Improving the Dependability of AMR Sensors Used in Automotive Applications

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***Abstract*—Electronic systems are replacing mechanical parts to improve the safety and performance of the cars. However, the electronic components should be dependable, meaning they should be trusted to work properly over time. AMR sensors are widely used in automotive for angle measurements. Nevertheless, they are affected by performance degradation and catastrophic faults. Both should be handled to guarantee the correct operation of the sensor over time. This paper proposed two modules, fault-tolerant, and self-calibration. Results show they allow to improve the dependability of the sensor.**

***Index Terms*—Dependability; self-x capabilities; fault-tolerant; angle error; AMR sensors**

I. INTRODUCTION

Electronic systems are increasingly be included in automotive applications. The aim is to improve safety as well as the performance of the cars. However, these applications are considered safety-critical. So, they demand reliable, high-performance components capable of operating for a long time. The sensors required should be trusted to provide the correct services despite the harsh operational conditions [1].

Magnetic sensors are widely used in automotive. They offer several key advantages, such as mechanical robustness due to the non-contact principle, a wide operating temperature range and low manufacturing cost. [2] [3]. Magnetic sensors, based on magnetoresistance effect (AMR sensor) are often used for angle measurement in automotive.

The sensor is configured with two Wheatstone bridges rotated 45 degrees with respect to each other, as shown in Fig.1. The magnetic angle is estimated from the two sinusoidal signals at the bridge outputs. However, these signs include undesired parameters, such as offset voltage, amplitude imbalance and extra harmonics that affect the performance of the sensor. Until now, the offset voltage is the parameter mainly compensated because it is the largest source of angle error. The compensation factors are estimated at the start of the sensor life. Although the offset voltage drifts due to aging effects, so far it remains inside the tolerant band allowed. However, this band will get smaller in the future, especially with the current trend of autonomous cars. Besides performance degradation in the sensor can also occur catastrophic faults. These are resulting from a short or broken condition in any of the bridge resistances [4].

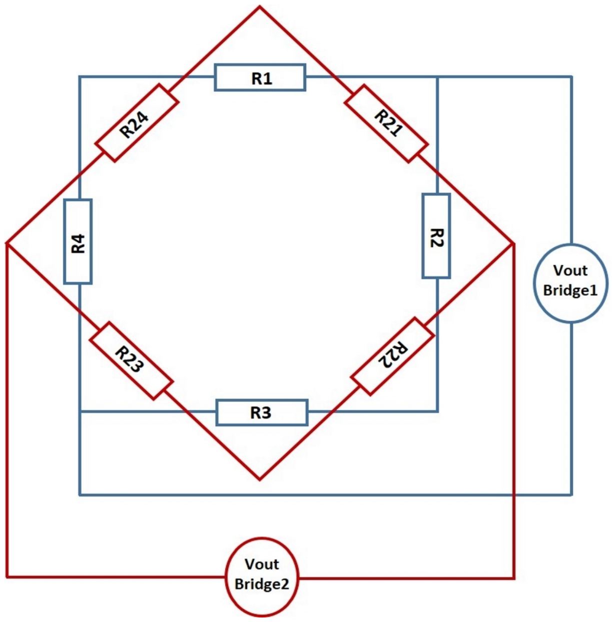

Fig. 1: Schematic of the Wheatstone bridges in an AMR sensor. Each **R** represents a magnetoresistance.

Dependability, as well as the accuracy requirements in automotive applications, are constantly increasing. Based on the sensor characteristics mention above. Therefore it is necessary to embraces strategies to guarantee that AMR sensors can handle catastrophic faults, but also the undesired parameters with their aging effects [5]. This paper proposes to combine two approaches to improve the dependability of AMR sensors. Fault-tolerant based on analytical redundancy for catastrophic faults and self-x characteristics to maintain the sensor performance over time.

The outline of the paper is as follows. Section II explains dependability in automotive applications. Section III presents the proposed methods discussed in section IV.

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II. DEPENDABILITY IN AUTOMOTIVE APPLICATIONS

Dependability represents the reliance on a system to perform its intended functions under certain conditions during a period of time. It cannot be measured by one quantity but rather by several attributes like reliability, availability, maintainability and safety [6] [7].

The automotive industry is moving ahead to have dependable electronic components. Especially regarding reliability and safety attributes. The reliability goal is to match the failure rate of 10^{-9} of a simple mechanical component. About safety, it should be satisfied the ASIL level D, which means a failure rate smaller than 10^{-8} per hour [8]. Maintainability should also be taken into consideration. It should be guaranteed the system keeps its performance over time despite undesired wearing and aging effects. [5]. In automotive applications, a fault-tolerant sensor should be at least fail-operational (FO). It means one failure is tolerated.

III. IMPROVING THE DEPENDABILITY OF AMR SENSORS

Different strategies can be used to improve the dependability of AMR sensors. Fault-tolerant methods enable the sensor to continue working if a catastrophic fault occurs. This can be accomplished by physical redundancy with the same type of sensor. Also by analytical redundancy with different sensors or process models. We proposed a fault-tolerant module that applies analytical reconfiguration to the sensor, as we presented in [9].

Self-x properties allow the sensor to look after itself to be sure it works in optimal conditions during its lifetime. A self-calibration module allows updating online compensation factors during the sensor lifetime. In this case, is updated the factors for offset voltage and amplitude imbalance, as detailed in [10]. These two are the first and second source of error in the angle calculation.

The proposed modules have been verified using data obtained from an analytical model of the sensor but also with data measured from commercial sensors. The fault-tolerant module allows obtaining a failure rate of 10^{-14}. This considering a failure rate of 10^{-7} per hour for the AMR sensor [7]. Figure 2 shows that with the self-calibration module, the maximum angle error of the sensor is not affected by aging effects, as occurs for the other two cases shown in the figure.

IV. DISCUSSION

A system has been proposed to improve the dependability of AMR sensors. It includes a fault-tolerant and a self-calibration module. The fault-tolerant allows the sensor to keep working if a catastrophic fault occurs. If compared with a traditional dual system with physical redundancy, our module does not require hardware duplication. An advantage regarding space and production costs of the sensor. The failure rates obtained

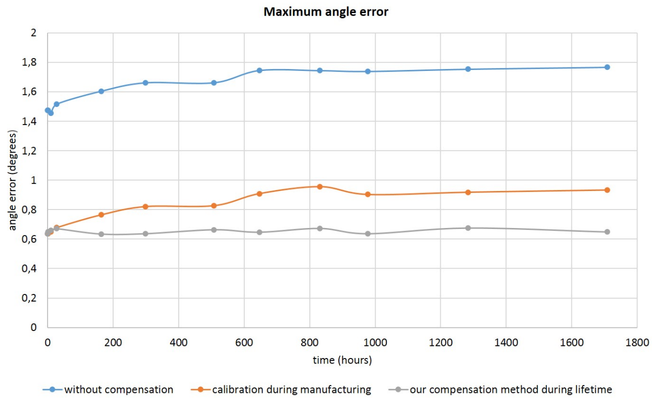

Fig. 2: Remaining angle error in a commercial sensor

satisfies the safety and reliability requirements demanded in automotive applications.

The addition of self-x properties allows improving the maintainability of the sensor. Through the compensation of the aging effects, it is possible to keep the sensor performance over time.

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