Master Thesis Proposal

Automated Root-Cause Analysis for Unexpected System Behavior

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1 Problem Statement

In general, systems are designed with a predefined set of rules to ensure that they operate in a desired and predictable manner. These systems, whether physical, digital, or hybrid, rely on consistent behavior to achieve their intended functions. However, in practice, every system inevitably encounters errors or unexpected behaviors. These anomalies can disrupt the system's functionality, sometimes making it partially or entirely inoperative.

Minimizing errors is of high importance, as system failures can lead to significant financial costs, operational inefficiencies, and, in certain contexts, even pose safety risks. Ensuring that systems operate with as few errors as possible is a critical objective across various domains, from manufacturing and software to healthcare and transportation.

Thus, having tools that can accurately and efficiently identify the reasons behind these unexpected behaviors is of great value. The goal of these tools is to find the actual root cause of the error.

In the context of this thesis, the observed system is an agricultural tractor, a vital tool that supports farmers in their agricultural operations. Like any other complex vehicle, tractors can occasionally exhibit unexpected behaviors that disrupt their functionality and even make them non-functional. For every error or disruption of functionality, farmers need to send their tractor to a workshop so that experts can examine the vehicle and manually try to find the root cause of the error. The process of finding the root cause of an error is difficult and time-consuming, which affects both experts, who want a faster way to find the error, and farmers, who want their vehicle in the field as soon as possible.

The main problem that this thesis aims to solve is to reduce the time required to find errors by developing a root cause analysis (RCA) tool that will help experts find root causes in a more automated way. This tool will not make decisions instead of experts but rather help them make correct decisions faster in finding the root cause of an error. By quickly identifying the causes of failures and reasons for failure, the RCA tool minimizes downtime, prevents unnecessary repairs, and helps address recurring issues, ultimately improving overall system performance and dependability.

Company AVL provided data about tractors that will be used for developing the root cause analysis tool. The data consists of three sources. The first source is time series data that contains signals of each tractor, the second is workshop data that contains information about unexpected behavior and errors, and the third source is data that contains knowledge about errors, behaviors, and possible root causes.

Developing such a tool can present many challenges that need to be tackled. The first problem that arises is how to identify the error that made a tractor non-functional from the data. The second problem will be finding reasons why a certain part broke based on the available data. There are also challenges regarding how to combine knowledge from three different sources to create an intelligent system.

2 Aim of the Thesis and Expected Results

The aim of this thesis is to explore the possibilities and implement an automated root-cause analysis tool tailored to agricultural tractors. This work emphasizes practical and applicational aspects, aiming to provide a viable solution to the identified problem. The ultimate objective is to create a tool that can benefit tractor manufacturers by enhancing their ability to identify and address the reasons for system failures effectively.

The implementation of the tool is based on tractor data provided by the company AVL. There are many different approaches that can be considered in implementing such a tool. One of the simplest approaches and the baseline for this thesis would be identifying errors using basic statistics. The baseline will try to estimate and provide reasons why certain parts of the tractor broke based on the numerical values of available signals.

The theoretical aspect will focus on finding more sophisticated methods that will hopefully improve on the baseline results, resulting in the tool providing more accurate root causes of errors and more comprehensive reasoning for why certain parts broke. Different methods will be investigated and evaluated, possibly including association rule mining [2] or causality [6] as a potential methods in identifying the underlying reasons behind errors. Additionally, a possible way of developing the tool is by using Large Language Models (LLMs) to combine knowledge from three different sources to create an intelligent system. Furthermore, the distribution of time to error for failed parts [3] will be explored, which can hopefully help in explaining the root cause of part failures. The general aim of the theoretical work will be to explain methods and implement those that could improve results.

The practical goal of this thesis is to develop an automated system that leverages data collected from tractors to analyze errors, predict their exact causes, and explain why they occurred. The expected outcome of this thesis is a practical tool that will identify the causes of specific part failures, such as a clutch.

Causes should be identified in the tractor data before the error occurs (time series data), where certain signals could explain why a part failed. For example, if the acceleration pedal signal was too high, that could be a reason why the clutch failed. To verify if this is the reason for the error, the tool can cross-reference it with domain knowledge data, where common errors and causes are documented. Ultimately, the goal of the tool is to assist experts in efficiently determining the possible root causes of unexpected behavior.

3 Methodology

The current methodological process consists of several steps.

1. **Data Exploration**
   The first step in creating a root cause analysis tool is to explore the data. A classified dataset provided by the company AVL will be the sole dataset used in this analysis. The final product, the root cause analysis tool, will heavily rely on the available data, making in-depth exploration essential. The dataset comprises three data sources: time series data on tractor behavior, structured tree data containing domain knowledge about failures, and workshop tabular data detailing the repair of specific parts. The initial steps involve exploring the dataset and gaining some domain knowledge. Following this, the time series data will be processed and summarized. Other methods may also be considered during exploration, as the optimal method for implementation is not yet known.

2. **Literature Review**
   The second step, after becoming familiar with the data, is to explore possible solutions by researching methods that could be used in the context of this thesis and are applicable to the available data. It is essential to find a way to process and summarize the time series data. There is a need to extract knowledge and identify indicators for errors from the large dataset. To explain the root cause, methods such as association rule mining or causal discovery could be helpful to research. One potentially helpful approach is implementing classification by time of failure data, which would classify errors into groups: early error, random error, and wear-out error. Additionally, the possibility of using Large Language Models (LLMs) as a core part of the tool should also be explored.

3. **Implementation**
   This is the main part of the thesis and the final result of it. How the implementation proceeds will be determined by the researched methods and choosing one of those as a way of first finding errors in the data. After that, it is important to implement a way of explaining those errors. In the implementation part, it will be important to see how the entire tool will be developed to be fully functional and also how to combine different data sources and types.

4 State of the Art

Root-cause analysis, as stated before, is a very useful tool with numerous applications across various fields. There are many approaches to implementing it, but in general, each approach is highly specific to the domain and use case. Therefore, I would argue that there is no definitive state-of-the-art solution for this exact problem.

An example of an approach that serves as inspiration for solving this problem was proposed by [5], where they explored automated root-cause analysis to solve cloud incidents. They mainly focused on using an LLM agent (RCA Agent [7] on the ReAct framework [8]) for reasoning and using different tools to enhance performance. Some tools they use are retrievers of different sources, like knowledge base documents. This could be useful in my setting because there is also a source of data with known errors. Where their approach differs from the setting of this thesis is in the data type. In their setting, everything is in textual format, and they do not have to extract knowledge from time series data. They track textual logs, whereas in this thesis, I track time series data to find the root cause.

Another solution in the domain of cloud incidents was proposed by [1], where they consider multi-source data, which is similar to the setting of this thesis. The difference between this article and the thesis is that the article focuses more on summarizing errors and classifying them into predefined classes. It lacks the explainability of errors and focuses more on summarizing the problem.

These approaches could be helpful for the automotive domain because of the need to combine different data sources and track steps before incidents happen. Both domains have errors in textual format, metric data in the form of time series, and some structure of knowledge from known issues.

The goal of this thesis is also to understand why errors occurred and to explain them as accurately as possible. To find possible reasons, causality could be used. The work by [4] tests and attempts to answer how effective causal inference-based RCA methods are in locating root causes.

5 Context within the Data Science Program

To complete this thesis, several courses within the Data Science Program are highly relevant. The first one, 188.995 Data-oriented Programming Paradigms, aids in the overall implementation and programming of the tool. For understanding the distributions of errors [3], 105.731 AKSTA Statistical Computing is particularly useful. As one of the initial steps is to familiarize oneself with the data, knowledge from the courses 188.305 Information Visualization and 186.868 Visual Data Science is beneficial, as visualization can significantly aid in data comprehension.

The knowledge of known errors and their descriptions is in textual format, and the course 194.093 Natural Language Processing and Information Extraction covers the main ideas about text processing. A highly important course for the implementation of this tool is 194.154 Generative AI, as the main tool will be LLMs.

There are many other courses that are relevant to the context of this thesis, but these are the main ones.

References

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