Ability to perform efficient fault diagnosis is essential to ensure smooth and safe operation of chemical processes. With increased integration across various units in a modern day chemical process, the need for automated diagnostic techniques is even more acute. Over the last couple of decades, several diagnostic strategies have been proposed in literature. The success of any diagnostic strategy depends on the location of the sensors measuring important variables in the process. Selecting an optimal set of variables to be measured in the process is called as the sensor network design problem. The focus of our current work is on choosing an optimal set of variables that can ensure reliable fault diagnosis. Sensor network design is primarily an activity that is performed at the design stage. Several approaches are available in literature for designing sensor networks. Several of these approaches utilize a digraph (DG) or a signed digraph (SDG) based representation of the process. This is convenient as digraphs are a qualitative representation of the cause-effect relationships amongst process variables. The nodes in a digraph represent process variables and root causes of abnormalities, while the edges represent the cause-effect relationships between adjacent nodes. The edges are unsigned in a DG, while signs (indicating direction of effect) are associated with edges in a SDG. Hence, DGs and SDGs can be generated without having detailed quantitative information (such as values of kinetic parameters) about the process and thus digraph based design approaches can be used at the process design stage. An SDG can be generated based on either on operator experience or from the first principles representation of a process Maurya et al. (2003a,b).

In literature, Raghuraj et al. (1999) used DG representation for sensor network design for fault diagnosis to ensure specific criteria such as observability and resolution of faults. Bhushan and Rengaswamy (2000) extended this work by representing a process as a SDG instead of a DG. Bagajewicz et al. (2004) proposed a Mixed Integer Linear Programming (MILP) based optimization approach for similar problems. Bhushan and Rengaswamy (2002) proposed the concept of unreliability of detection where fault occurrence and sensor failure probabilities are incorporated in the sensor network design procedure. All the above approaches assume that the SDG of the process model is accurate and don't consider errors (model-plant mismatch) in the SDG representation. Such model-plant mismatch can typically manifest in terms of wrong signs being assigned to the edges in the SDG. This can happen, when: (i) some signs on the edges of the SDG are not known

and instead represent only an “educated" guess, and (ii) even if the signs on the edges of the SDG are accurate to begin with, they may become erroneous if the true signs change over a period of time due to change in the process conditions. In case the underlying SDG model is not an accurate representation of the process, the resulting sensor network design may just not be suboptimal, but it may also fail to satisfy important reliability or observability requirements. Recognizing this aspect, Bhushan et al. (2008) proposed the idea of distributed sensor network that has a higher chance of ensuring designed performance in the presence of model-plant mismatch. However, the approach considers model-plant mismatch in a generic way and does not take into consideration information about specific uncertain edge-signs that may be available. Recently, Kolluri et al. (2013) proposed set cover problem where sensor networks are designed for ensuring observability and resolution of faults while incorporating information about uncertain edge-signs. Their approach involved designing sensors that could observe and distinguish between various scenarios where faults could occur and the uncertain edges could simultaneously change signs. However, their approach assumed that all scenarios were equally probable. In practice, this will not be the case. Different faults and sensors will have different probabilities of occurrence and failure, as has been considered in the earlier works in literature (Bhushan and Rengaswamy, 2002). Additionally, it may be possible to assign different confidence levels to the uncertain edge signs. For example, it may be known that a particular edge does not change sign even for large variations in the quantitative values of underlying parameters/variables, while some other edge may change sign even for a small variation in the underlying quantitative values. Thus, the sign of the former edge can be specified with a higher confidence than of the latter.

In the current work we present sensor network design approaches that incorporate probabilities of fault occurrence and sensor failures as well as user specified confidence in edge signs. This is done by extending the notion of unreliability of detection presented in literature earlier Bhushan et al. (2008) to the case when some edge signs in the underlying SDG representation are known to be uncertain with varying degrees of confidence. Towards this end, different scenarios namely, of (i) a fault occurring alone with no change in edge signs, and (ii) a fault occurring along with simultaneous change in an uncertain edge sign, are considered. For each of these scenarios, through propagation in the signed digraph, the effect on the process variables is obtained. Under the assumptions of various

events (fault occurrences, sensor failures, edge sign changes) happening independently, analytical expression of probability of a scenario occurring and remaining undetected (due to simultaneous failure of sensors) can be obtained. This probability is labeled as the unreliability of detection. The sensor network design problem is then cast as an optimization problem that minimizes the maximum unreliability of detection amongst all scenarios. Incorporating probabilities in the sensor network design approach is specially relevant for cases when there are limitations on the number/type of sensors that can be used in the process due to availability of only limited resources for sensor network design. In such cases, incorporation of probabilities provides a natural way of prioritizing the limited resources towards scenarios that are more likely to occur. The applicability of the proposed sensor network design approach is demonstrated by applying it to various case studies taken from literature. The results indicate the utility of the approach in obtaining a sensor network that can enable simultaneous identification of the fault that has occurred as well as a simultaneous change in edge sign, if any.

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