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Monitoring/detection systems: reliability based performance assessment

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monitoring, detection, system, modelling, performance, reliability, assessment

Abstract

Monitoring & Detection (M&D) systems are introduced in almost all daily life aspects. Today, it is unlikely to find out a system that is not equipped with a sort of M&D apparatus, even the most ordinary and uncritical systems. Objective assessments of the performances of M&D systems are increasingly needed. Performance assessment may be motivated by commercial interests or by certification concerns if the application field is ordinary or uncritical. While, if the application filed is critical, safety and security aspects may become the major focus. The paper classifies in three classes the models that are the most-frequently used to describe M&D systems. The author proposes for each class a suitable indicator of performance based on M&D-systems reliability targets.

1. Introduction

Monitoring & Detection (M&D) systems are introduced in almost all daily life aspects. Today, it is unlikely to find out a system that is not equipped with a sort of M&D apparatus, even the most ordinary and uncritical systems.

M&D systems are used in industrial plants (power generation, petro-chemical, pharmaceutical laboratories, nuclear power plants, ...), air-ports, high ways, air and sea control, control of boarders, camera-surveillance in streets, railway stations, hospitals and stadiums, and telecommunications traffic monitoring.

But they are also used in washing machines, vehicles' speed-control systems, cities' traffic control systems, in-house light remote-control systems, and television audiometer control

They are used to control normal operations, to detect abnormal situations or to identify a searched signal.

In today complex systems, they are required to be not expensive, small in size, remote-controlled and do not affect the normal operation of the controlled systems. In all cases, the M&D systems are required to be highly reliable and robust.

In practice, the M&D system may operate in hostile environments or non-standard operating conditions. Sometimes, they even operate in unexpected conditions. The performance of the M&D depends strongly on its operating environment, [1], [3], [5], [6]. This is often very difficult to be taken into account.

The paper tends to contribute into the development of a generic formal methodology in order to describe the performance and the failure of the M&D systems. Such generic and formal approaches are generally hurt by many practical difficulties.

One of the sources of these difficulties is the absence of a classification of all the models describing the performance and the failure of the M&D system.

The paper contributes then into the classification of the models that are used in this domain and to identify their main features in terms of mathematical objects. Modelling the failure of detection systems may take different forms and employ varying mathematical concepts, [1], [2], [6].

The paper does not claim an exhaustive classification. It focused on three main classes covering the most treated applications which the author met these last 25 years.

2. General description

We aim at identifying at least the major models that describe the performance and the failure of the M&D systems. The author is aware that this is not an easy task and that an exhaustive identification of models is out of reach at present.

How generally do we describe quantitatively the performance or the failure of M&D systems?

One may immediately respond that, a M&D arrangement is always designed to detect a "searched event/signal". Once the searched event is detected, the M&D system reacts. Subsequently, a corresponding detection system will fail if:

- The searched event occurred but the system did not detect its occurrence or react as if it did not occur. This is a "failure to detect" situation. or
- The searched event did not occur instead the system indicates it occurred or react as if it occurred. This is a "false detection" situation.

These are the most elementary failure modes which one used to meet in practical situations. They may be described by two mutually exclusive elementary models:

- Elementary failure modes are independently described by occurrence probabilities.
- Elementary failure modes are independently described by occurrence rates.

The "failure to detect" probability or rate and the "false detection" probability or rate are basic inputs to all models describing the M&D systems performance and failure. They may results from the operational feedback or simply from some detailed reliability analyses of each failure mode. This point is out of the frame of the paper and will not be treated here.

However, we will consider in the following (§2.2,§2.3), that elementary occurrence rates are constant in time. This is mainly in order to simplify the paper and to avoid deviating our intention from our principal focus which is establishing the classification of the models describing the performance and the failure of M&D systems.

Regarding our principal focus, one may then distinguish the following three classes of models describing the M&D system.

The 1st class covers the M&D systems where the "failure to detect" and "false detection" modes are independently described by occurrence probabilities ν and μ, respectively. This class will be called "static models class" (§0). The elementary failure modes may still be time dependent, but the overall system failure model combines the elementary failures in instantaneous way. The searched event occurs with a constant occurrence rate λ or with an occurrence time-dependant occurrence probability. The event may or may not be renewed.

In the 2nd class, the elementary failure modes "failure to detect" and "false detection" are independently described by occurrence rates ω and β, respectively, and will be called "dynamic models class" (§2.2). The overall system failure model combines the elementary failures in integral way. The searched event occurs with a constant occurrence rate λ or with an occurrence time-dependant occurrence probability. The event is not renewable.

In the 3rd class, the elementary failure modes "failure to detect" and "false detection" are independently described by occurrence rates ω and β, respectively, and will be called "dynamic models class with renewal" (§2.2). The overall system failure model combines the elementary failures in integral way. The searched event occurs with a constant occurrence rate λ or with an occurrence time-dependant occurrence probability. The event is renewable.

For both classes 2 and 3, the occurrence order is impacting on the model. The sequence we are interested in is given in the following order: the failure occurs first, and then detection (or detection failure) occurs. The impact of the occurrence order on the modelling of sequences of events is treated in [4].

2.1. Static models

The controlled system contains a given number of "searched events" and the detection system should detect at least a predefined percentile with a fixed success probability. Both the target percentile and its corresponding probability are predetermined by some authority (safety authority, managerial authority, certification body,...).

This is the case of the annual inspection of the tubes in a steam generator in power plants. Steam generators in power stations may often be controlled each year. Each SG contains some thousands of tubes. Many tubes may show inacceptable cracks at each annual inspection. The ideal situation is to detect all cracked tubes and either they are replaced or plugged. The inspection should detect the maximum number of the cracked tubes.

The detection system is then fully defined if one knows its "failure to detect" probability, ν, and its "false detection" probability, μ, versus a given event.

Let p^- be the probability that a tube suffers a crack before the inspection, the probability that a tube suffers a crack after the inspection p^+ will then be given by:

$$p^+ = \frac{\nu p^-}{\nu p^- + (1-\mu)(1-p^-)} \quad (1)$$

Very often, the power production department in the installation would fix an objective target value of the probability of failure per tube, p_0, in the steam generator. So, the M&D procedure and system will be judged satisfied if p^+ is lower than p_0. Or, one may target the overall failure probability of the steam generator with its N tubes.

Before the inspection, the probability $P^-_{n/N}$ that n tubes out of N are affected, is given by:

$$P^-_{n/N} = \frac{N!}{n!*(N-n)!}(p^-)^n(1-p^-)^{N-n} \quad (2)$$

After the inspection, the probability $P^+_{n/N}$ that n tubes out of N are affected, is given by:

$$P^+_{n/N} = \frac{N!}{n!*(N-n)!}(p^+)^n(1-p^+)^{N-n} \quad (3)$$

2.2. The dynamic models

The searched event occurs and its effects can continuously be detected in the time. This may be the case of online continuous monitoring of toxic fluent release from industrial plants.

The reliability of the detection system can be defined as the probability of detecting a hazardous-material release within a given interval of time.

Let $q(T)$ be the probability of failure to detect a hazardous-material release in a given interval of time "T", which will be described by:

$$q(T) = \frac{\lambda}{\sigma}\left[e^{-\lambda T} - e^{-\omega T}\right], \quad (4)$$

where,

$$\sigma = \omega - \lambda$$

where λ and ω are the occurrence rate of the event and the detection rate of the detection system.

Let $f(T)$ be the probability of a false detection in a given interval of time "T", which will be described by:

$$f(T) = e^{-(\lambda+\beta)T}, \quad (5)$$

where β is the "false detection" occurrence rate.

2.3. Dynamic detection with renewal

The searched event occurs repetitively. However, the characteristic of the repetitive occurrence is random. This may be the case with an online monitoring system that should detect pressure chocks occurrence and reacts (emits a signal) if the pressure gets higher than a critical threshold. In a given laps of time (T), pressure shocks higher than the acceptable threshold may occurs N times without being detected, [4].

$$P_k(t) = \Psi_k(t).e^{-\lambda t} - \Phi_k(t).e^{-\omega t} \quad (6)$$

where;

$$\Psi_k(\sigma t) = \left(\frac{\lambda\omega}{\sigma^2}\right)^k.\left[\sum_{j=0}^{k}(-1)^j.C_j^k\frac{(\sigma t)^{k-j}}{k-j!}\right],$$

$$\Phi_k(\sigma t) = (-1)^k.\left(\frac{\lambda\omega}{\sigma^2}\right)^k.\left[\sum_{j=0}^{k}B_j^k\frac{(\sigma t)^{k-j}}{k-j!}\right],$$

where, $\sigma = (\mu - \lambda)$, and

$$C_0^k = 1, B_0^k = 0, k \geq 0$$

$$C_k^k = B_k^k, B_k^k = C_{k-1}^k + B_{k-1}^k, k \geq 1$$

$$C_{j-1}^k = C_{j-2}^k + C_{j-1}^{k-1}, \; k \geq j \geq 2$$

$$B_{j-1}^k = B_{j-2}^k + B_{j-1}^{k-1}, \; k \geq j \geq 2$$

The probability of a false detection in a given interval of time "T", $f(T)$, is given by 0.

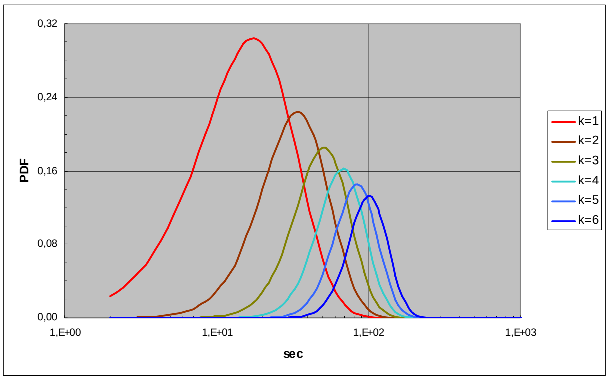

Figure 1. Spectral Probability Density Function ($\lambda = 10^{-1}\ s^{-1}$, $\omega = 1{,}50 * 10^{-1}\ s^{-1}$)

3. Discussion

The main target of the paper is to contribute into the development of models to describe M&D systems performance and failure. Three major classes of M&D models and their main characteristic were clearly identified. They do not cover the whole field but they are sufficiently representative of the major part.
In the 1st class "static models", (§.0), we can obviously determine the probability of failure of the controlled system before and after the control.
The performance of the M&D system can then be described in terms of: how much improvement does the control bring to the controlled system?
One may use an M&D performance factor, ε, described by:

$$\varepsilon = \frac{w^+}{w^-} = \frac{(1-\mu)}{\nu}$$

where,

$$w^- = \frac{1-p^-}{p^-}$$

$$w^+ = \frac{1-p^+}{p^+}$$

where, w^- and w^+ are the reliability to unreliability weight factor of a tube, before and after the control, respectively.
Generally, the M&D procedure and system is effective once ε is higher than one. However, this may not be enough to accept the M&D system. One may require that

$$\varepsilon > \varepsilon_0$$

where, ε_0 is a determined target value integrating some other economic, safety or societal targets.
For the 2nd and the 3rd classes, on may propose different measures of performance. One of these possible performance measures may be the mean occurrence time $\overline{T}_k$ of the sequence "failure occurs and not detected", k times. It is elementary to demonstrate that starting from 0 one may determine $\overline{T}_k$ suh as:

$$\overline{T}_k = \left(\frac{\lambda\mu\alpha}{\sigma^2}\right)^k *$$

$$\left(\frac{1}{\lambda}\sum_{j=0}^{k}(-1)^j \cdot C_j^k \cdot \left(\frac{\sigma}{\lambda}\right)^{k-j} - \frac{(-1)^k}{\mu}\cdot\sum_{j=0}^{k} B_j^k \cdot \left(\frac{\sigma}{\mu}\right)^{k-j}\right)$$

where, $\sigma = (\mu - \lambda)$

4. Conclusion

The author has tried in this work to classify the models describing the failure of detection systems in 3 large classes. The classification is mainly based on the fundamental mathematical characteristics of each model.
For each class of models, the author proposes a performance measure. These proposed measures are illustrative examples but are certainly not exhaustive.
This work is still under development and, definitively, not yet conclusive.

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