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282805 Fault Detection and Identification Based On Kalman Filtering Under Randomized Sensing Strategies

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Classic strategies for fault detection and identification (FDI) are focused on random and unintended faults in process systems. However, in an increasingly cyber-linked world, intended malicious attackes are an increasing reason for concern in safety-critical systems such as nuclear power generation systems, destillation plants and distribution systems for gas, oil and power. Recently, a probabilistic approach to sensor selection has been proposed to randomize the selected variables for which measurements are sent through a given channel. In doing so, one attempts to thwart cyber-attacks which take form in manipulating data so to mimic a non-existing situation. This can consist of emulating perfect operation when the actual system status is of a lower quality so to increase the probability of a dangerous event or in emulating an abnormal situation when there is none in reality so to promote an emergency shutdown and associated risks and costs. This is a promising approach to achieve resilience against cyber-attacks. However, this results in a time-varying nature of the obtained observations. In this contribution, an existing Kalman-filter based strategy is adjusted to account for this time-varying nature.

For a given linear state-space system, the equations with default monitoring strategies, i.e. with all states measured are written as follows:

$\mathbf{x}(k) = A \,.\, \mathbf{x}(k-1) + B \,.\, \mathbf{u}(k-1) + F \,.\, \mathbf{v}(k-1)$ (Eq. 1)

$\mathbf{y}(k) = C \,.\, \mathbf{y}(k) + D \,.\, \mathbf{w}(k)$ (Eq. 2)

In normal operational conditions, the input and output disturbances are distributed as white noise sequences:

$\mathbf{w} \sim N(0, Q)$ (Eq. 3)

$\mathbf{v} \sim N(0, R)$ (Eq. 4)

Equation (1) is modified as follows for an input fault as of the introduction of the fault start time, k_f:

bias type: $\mathbf{v}_f(k) = \mathbf{v}(k) + \mathbf{g} \,.\, b \mid k >= k_f$ (Eq. 5)

drift type: $\mathbf{v}_f(k) = \mathbf{v}(k) + \mathbf{g} \,.\, b \,.\, (k\text{-}k\_f) \mid k >= k_f$ (Eq. 6)

stuck type: $\mathbf{v}_f(k) = \mathbf{v}(k) + \mathbf{g} \,.\, (\mathbf{v}(k_f)-\mathbf{v}(k)) \mid k >= k_f$ (Eq. 7)

In these equations, b is a scalar value which represents the magnitude of the fault. The column vector g is called the signature vector and consists of zeros and ones and determines which input is affected. For instance for a fault in the first input: g = [1 0]' . With these equations, one adds a deterministic sequence to the zero-mean normal noise sequence. This modified disturbance input, vf(k), is used to replace $\mathbf{v}_k$ in Equation (1).

Similarly, the output faults are defined as follows:

bias type: $w_f(k) = w(k) + g * b \mid k >= k_f$ (Eq. 8)

drift type: $w_f(k) = w(k) + g * b * (k-k_f) \mid k >= k_f$ (Eq. 9)

stuck type: $w_f(k) = w(k) + g * (v(k_f)-v(k)) \mid k >= k_f$ (Eq. 10)

The scalar b and vector g are defined in the same way as for inputs. The modified disturbance input $\mathbf{w}_f$ is used to replace **w** in Equation (2).

The Fault Detection and Identification (FDI) scheme based on the Kalman filter consists of three major components. This includes (1) Kalman filtering, (2) Fault Detection Test and Fault Confirmation Test and (3) Fault Identification. We refer to [1-3] for details. In the presented work, we will elaborate on the effects of sensor selection probabilities, p_j, on the performance of the Fault Detection and Identification method.

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