
- **Firm**: a few times will simply degrade performance, but after may lead to system failure
- **Hard**: complete and catastrophic system failure
    - **Safety Critical**: may cause injury / death (a type of hard)

- **Controller** [C(s)]:
- **Input** [E(s)]:
- **Output** [U(s)]:
- $U(s) = C(s)E(s)$

Difference Equations

Forward difference method: derivatives using $f'(x) = \frac{f(x+h) - f(x)}{h}$

Backwards Difference method: derivatives using $f'(x) = \frac{f(x) - f(x-h)}{h}$

e.g.)

u[n] – u[n–1] = 48e[n] – 40e[n–1]

$$a\dot{U} + bU = c\dot{E} + dE$$

$$a\frac{u(kT_s) - u((k-1)T_s)}{T_s} + bu(kT_s) = c\frac{e(kT_s) - e((k-1)T_s)}{T_s} + de(kT_s)$$

$$a\frac{u(kT_s)}{T_s} - \frac{au((k-1)T_s)}{T_s} + bu(T_s) = c\frac{e(kT_s)}{T_s} + de(kT_s) - c\frac{e((k-1)T_s)}{T_s}$$

Group:

$$\left(\frac{a}{T_s} + b\right)u(kT_s) + \left(-\frac{a}{T_s}\right)u((k-1)T_s) = \left(\frac{c}{T_s} + d\right)e(kT_s) - \left(\frac{c}{T_s}\right)e((k-1)T_s)$$

Equate each section to the values from the equation:

$$\frac{a}{T_s} + b = 1$$

$$b = 1 - \frac{a}{T_s}$$

$$\boxed{b = 1 - 10a}$$

$$\frac{a}{T_s} = 1$$

$$\boxed{a = \frac{1}{10}}$$

$$\boxed{b=0}$$

$$\frac{c}{T_s}+d=48$$

$$\boxed{d=48-10c}$$

$$-\frac{c}{T_s}=-40$$

$$\boxed{c=4}$$

d = 48 – 40 **= 8**

$$\tfrac{1}{10}\dot{U}+0U=4\dot{E}+8E$$

$$\frac{U}{E}(0.1s)=4s+8$$

$$\tfrac{U}{E}=\frac{4s+8}{0.1s}$$

Task optimization

Task [T]: $T_i=\left(p_i,r_i,e_i,d_i\right)$

Period [p]: time between tasks are repeatedly released

Release time [r]: time it takes to release task

Execution time [e]: slowest time task could take to be completed (but assume the tasks will take this long no matter what)

Deadline [d]: when task <u>needs</u> to be completed

Number of tasks [n]:

Processor Utilization [U]: used as a priority level $U=\sum_{i=1}^{n}\frac{e_i}{p_i}$

If U > 1, nothing is feasible

If $r_i = 0$ and $p_i = d_i$, then write $T_i = (p_i, e_i)$

Types of Scheduling

Static

Static Scheduling:

- task's priority is assigned before execution and does not change
- If a task misses its deadline, you mess up all the deadlines after it like an airport at Christmas
- A.K.A. **Fixed priority**

FIFO

First In First Out (FIFO):

- Could cause problems for tasks whose execution time is significantly shorter than the rest when there are deadlines
    - E.g. T_1 = (100, 3); T_2 = (2, 1)

- A.K.A. **First Come, First Served (FCFS)**

Cyclic Executive: frame-based scheduling
- When you allocate an amount of time where a task can execute
- Can have multiple executions of the same task
- Tasks might not even fill the full frame

Schedule: the order in which tasks will be executed
Hyperperiod [H]: the entire length of a cycle, least common multiple

Harmonic: every task period evenly divides every longer period

Pre-empting: splitting a task up into multiple mini tasks. Also, if a task misses its deadline, halt the task at the deadline

Frame Size [f]:
- The best way for computers to segment the schedule in a way that it verify that the appropriate tasks have been executed
- Process: try each see which is the largest frame size that follows all the below constraints from 1 to e_{max}.
- Constraints:
  1. $f \geq \max_{1 \leq i \leq n}(e_i)$
  2. H % f = 0
  3. $2f - \gcd(p_i, f) \leq d_i$

Least Compute Time (LCT): tasks with smallest execution times executed first
- Think *greedy*
- Works poorly; worse than RR

Rate Monotonic (RM): shorter period, higher priority
- Think: tasks requiring frequent attention should have higher priority
- If harmonic, feasible as long as U ≤ 1
- If non-harmonic, guaranteed feasible if $U \leq n\left(2^{\frac{1}{n}} - 1\right)$
  - If the equation fails, it still might be, so draw the whole thing to be safe.

Dynamic

Dynamic: each of the tasks' priorities can change. *Think*: while for static priorities it is constantly re-evaluating <u>which</u> task has the highest priority, dynamic scheduling also re-evaluates <u>the actual</u> priorities, themselves.

The only two optimal dynamic priorities are:
- **Earliest Deadline First (EDF)**:
  - more flexible, better U
  - If deadlines < periods, still optimal, but determining feasibility is NP-hard
  - Always feasible if U ≤ 1
- **Least Slack Theorem (LST)**: not as popular as EDF

Multiprocessor

Once you have multiple processors, neither EDF nor RM are guaranteed to work.

Look into first-fit algorithms

Task Interactions

Suspended: active choice, of access prevention until algorithm allows it to
Blocked: as a result of waiting for a resource to be free

How to do the timing diagrams with locks:

- S_1 = lock(S_1)
- S_1^ = unlock(S_1)

One-shot Tasks: non-periodic tasks

Critical Section: when a task tries to acquire a shared resource already locked by another task

Priority Inversion: a method of avoiding deadlock by telling high priority tasks to share their resources with the lower priority tasks even when it's not their turn

- Allocate time, where T_1 has access to shared resource, so the time not allocated can be pre-empted
- Connect the pre-empted by T_1 when T_1 wants to access the resource
- Protect the resource with a semaphore
- You can make it so that tasks can use the resource even after they release the semaphore, but you risk overwriting in that time

Priority Inheritance Protocol (PIP):

- Temporarily raise the priority of a task only if and when it actually blocks a higher priority task; on leaving the critical section, the task priority reverts to its original value
- Issues:
    - If only one shared resource, there's only one possible schedule
    - If more than one resource blocking:
        - Blocking time may be excessively long
        - Deadlock may occur
    - If accessing multiple resources, you can only use them in the same order

Priority Ceiling Protocol (PCP): tasks entering a critical section can only access the blocked resource if it has a priority higher than the priority ceiling

- **Priority Ceiling (PC)**: maximum priority of all tasks ever going to access a resource
- Only need to check PC when entering a critical section
- If any task needs priority higher than the priority ceiling of ALL of the semaphores currently locked, it's suspended
- Main advantages:
    - No locked resources, so free access
    - "The state of the art when resolving resource-contention issues"

- "Deadlock free for an arbitrary number of tasks with an arbitrary number of resources acted upon in an arbitrary way."
    - **Deadlock**: think if you and I are at a table with one fork and one knife and you need both to eat, but you take the fork and I take the knife.

Sporadic Server

Execution Budget [e_s]: periodic tasks aren't flexible…
Execution time [e_i]: …sporadic tasks are

Deadline [d_i]: absolute deadline
Release Time [r_i]: delay before the task is released to be executed

Set of Sporadic Tasks [θ]:
Sporadic Task [S_i]:

- Non-periodic task (a.k.a. aperiodic)
- (r_i, e_i, d_i)
- Typically interrupt-driven

Rules [ρ]: set of rules regulating a sporadic server

Sporadic Server [Φ_s]: (p_s, e_s, θ, ρ)
Periodic Task: (p_s, e_s) a type of sporadic server

- no expectation of when it finishes, only that a new one is queued every period

Assume:

- Φ_s scheduled with T_i according to RM

We don't use K_d because it looks at the derivative regardless of the size of the error function. If your error is a sine function with a small amplitude, K_d will only take the derivative into account and it will overcompensate.

Open loop response: plant with no control

Ziegler-Nichols Tuning Rule: a PID tuning rule
Look at the *open loop response*. It could have a longer rise time / overshoot than preferred.

1. Tangent to curve on upslope

High sample rate → lots of high frequency noise

Effective Utilization [δ]:

$U = U_{periodic} + \delta U_{sporadic}$

Error bound [ε]:

Slack [ω]:
Acceptance Test: check of stuff

$$\omega(S_k,t)=\left\lfloor \frac{d_k-t}{p_s} \right\rfloor e_s - e_k - \sum_{S_i\in\theta:d_i<d_k} e_i - \xi_i$$

1. If $\omega(S_k, t) < 0$, reject task
2. If $\omega(S_k, t) \geq 0$, need to check if already accepted sporadic tasks are adversely affected, i.e. $\omega(S_j, t) - e_k \geq 0$ holds for all $S_j \in \theta$ with $d_j \geq d_k$.

The set θ is maintained dynamically.

Clocks

Computer Clock [C]:
Standard Clock [C_s]: perfect clock; has real time

Attributes:

- Correctness
- Bounded Drift
- Monotonicity
- Chronoscopicity

(EPS): a bounded/maximum difference between the clock time and the real time
$|C(t) - C_S(t)| \leq EPS$

Reset time [r]: the real time you set the clock to when you reset it

Drift [E]: rate of change of the clock value away from a perfect clock (each second)

- There's usually a reason why a clock drifts

Drift Bound [ρ]: maximum drift

$$\left|\frac{dC(t)}{dt}-1\right| \leq \rho$$

Reset Error [ε]: error between actual time and time clock was set to at reset

Total Error [E]: E(t) = ε + drift_since_reset
drift_since_reset ≤ ρ(C(t) − r)
E(t) = ρ(C(t) − r) + ε ≤ EPS
C(t) − r ≤ (EPS − ε)/ρ

Real time will be within this interval – [C(t) − E(t), C(t) + E(t)]

Monotonicity: Clock will always have a consistent spacing and will only move in one order (forward / backwards)

SSL certs will fail signature if your clock is wrong as to ensure this

Chronoscopicity [γ]: maximum changing drift second derivative of stuff $\left|\frac{\mathrm{d}^2 C(t)}{\mathrm{d}t^2}\right| \le \gamma$

Cristian's Algorithm

Minimum Latency [T_{min}]:
Request Send Time [T_0]:
Request Receive Time [T_1]:
Server Time [T_{server}]: time returned by the server

$T_{\text{new}} = T_{\text{server}} + \frac{T_1 - T_0}{2}$

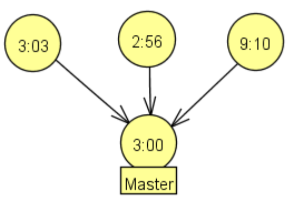
Accuracy is $\pm \frac{T_1 - T_0}{2} - T_{\min}$

Round Trip Time (RTT):

Berkeley

Not often used, but useful for learning

1. Elect 1 node to be the **master**, the one that runs the algorithm



2. Finds the average of the nodes. However, that's probably going to find a value that isn't near any of them.
3. Eliminate the outliers:
    a. Standard deviation: the more outliers, the harder to remove them, i.e. $\sqrt{\tfrac{1}{2} \times \Sigma (x_i - \mu)^2}$
    b. Median
    c. **Maximum deviation**: maximum clock drift × time since last synchronization; sometimes it's good to use physical limitations as the minimum check to ensure accuracy
    d.

PID Control

Plant [G(s)]: a transfer function, e.g. $\frac{1}{s^2 + 10s + 20}$

Remember this from 3DX4? Most of the stuff is still there, so refer to that. More here.
Each of the K's represent a different error or gain

4 types of controllers [P(s)]:

- **Proportional Controller (P),(PC)**: $\frac{K_p}{s^2 + as + \left(b + K_p\right)}, \frac{K_p}{s^2 + 10s + \left(20 + K_p\right)}$

- **Proportional Integral (PI)**: $\frac{K_p s + K_i}{s^3 + as^2 + \left(b + K_p s + K_i\right)}$ $\frac{K_p s + K_i}{s^3 + 10s^2 + \left(20 + K_p s + K_i\right)}$
- **Proportional Derivative (PD)**: $\frac{K_d s + K_p}{s^2 + \left(a + K_d\right)s + \left(b + K_p\right)}, \frac{K_d s + K_p}{s^2 + \left(10 + K_d\right)s + \left(20 + K_p\right)}$
- **Proportional Integral Derivative (PID)**: $\frac{K_p s + K_i + s^2 K_d}{s\left(s^2 + as + b\right) + K_p s + K_i + s^2 K_d}$

  $$\frac{K_d s^2 + K_p s + K_i}{s^3 + \left(10 + K_d\right)s^2 + \left(20 + K_p\right)s + K_i}$$

  $$s^3 + 10s^2 + K_d s^2 + 20s + K_p s + K_i$$

  $$= s\left(s^2 + 10s + 20\right)$$

$$u(t) = K_p e(t) + K_d \dot{e}(t) + K_i \int_0^t e(v)\,\mathrm{d}v$$

Dominant pole: largest magnitude

Finding a zero: Numerator = 0
Finding a pole: Denominator = 0

Sampling

Closed loop: Good sampling rate is 10-20× the bandwidth

1Hz = 2π rad

$T_s \approx \frac{\text{dominant pole} \frac{rad}{s}}{2\pi \text{rad}}$

$$H(s) = \frac{1}{\frac{s^2}{\omega_n^2} + \frac{2\zeta s}{\omega_n} + 1}$$

$$\omega_h \approx \frac{\omega_n}{2\zeta}$$

$$\omega_h = \omega_n \sqrt{1 - 2\zeta^2 + \sqrt{2 - 4\zeta^2 + 4\zeta^4}}$$

If sampling rate is given, use C(s) to get: $\frac{C}{T_s}\left(u[k] - u[k-1]\right) + Du[k] = \frac{A}{T_s}\left(e[k] - e[k-1]\right) + Be[k]$

If not, use –3dB frequency

Designing a PID Controller

1. Obtain an open-loop response and determine what needs to be improved
2. Add K_p to improve the rise time

3. Add K_d to improve the overshoot
4. Add K_i to eliminate the steady-state error
5. Adjust each of K_p, K_d, and K_i until you obtain a desired overall response. You can always refer to the table below to find out which controller controls what characteristics.

Increasing this	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
K_p	Decrease	Increase	Small Change	Decrease
K_d	Small Change	Decrease	Decrease	No Change
K_i	Decrease	Increase	Increase	Eliminate

Ziegler-Nichols Tuning Rule:

- a plant with neither integrators nor dominant complex-conjugate pairs
- Look at the *open loop response*. It could have a longer rise time / overshoot than preferred.
- Tangent to curve on upslope
- For PID controllers

Gain [H(s)]:

Noise frequency [ω_n]:
Noise amplitude [a_n]:
Open loop: plant with no control
Closed loop: $H(s)=\frac{C(s)G(s)}{1+C(s)G(s)}$

$$H(s)=K_C\frac{\prod_{i=0}^{N}(s-z_i)}{\prod_{j=0}^{M}(s-p_j)}$$

$$C(s)=K_D s+K_P+\frac{K_I}{s}$$

So, you need to rearrange your H(s) that is in the first formula to look more like the second formula

Jitter

Jitter [J]: a delay
Relative Jitter: difference in response time between current and previous response times
$\max_k |R_{i,k+1} - R_{i,k}|$
Absolute Jitter: difference between largest response time and smallest response time
$\max_k R_{i,k} - \min_k R_{i,k}$

Absolute jitter ≥ relative jitter

Fail

- **Fail-safe**: in the event of a specific type of failure, responds in a way that will cause no harm, or at least a minimum of harm, to other devices or to personnel

- **Fail-stop**: detects exceptions, but doesn't worry about handling them or raising them
    - failure in one component might not be visible until it leads to failure in another component
- **Fail-fast**: when a problem occurs, a fail-fast system fails immediately

Voting Schemes

Plurality [k]: number of votes needed for a majority

- **Median voter**: chooses median value as *correct* output (for this example, 2.00)
- **Majority voter**: given observations, d_i, and tolerance ε, i.e. willingness for error in *correct* value:
    1. Construct sets, P_k: $x \in P_k \leftrightarrow |x - y| \leq \varepsilon$ for all $y \in P_k$, where P_k has all elements within ε of each other, P_k is maximal, i.e. cannot add any points to it
    2. Choose P_k with largest $|P_k|$, where $|P_k|$ = len(P_k)
        - If $|P_k|$ > floor(N/2): choose any one of P_k as *correct* value or a combination of many
        - Else, no result
        - e.g. Choose:
            - $\varepsilon = 0.1$
            - $P_1 = \{2.00, 2.01, 1.98, 2.05\} \Rightarrow |P_1| = 4 > \text{floor}(5/2) \leftarrow$ majority chooses value in P_k
            - $P_2 = \{1.80\}$
        - What is the minimum value of ε that leads to the majority voter outputting a value?

$\varepsilon = 0.03$ (i.e. range of 2.00, 2.01, 1.98); d_1, d_2, d_3 all satisfy $|d_i - d_j| \leq 0.03$

- **K-plurality**: make a section of size k
- **Pair-and-spare**: when you have 2 sets of 2

Modular Redundancy (MR): when you have multiple separate redundant systems
Triple Modular Redundancy (TMR): having 3 systems with the same purpose running together. This ensures that if a system is not working properly, the things it outputs is compared against the other 2 systems and can be verified as wrong

Cold spare: a redundant system that is off until needed
Warm spare: a redundant system that is in a standby state until needed
Hot spare: a redundant system that is functional, on, and actively collaborating with the primary system

Byzantine General's Problem: useful for sensors with noisy values

$n \geq 3t + 1$
[n]: number of generals
[t]: number of traitorous generals

A lot of these problems are based on binomial

Information Redundancy

e.g. 1101100_, '_' is a **parity** or **checksum**, where the number of 1's are identified as even (1) for **even parity** and odd (0) for **odd parity**.

- Can detect single bit errors

- Cannot correct errors
- Adding more bits can also allow for correction
- Used in all **C**ommunication p**R**oto**C**ols **(CRC)**

Execution Time

Underestimate the time

Best Case Execution Time (BCET):
Worst Case Execution Time (WCET):

(BCET^): estimation of BCET
(WCET^): estimation of WCET
BCET^ < BCET < WCET, WCET^

Natural Language Standards

Formal requirement: If <condition>, <action> shall occur

Soft requirement: within <response time>, <minimum probability> of the time
Hard requirement: within <response time>

QoS: a functional requirement with a hard / soft requirement to a