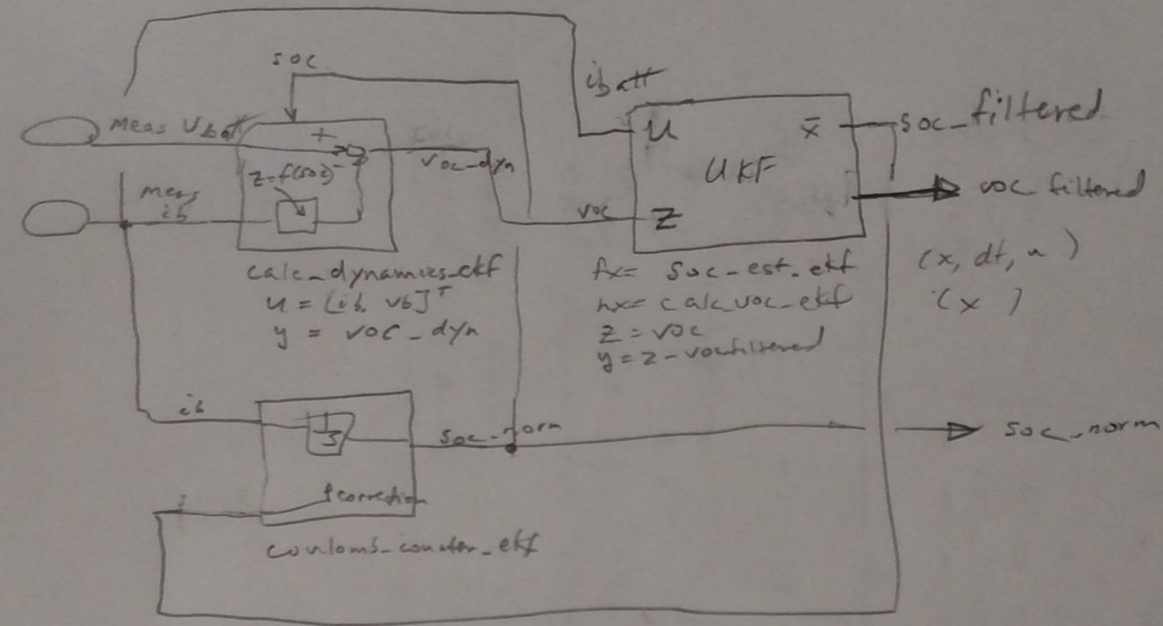


fx → soc_est_ekf(x, dt, u)

$$\left.\begin{aligned} X_k &= [soc\_k],\quad u_k = [ib,] \\ X_{k+1} &= e^{-\frac{\Delta t}{\tau_{sd}}} * X_k + R_{sd}(1-e^{-\frac{\Delta t}{\tau_{sd}}}) * u_k \end{aligned}\right\} \text{f\_ekf}$$

h_ekf → calc_voc_ekf(X_k) → voc_filtered

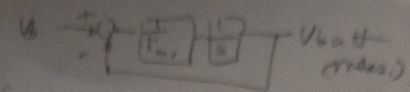
y = z - voc_filtered

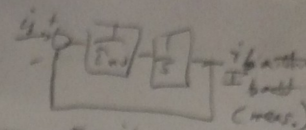
GP_battery_UKF.py

DG 11/21/2021

Add.

Anti-Alias filter.





$$s\,V_{batt} = \frac{V_b}{\tau_{aaf}} - \frac{V_{batt}}{\tau_{aaf}}, \quad s I_{batt} = \frac{i_b}{\tau_{aaf}} - \frac{I_{batt}}{\tau_{aaf}} \qquad I = i_b + I_b$$

$(V_{bc} + R_a I + V_b)$

$$\begin{Bmatrix} \dot V_{bc} \\ \dot V_{cd} \\ \dot V_{batt} \\ \dot I_{batt} \end{Bmatrix} = \begin{bmatrix} -\frac{1}{R_{ct} C_{ct}} & 0 & 0 & 0 \\ 0 & -\frac{1}{\tau_{dif}} & 0 & 0 \\ 1/\tau_{aaf} & \frac{1}{\tau_{aaf}} & -\frac{1}{\tau_{aaf}} & 0 \\ 0 & 0 & 0 & -\frac{1}{\tau_{aaf}} \end{bmatrix} \begin{Bmatrix} V_{bc} \\ V_{cd} \\ V_{batt} \\ I_{batt} \end{Bmatrix} + \begin{bmatrix} \frac{1}{C_c} & 0 \\ \frac{1}{C_d} & 0 \\ R_a/\tau_{aaf} & 1/\tau_{aaf} \\ \frac{1}{\tau_{aaf}} & 0 \end{bmatrix} \begin{Bmatrix} I \\ V_{oc} \end{Bmatrix}$$

$$\begin{Bmatrix} V_b \\ I_{oc} \\ V_{batt} \\ I_{batt} \end{Bmatrix} = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} R_a & 1 \\ 1 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

$$\{V_{oc}\} = \begin{bmatrix} -1 & -1 & 0 & 0 \end{bmatrix} \qquad \begin{bmatrix} -R_a & 1 \end{bmatrix} \begin{Bmatrix} I \\ V_b \end{Bmatrix}$$

assume $I = I_{batt}$, $V_b = V_{batt}$

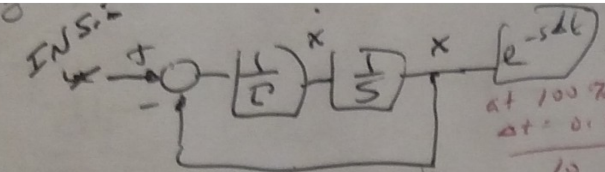
$\tau = 0.159$ s small compared to

The AAF should be in hardware model but not EKF dynamics model - no value added.

Adding AAF to EKF would triple ~~complexity~~ size of EKF and $\underset{WAG}{\sim 2^3} = 8\times$ more complex

11/24/2021

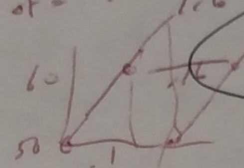
Example



$x = \begin{Bmatrix} x \\ \dot{x} \end{Bmatrix}$

$A = \begin{bmatrix} 0 & 1 \\ -\frac{1}{\tau} & 0 \end{bmatrix}$ $\quad B = \begin{bmatrix} 0 & \frac{1}{\tau} \end{bmatrix}$

Δt 100 %/sec
$\Delta t = 0.1$ sec/update
10 %/update
tau = .16 .625
Δt = .1 1.6



t^{vel}

$H = [1 \quad 0]$ $\quad R$ = noise_std

$F = e^{A \Delta t}$ $\quad F = \begin{bmatrix} 1 & -\frac{\Delta t}{\tau} \end{bmatrix}$

$= \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} + \begin{bmatrix} 0 & 1 \\ -\frac{1}{\tau} & 0 \end{bmatrix} \Delta t$

tracker.$F = \begin{bmatrix} 1 & \Delta t \\ -\frac{\Delta t}{\tau} & 1 \end{bmatrix}$

A $\quad$ u: 10 16

$\begin{bmatrix} -\frac{1}{\tau} & 0 \\ 0 & 0 \end{bmatrix} \Delta t$ $\quad \left(\frac{1}{\tau} \quad \frac{1}{\tau} \right)$

$1 - \frac{\Delta t}{\tau}$

```
class Lag(object):
    __init__(self, pos, vel, noise_std):
        s.vel = vel
        s.noise_std = noise_std
        s.pos = pos
    read(self, in)
self.vel = (in - self.pos)/tau
        s.pos = self.vel * dt
        s.pos = s.pos + self.vel * dt
        return s.pos + randn() * self.noise_std

pos, vel = 0, 0
lag2 = Lag(pos, vel, noise_std=1)
```

lag2o.f = $\left[x + \dot{x}\Delta t \right], \left[\dot{x} - \Delta t / \tau \right]$ $\quad + (u - x)\frac{\Delta t}{\tau}$

$\bar{x} = \dot{x} + (u-x)\Delta t/\tau$

$\bar{x} = [x, \dot{x}]^T$

class INSim

lag2o.Q
tracker.Q = q = Q_dis. (dim = 2, dt = dt, var = 0.001)

init P = np.eye(2) * 10.

D why does R appear $\bar{x}$?

$F = \begin{bmatrix} 1 - \frac{\Delta t}{\tau} & 0 \\ 0 & 0 \end{bmatrix} \begin{matrix} x \\ \dot{x} \end{matrix}$

$\bar{x} = f(u, x)$

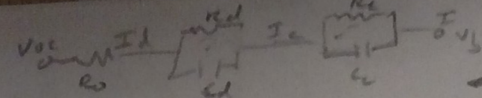
e = pos_in − pos $\quad$ = 16
v = e / tau $\quad$ = 6.25 100
pos = pos + $\Delta t \times v$

$A = -\frac{1}{\tau}, B = \frac{1}{\tau}$ $\quad x = x - \frac{x \Delta t}{\tau}$

$\bar{x} = \left(1 - \frac{\Delta t}{\tau}\right)x + \frac{\Delta t}{\tau} u$

2 → 1

11/22/2021



$I = I_b$

$V_{bc} = V_b - V_c$

$V_{cd} = V_c - V_d$

$V_{do} = V_d - V_o$

$i_1 + i_2 = I$ $\quad i_4 + i_5 = I_c$

$i_1 + i_3 = I_c$ $\quad i_4 + i_6 = I_d$

$i_2 = i_3$ $\quad i_5 = i_6$

$\cancel{i_1 + i_2 = I}$

$C_c s V_{bc} = i_2 = i_3$

$V_{bc} = i_1 R_c$

$C_d s V_{cd} = i_5 = i_6$

$V_{cd} = i_4 R_D$

$V_{do} = I_d R_o$

$V_{oc} + V_{do} + V_{cd} + V_{bc} = V_b$

$C_c s V_{bc} + \frac{V_{bc}}{R_c} = I$

$C_d s V_{cd} + \frac{V_{cd}}{R_d} = I$

$\frac{V_{do}}{R_o} = I$

$V_c = V_{oc} + I R_o + V_{cd}$

$V_d = V_{oc} + I R_o$

$V_b = V_{oc} + I R_o + V_{cd} + V_{bc}$

$V_{do} = I R_o$

$V_b = V_{oc} + I R_o + V_{cd} + V_{bc}$

$s V_{bc} = \frac{I}{C_c} - \frac{V_{bc}}{R_c C_c}$

$s V_{cd} = I/C_d - \frac{V_{cd}}{R_d C_d}$

$$\begin{Bmatrix} \dot{V}_{bc} \\ \dot{V}_{cd} \end{Bmatrix} = \begin{bmatrix} -\frac{1}{R_c C_c} & 0 \\ 0 & -\frac{1}{R_d C_d} \end{bmatrix} \begin{Bmatrix} V_{bc} \\ V_{cd} \end{Bmatrix} + \begin{bmatrix} 1/C_c & 0 \\ \frac{1}{C_d} & 0 \end{bmatrix} \begin{Bmatrix} I \\ V_{oc} \end{Bmatrix}$$

$$\begin{Bmatrix} V_b \\ I_{oc} \end{Bmatrix} = \begin{bmatrix} 1 & 1 \\ 0 & 0 \end{bmatrix} + \begin{bmatrix} R_o & 1 \\ \phi & 0 \end{bmatrix} \begin{Bmatrix} \quad \end{Bmatrix}$$

$R_{eq} = R * NumCells$

$C_{eq} = \frac{C}{NumCells}$

compatible with SOC = VOC = 0-1 simplification

for EKF

$$\begin{Bmatrix} V_{oc} \\ \cancel{B} \end{Bmatrix} = \begin{bmatrix} -1 & -1 \end{bmatrix} \begin{Bmatrix} V_{bc} \\ V_{cd} \end{Bmatrix} + \begin{bmatrix} -R_o & 1 \end{bmatrix} \begin{Bmatrix} I \\ V_b \end{Bmatrix}$$

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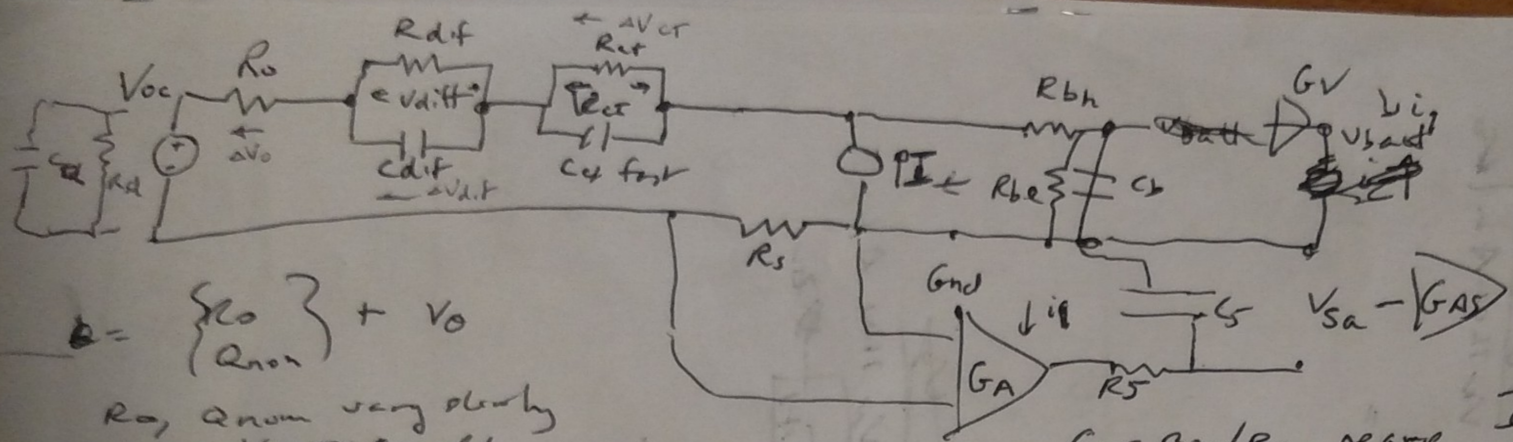


(1) CT = charge transfer
Dif = Diffusion phenomena

Taborelli
1 cell
$R_O = f(soc)_{6-2}$ mΩ
$R_{CT} = .0016$
$\tau_{CT} = 3.68\,s$
$R_{Dif} = .0077$
$\tau_{dif} = 83.74\,s$
$Q_{nom} \equiv soc$

$Q = \begin{Bmatrix} R_o \\ Q_{nom} \end{Bmatrix} + V_\theta$

R_o, Q_{nom} vary slowly
so $V_\theta \approx$ small
$\theta = x$, $V_\theta = Q$

$I >> i_q$

$G_A = R_2/R_1$ op amp
$GV = R_{bh}/R_{be}$ software
$GAS = 1/G_A/R_s$

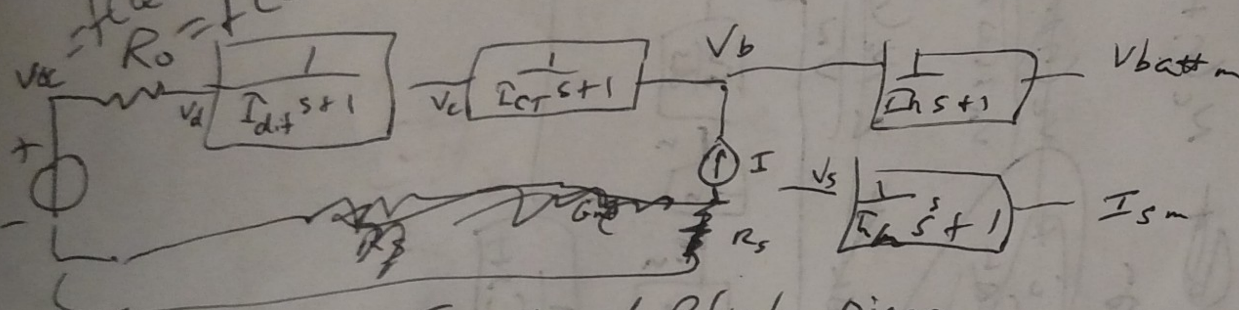
$R_1 = 5600$
$R_2 = 27000$

$R_5 = 8200$
$C_5 = 10e^{-6}$

$R_{bl} = 470\,\Omega$
$R_{be} = 20000$
$C_S = 47\,e^{-6}$

$\tau_s = \tau_b = \frac{1}{2\pi} = 0.159$
τ_h

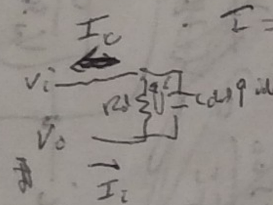
$\mathscr{f}(Q_{nom})$
$R_O = f(Q_{nom})$



$x = \begin{Bmatrix} V_\theta^Q \\ V_d \\ \dot V_d \\ V_c \\ \dot V_c \\ V_b \\ \dot V_b \\ V_{batt} \\ V_s \\ \dot V_s \\ I_s \end{Bmatrix}$

Functional Block Diagram

$V_o = I(\cancel{R_o + R_d + R_c})$



$I = i_{Rd} + i_{dl}$

$s\Delta V = \frac{-i}{C}$

$\Delta V = Ri_R$

Rsd: discharge
10 A-h in 1 month
$dt = 1\,mo = 2.6e6$
$\Delta soc = 0.1$
$i = \frac{0.1 \times 3600 \times 100}{2.6\,e6}$
0.014 Amp
$R = \frac{12}{i} = 900$
$\approx 1000\,\Omega$

$k = \frac{12 \times 2.6e6}{0.1 \times 3600 \times 100}$

$C_q = 3600 \times nom\,Ldg$

$soc + \frac{i \times dt}{3600\,nom\,C_q}$

$C_q =$

$Pow = i\,nom$

$soc + \frac{Pow \times dt}{nom\,V\,3600\,nom\,C_q}$

11/22/2021