

Fault Tolerance Report

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1. Introduction

The automotive industry has witnessed significant advancements in recent years, with the integration of complex electronic systems and software into modern vehicles. As cars become more connected and autonomous, ensuring fault tolerance in car systems has become a critical concern. Fault tolerance refers to the ability of a system to continue functioning correctly in the presence of faults or failures.

This report aims to explore the proactive and reactive approaches utilized for achieving fault tolerance in car systems. Proactive approaches involve preventive measures to minimize the occurrence of faults, while reactive approaches focus on detecting and recovering from faults when they do occur. By implementing these approaches effectively, automotive manufacturers can enhance the safety, reliability, and performance of their vehicles.

2. Proactive Approaches for Fault Tolerance

2.1. Redundancy and Diversity

One of the primary proactive approaches for fault tolerance in car systems is the incorporation of redundancy and diversity. Redundancy involves the duplication of critical components or subsystems, ensuring that if one fails, a backup can take over seamlessly. This redundancy can be achieved at various levels, such as sensors, actuators, and computing systems. Additionally, diversity in the selection of components from different manufacturers or implementing different technologies can further enhance fault tolerance by reducing the likelihood of common-mode failures.

2.2. Fault Prevention and Error Detection

Another proactive approach involves implementing fault prevention mechanisms and error detection techniques. This includes rigorous testing and validation processes during the development phase to identify and rectify potential faults before deployment. Techniques such as formal verification, model checking, and simulation can aid in ensuring the correctness of the system's design and behavior. Furthermore, the use of advanced diagnostic algorithms and error detection mechanisms can enable early detection of faults, allowing for timely preventive actions.

3. Reactive Approaches for Fault Tolerance

3.1. Fault Detection and Diagnosis

Reactive approaches focus on detecting faults when they occur and diagnosing their root causes. Car systems employ various techniques such as built-in self-tests (BIST), on-board diagnostics (OBD), and anomaly detection algorithms to monitor the health and performance of critical components. These approaches enable the identification of faults and provide valuable information for subsequent actions, such as fault isolation and recovery.

3.2. Fault Recovery and Mitigation

Once a fault is detected and diagnosed, reactive approaches aim to recover from the fault and prevent its propagation. Fault recovery mechanisms may involve reconfiguring the system to bypass the faulty component or subsystem, activating backup systems, or implementing fail-safe modes. Additionally, advanced algorithms can be employed to optimize the system's behavior and mitigate the impact of faults, ensuring the continued functionality and safety of the vehicle.

4. Integration of Proactive and Reactive Approaches

To achieve comprehensive fault tolerance, it is essential to integrate both proactive and reactive approaches. Proactive measures help minimize the occurrence of faults, while reactive measures provide swift responses and recovery when faults do arise. By combining these approaches, car systems can ensure a robust and resilient architecture that enhances the overall safety and reliability of the vehicle.

5. Faults discussed:

1) Dash battery light on

2) *Low oil pressure*

3) *Air conditioning / heating system*

4) *Fuel leakage*

5) Dash Battery light on:

5.1) The problems that accompany the activation of the light:

It is a small light that indicates that there is a problem with the car battery or its charging system. If the light is on, then most likely the car won't start, as the battery is responsible for creating sparks inside the combustion chambers to start the engine.

5.2) What causes the light to turn on:

- 1) A part of the car's electronics was left turned on for a long period of time without the engine working, which caused the battery's death.
- 2) A bad battery, or an old battery that needs replacement.
- 3) The charging cable is not connected properly to the battery poles.
- 4) The charging cable is not connected properly to the car's dynamo in the engine.
- 5) The dynamo doesn't charge the battery.
- 6) The dynamo belt is too loose to rotate the dynamo pulleys correctly. This fault often accompanies the increase of engine temperature, as the water coolant pump pulley is connected to the same belt that rotates the dynamo.

5.3) Algorithms for redundancy:

Having an extra battery installed, this works if the fault was from the main battery. Another battery sensor would help specify the faulty battery.

-Pros: Ensuring that the car would start even if the main battery died.

-Cons: Using more space in the engine chamber.

5.4) Algorithms for fault detection and correction:

- 1) **Read and interpret Diagnostic Trouble Codes (DTCs):**

Connect an OBD-II scanner to the vehicle's diagnostic port and retrieve and record any stored DTCs related to the charging system or battery. Refer to the scanner's documentation or a reliable database to interpret the DTCs, and understand the specific issues indicated by each code.

-Pros: Can access the history of the battery's state.

-Cons: Only works for modern cars that have smart computers.

2) Visual Inspection:

Inspect the battery, battery terminals, battery cables, and dynamo connections for signs of damage, corrosion, or loose connections. If any issues are identified, fix them, or call a mechanic.

-Pros: Would save money if it was just a loose wire.

-Cons: Needs time and tools.

3) Battery Load Test:

Perform a battery load test using a battery tester. Apply a load to the battery while monitoring its voltage. If the voltage drops excessively or the battery fails to maintain an acceptable voltage, it may need to be charged or replaced.

-Pros: Detects battery problems fast.

-Cons: Needs tools, probably needs a mechanic.

4) Charging System Test:

Use a voltmeter or multimeter to measure the voltage across the battery terminals while the engine is running. Compare the measured voltage to the manufacturer's specifications.

-Pros: A simple algorithm and cost-effective.

-Cons: Doesn't provide complete evaluation of the charging system.

5) Dynamo Check:

Inspect the dynamo for any visible damage or loose connections. Test the output of the dynamo using a voltmeter or multimeter. If the output voltage is significantly lower or higher than the specified range, the dynamo may be faulty and require further inspection or replacement.

-Pros: Great for detecting the dynamo's output.

-Cons: Complex repairs if it was faulty.

6) Belt and Tension Inspection:

Inspect the serpentine belt that drives the dynamo. Ensure it is in good condition, properly tensioned, the right model for the car's engine, and not slipping or worn. If the belt is damaged or loose, it may need to be replaced or adjusted.

- Pros:** Helps maintain optimal performance and prevents belt slippage, which could cause serious damage to the engine, especially the hoses.
- Cons:** Needs professional expertise, as the smallest adjustments could damage something.

6) Low oil pressure:

Oil is needed to lubricate the engine to create a protective film between its mechanical parts, decreasing their contact. “Low Oil Pressure” a critical fault that can lead to engine damage or failure as there could be a leak.

6.1) How it is detected:

This fault is detected by monitoring oil pressure sensors in the engine’s lubrication system.

6.2) Causes:

- 1) Insufficient oil level
- 2) Infrequent oil changes
- 3) Clogged oil filter
- 4) Faulty oil pressure sensor
- 5) Engine wear

6.3) Fault tolerance:

1) Redundancy:

Implementing redundant oil pressure sensors to provide backup measurements, in case one of the sensors failed. Relying on the measurements of more than one sensor provides more accurate reading for the oil pressure.

2) Error Detection and Correction:

Implementing algorithms to ensure the data integrity of the oil pressure to prevent wrong readings from affecting the system performance.

6.4) Algorithms:

1) Redundant Sensor Consensus Algorithm:

This algorithm is used for error detection and correction. This algorithm compares the different readings from different sensors in the system, calculates a value based on most of the readings.

The algorithm compares the differences in the redundant sensors' readings, indicating potential failures in the sensors.

- **Advantages:**
 - Redundancy improves the reliability of detecting low oil pressure faults, reducing false alarms.
 - Detects the oil pressure fault early, allow the driver to check the car system and avoid what may cause the fault.
- **Disadvantages:**
 - Implementing redundant sensor system increases the complexity that can increase the cost of manufacturing, maintenance and trouble shooting.
 - Sophisticated algorithms can increase the cost of the car.

2) Multimodal:

Multiple Linear Regression model is used to create linear regression models, each tailored to a specific subset of data. This uses separate linear regression models to capture the specific characteristics and relationship within each subset of data. The models can be used to predict the likelihood of low oil pressure for new incoming events. After obtaining the scores, isolation forest model excels to identify outliers or anomalies within data set. The anomaly score obtained from isolation forest can be compared against a predefined threshold to classify the low oil pressure as normal or abnormal.

- **Advantages:**

They provide much more convenient forms of interaction designed around user needs.
- **Disadvantages:**

Combinations of impairments can increase the complexity of a Multimodal System to the point where it may prove too difficult to find a satisfactory solution.

7) Air Conditioning/Heating System Faults:

7.1) How It's Detected:

1) Symptoms:

1) No Cooling/Heating:

The most noticeable sign is the absence of cold or hot air when the A/C or heater is turned on.

2) Weak Airflow:

Airflow may be weak due to blockages or fan issues.

3) Unusual Noises:

Strange noises when the A/C or heater is operating.

4) Foul Smells:

Musty or moldy odors indicating possible mold or bacteria growth.

5) Foggy Windows:

Improper defogging due to malfunctioning heater core.

2) Diagnostic Tools:

OBD-II Scanner: Retrieves trouble codes from the car's computer system.

Pressure Gauges: Measures refrigerant pressure to identify leaks or system blockages.

Thermometer: Checks the temperature of the air being emitted from the vents.

Visual Inspection: Looks for signs of leaks, damage, or wear in system components.

7.2) Causes:

1) Compressor Failures: Compressor issues can prevent the system from cooling.

2) Electrical Problems: Faulty wiring, blown fuses, or sensor failures.

3) Clogged Filters: Dirty or blocked cabin air filters restrict airflow.

4) Thermostat Problems: Malfunctioning thermostats can cause improper temperature regulation.

5) Heater Core Issues: Clogs or leaks in the heater core can affect heating performance.

7.3) Fault Tolerance:

Fault tolerance in HVAC systems ensures continued operation, though possibly at reduced efficiency, until repairs can be made.

For example:

Redundant Components: Dual-zone systems can maintain functionality in one zone even if the other fails.

Manual Override: Allows manual control of the system if automatic controls fail.

7.4) Algorithms:

7.4.1) Control Algorithms

1) PID Control (Proportional-Integral-Derivative)

PID control continuously adjusts the HVAC system parameters (like compressor speed and airflow) to maintain the desired temperature by minimizing the error between the setpoint and the actual temperature.

Advantages:

Simplicity: PID controllers are relatively simple to implement and tune.

Reliability: They have been extensively tested and proven in various applications.

Precision: Good at maintaining a stable temperature with minimal fluctuation.

Disadvantages:

Tuning Difficulty: Requires proper tuning of three parameters (proportional, integral, derivative) which can be complex.

Overfitting: Can be overly sensitive to specific operating conditions and less adaptive to varying conditions.

Lag in Response: May have a slower response time to sudden changes in temperature.

2) Fuzzy Logic Control

Fuzzy logic control adjusts the HVAC system parameters based on a set of heuristic rules, providing a more adaptive and flexible response to changing conditions compared to traditional control methods.

Advantages:

Adaptability: Better handles the nonlinearities and variations in a system's behavior.

User-Friendly: Easier to set up without needing precise mathematical modeling.

Robustness: More robust in dealing with noisy and imprecise data.

Disadvantages:

Complexity: More complex to design compared to PID controllers.

Computational Load: Requires more computational resources, which might be a constraint in low-power systems.

Tuning Challenges: Designing the fuzzy rules and membership functions can be time-consuming.

7.4.2) Diagnostic Algorithms

1) Fault Detection and Isolation (FDI)

FDI algorithms detect and diagnose faults in the HVAC system, allowing for timely interventions to maintain system reliability and performance.

Advantages:

Accuracy: Precisely identifies the fault and its location within the system.

Preventive: Enables early detection of potential issues, allowing for timely intervention.

Detailed Analysis: Provides comprehensive insights into system performance and health.

Disadvantages:

Complexity: Can be complex to implement and require extensive sensor networks.

Cost: Higher upfront cost due to additional sensors and computing capabilities needed.

Maintenance: Requires regular updates and maintenance to ensure accuracy.

8) Fuel Leakage:

Fuel leakage is one of the most dangerous malfunctions that can occur in a vehicle because it can lead to a fire or explosion, posing a significant threat to the life of the driver, passengers, and surrounding people. Gasoline or diesel are highly flammable, and any small spark or heat source can ignite the leaked fuel, leading to catastrophic accidents.

8.1) Causes of fuel leakage:

- 1) Corrosion or Damage of Fuel Hoses.
- 2) Loose Connections.
- 3) Damaged Fuel Tanks.
- 4) Leakage from the Injection System.
- 5) Seal and Gasket Failures.

8.2) Algorithms and why they are used:

8.2.1) Structural Redundancy:

Method: Designing the fuel system with redundant fuel paths (such as dual pipes), so that if a leak occurs in one path, it gets sealed and the other can continue to function normally to prevent fuel loss.

Advantages:

- 1) Significantly improves safety and reliability.
- 2) Ensures the system can continue to operate even in the event of a leak.

Disadvantages:

- 1) Substantial increase in cost and structural complexity.
- 2) Requires more space within the vehicle to install the redundant system

8.2.2) Sensor-Based Detection Algorithm:

Method: This algorithm relies on using multiple sensors (such as pressure sensors, temperature sensors, and gas sensors) to measure abnormal changes that may indicate a fuel leak. Data is collected from the sensors and analyzed using specialized software to determine if there is a leak.

Advantages:

- 1) High accuracy in detecting leaks.
- 2) Ability to precisely locate the leak.
- 3) Rapid response to sudden leaks.

Disadvantages:

- 1) High cost of installing and maintaining sensors.
- 2) Some sensors may be prone to errors or wear over time.
- 3) Complexity of the system and difficulty integrating with existing systems.

8.2.3) Model-Based Detection Algorithm:

Method: This algorithm relies on creating a mathematical model of the car's fuel system. The system compares real performance data from the vehicle with the expected data from the model. Significant deviations between the model and the actual data may indicate a leak.

Advantages:

- 1) Can detect small leaks that sensors might miss.
- 2) Can be used to analyze and improve overall system performance.

Disadvantages:

- 1) Requires accurate and complex models, which can be difficult to develop.
- 2) Prone to errors if the model is inaccurate or if there are changes in the vehicle's operating conditions.

9) Conclusion

In conclusion, fault tolerance in car systems is of paramount importance to guarantee the safe and reliable operation of modern vehicles. Proactive approaches, such as redundancy, diversity, fault prevention, and error detection, aim to minimize the occurrence of faults. Reactive approaches, including fault detection, diagnosis, recovery, and mitigation, focus on timely responses and effective recovery from faults. By integrating these approaches, automotive manufacturers can build fault-tolerant car systems that enhance passenger safety and vehicle reliability in the face of potential faults or failures.