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$$\begin{cases} \rho_t = \dfrac{\sqrt{r_{mt}}}{\sqrt{r_{mt}} + \sqrt{p_{mt}}} \\ W_t = \dfrac{C_d^a P_{t|t-1} C_d^{aT}}{1-\rho_t} + \dfrac{R^a}{\rho_t} \\ K_t^e = \dfrac{P_{t|t-1} C_d^{aT} W_t^{-1}}{1-\rho_t} \\ \delta_t = 1 - (Y_t - C_d^a \hat{X}_{t|t-1}^a)^T W_t^{-1} (Y_t - C_d^a \hat{X}_{t|t-1}^a) \\ \hat{X}_{t|t}^a = \hat{X}_{t|t-1}^a + K_t^e (Y_t - C_d^a \hat{X}_{t|t-1}^a) \\ P_{t|t} = \delta_t \left(\dfrac{P_{t|t-1}}{1-\rho_t} - \dfrac{P_{t|t-1}}{1-\rho_t} C_d^{aT} W_t^{-1} C_d^a \dfrac{P_{t|t-1}}{1-\rho_t} \right) \\ \hat{X}_{t+1|t}^a = A_d^a \hat{X}_{t|t}^a + B_d^a U_t \\ \beta_t = \dfrac{\sqrt{Tr(Q^a)}}{\sqrt{Tr(Q^a)} + \sqrt{Tr(A_d^a P_{t|t} A_d^{aT})}} \\ P_{t+1|t} = \dfrac{A_d^a P_{t|t} A_d^{aT}}{1-\beta_t} + \dfrac{Q^a}{\beta_t} \end{cases} \tag{3}$$

4. Modified GPC for unmanned helicopters

To eliminate the negative influence of model errors and control delay in flight, besides the active estimation algorithm like ASMF that does not require a normal distribution assumption, an effective control algorithm has to be designed according to the reference model of Eq. (1) while adopting the on-line estimation of f as compensation.

We describe the normal GPC in Section 4.1, and then, the modified scheme is proposed in Section 4.2 & 4.3 to eliminate the negative influence of model errors in real applications.

4.1 Preliminary work for generalized predictive control

Generally, for a linear system with actuator time delay like,

$$\begin{cases} X_{t+1} = A_d X_t + B_d u_{t-k} + W_t \\ y_t = C_d X_t \end{cases} \tag{4}$$

where $X_t \in R^{n\times 1}$ is the system state vector at sampling time t, $y_t \in R^{l\times 1}$ is the output vector, $u_t \in R^{m\times 1}$ is the control input vector, k is the actuators' time-delay and W_t is process noise; traditional Generalized Predictive Control (GPC) [23] can be designed as:

Step I: Make prediction

Firstly, for the case that predictive step i is less than time-delay k (i.e., the time instant that system behavior cannot be regulated through current and future control action), prediction can be denoted as following equation,