Summary of: Solving Industrial Fault Diagnosis Problems with Quantum Computers

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Abstract

This is an extended abstract of the manuscript 'Solving Industrial Fault Diagnosis Problems with Quantum Computers' [1] that was published in the journal Quantum Machine Intelligence in 2024. The article presents two approaches to perform fault diagnosis: (i) using Grover's algorithm, and (ii) using the Quantum Approximate Optimization Algorithm. We found the Grover algorithm generates more solutions and needs some post-processing to obtain minimal diagnoses, but it is much faster than the more accurate QAOA approach.

Keywords

Fault Diagnosis, Quantum Computation, Cyber-physical Systems

1. Extended Abstract

Modern industrial cyber-physical systems are characterized by high interconnectivity, modularity, throughput, and number of system parameters. But what happens if such systems fail? Especially in environments with little human oversight (such as in a ship's engine room) reliable and automated diagnosis increases system resilience. However, fault diagnosis is a challenging task that demands in many cases exponential runtime [2]. To mitigate the runtime issues, efficient quantum computation for fault diagnosis problems has become an important area of applied research. Nowadays, quantum fault diagnosis faces two problems: i) Efficiently solving the diagnosis problem: Many diagnostic procedures are based on reduction to the NP-complete satisfiability problem [3]. ii) Obtaining available models from heterogeneous cyber-physical systems: In practice, many companies still rely on manual and expert-driven diagnosis and repair procedures. These, however, are often expensive, slow, and error prone.

Classical fault diagnosis has been extensively researched in the past. Many different algorithms and methodologies have been developed. But only a few publications are available using quantum computers (all of them use quantum annealers). Our article proposes two novel approaches to conduct fault diagnosis of cyber-physical systems on universal quantum computers (QC) and applies them in a general methodology for QC-based industrial fault diagnosis.

We answer two research questions: How can quantum computers be applied for efficient fault diagnosis in industrial production settings and what are the benefits? How is the model for fault diagnosis obtained? While there is some related work on solving the diagnosis problem for combinatorial circuits using quantum computers [4], there exist so far no QC-based approaches for diagnosis of cyber-physical systems. This is due to two challenges: i) The system description (i.e. the model of the system) is hard to find and in many practical use-cases unavailable. ii) Cyber-physical systems produce continuous, discrete, and binary data, rendering diagnosis more complicated, as many diagnosis algorithms assume a model specified in Boolean logic. iii) To perform fault diagnosis, algorithms attempt to find a satisfying assignment within some knowledge base through MaxSAT solving. But solving a MaxSAT problem is NP-complete.

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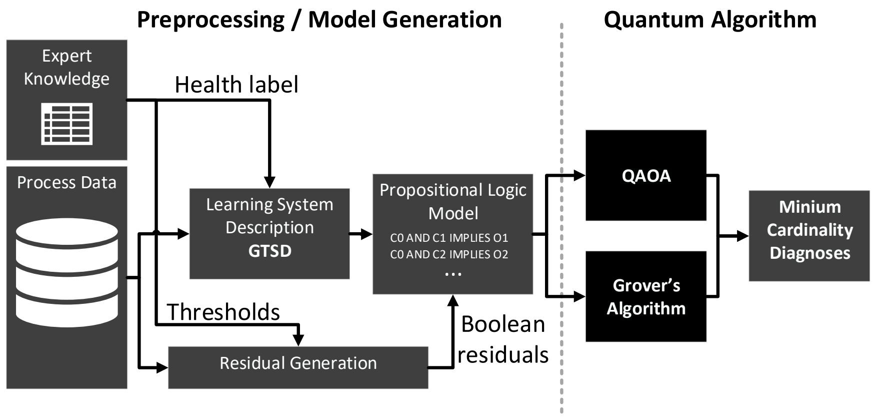

Figure 1: Our methodology: We first learn a system description and then perform QC-based fault diagnosis.

In our article, we present a data-driven and explainable fault diagnosis approach and demonstrate its usage on an IBM Falcon quantum processor. For this, we make three contributions: (i) A novel algorithm qDiagCPS_Grover that trades speed for accuracy. (ii) The novel algorithm qDiagCPS_QAOA which is slower in absolute terms, but more accurate. (iii) The algorithm GTSD that creates propositional logic system descriptions (system models) from data.

The motivation behind our contributions is the following: Since diagnosis is an NP-complete problem, it is reasonable to look for more efficient solutions using quantum computers. To realise this, we use two approaches: a) We convert a propositional logic model into a SAT problem and use Grover's algorithm [5] to find the minimum satisfying assignment. b) We transform the propositional logic model into a quadratic binary optimization problem (QUBO), which is solved using the Quantum Approximate Optimization Algorithm (QAOA). We conclude that both solutions find the minimum cardinality diagnosis $\omega' \subset \omega$, with $\omega \in COMPS$ being the set of faulty components within the set of all components *COMPS*.

The evaluation was performed on several systems and benchmarks modelling use-cases from the process industry. While we received good results, especially with the QAOA-based algorithm, too few qubits were available to perform relevant evaluations that scale for cyber-physical systems.

Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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