Information Sciences 259 (2014) 321–334

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Automatic field data analyzer for closed-loop vehicle design

Yilu Zhang *, Xinyu Du

Electrical & Controls Systems Lab, GM Global R&D, 30500 Mound Road, Warren, MI 48090, USA

ARTICLE INFO

Article history:
Available online 14 August 2013

Keywords:
Vehicle diagnostic
Battery management system
Lead–acid battery
Knowledge extraction
Feature ranking

ABSTRACT

Rapidly increasing complexity of vehicle systems is calling for technologies to promptly analyze field problems, and effectively identify weakness in vehicle engineering design, in order to enhance product quality. Recent vehicular communication technologies allow for remote access to extensive amount of vehicle data in a cost-effective way, which enables in-depth field issue analysis. However, practical solutions are still lacking to effectively turn the massive amount of raw data into actionable design enhancement suggestions.

In this paper, we propose a general framework, named Automatic Field Data Analyzer (AFDA), and related algorithms that analyze large volumes of field data, and identify root causes of faults by systematically making use of signal processing, machine learning, and statistical analysis approaches. AFDA evaluates vehicle system performance, generates feature vectors that represent different root causes of faults, and identifies the features that are most relevant to system performance fluctuation, which eventually reveals the underlying reasons for the faults. This paper presents a case study of AFDA in the application of vehicle battery, where gigabytes of real vehicle data are sifted through, and the root causes of field issues are identified. The results well match the findings from experts with years of experiences. The proposed data-based scheme and approaches can be generally applied to any vehicle systems.

1. Introduction

A typical process of vehicle engineering design is illustrated in Fig. 1. The closed-loop process starts with concept generation, goes through mathematical modeling and simulation, lab testing and bench studies, vehicle testing, and eventually reaches the final products on the road. There are feedback paths from each step to previous ones, where the vehicle system is analyzed under different operating conditions; performance is evaluated; and design changes are initiated. The fielded products are exposed to real and diversified usage conditions, and therefore, the feedbacks from fielded products are most valuable in enhancing vehicle design. Similar to many other manufacturing industries, the automotive industry relies on warranty data analysis to identify field problems, and to enhance next-generation vehicle design [31].

With the rapidly increasing complexity of the vehicle system and the mounting time-to-market pressure, the effectiveness of warranty feedback is challenged for at least the following reasons. First, warranty reports are delayed feedbacks, when faults or failures are already present. Secondly, many vehicle faults have an intermittent nature, which is a popular characteristic for any complex systems. As a result, a significant number of vehicle warranty reports are "customer concern not duplicated," which do not provide specific design enhancement information. Thirdly, warranty reports are snapshots of vehicle history, and do not provide the fault degradation information that is critical to enhance system quality.

* Corresponding author. Tel.: +1 586 298 0253; fax: +1 586 986 1647.
E-mail addresses: yilu.zhang@gm.com (Y. Zhang), xinyu.du@gm.com (X. Du).

0020-0255/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.ins.2013.08.010

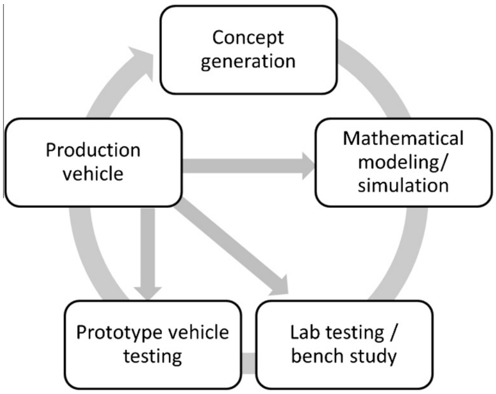

Fig. 1. A high-level illustration of vehicle design process. For clear illustrations, not all feedback loops are illustrated.

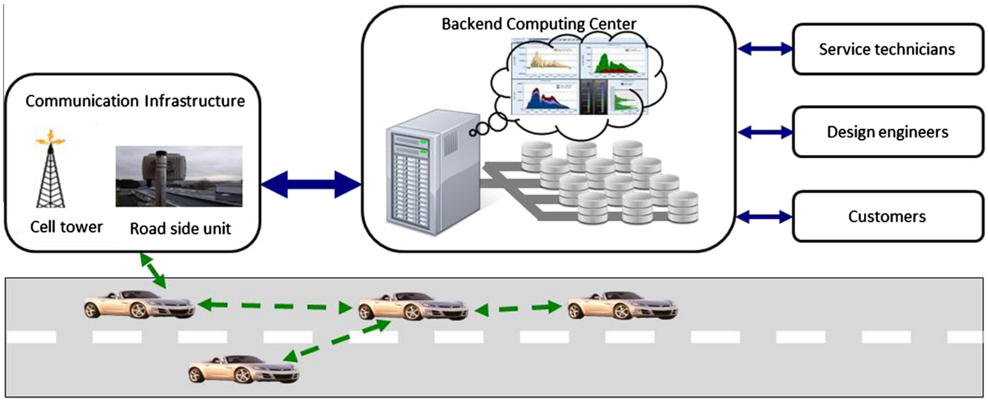

Fig. 2. An illustration of Connected Vehicle Diagnostics and Prognostics concept.

Lately, technologies are becoming available to enable a more effective closed-loop vehicle design process. In particular, the fast advancing vehicular networking technologies allow for cost-effective measurement and data collection from a large number of on-road vehicles over their entire lifecycle [20]. When this data is collected at a large scale and archived in database systems, data analytic methods can be utilized to extract actionable knowledge, and provide valuable feedbacks to product teams. Evolving from the efforts on remote vehicle diagnostics [41,35], a recent proposed concept, called *Connected Vehicle Diagnostics and Prognostics* (*CVDP*) [44], provides a solution to implement such a closed-loop vehicle design process that has a higher level of effectiveness. However, an array of research and implementation issues remains to be addressed, ranging from onboard electronic control unit design, vehicle networking, backend high-performance computing, to knowledge discovery (see Fig. 2).

This paper focuses on the knowledge discovery part. Specifically, we propose a framework that analyzes large volumes of on-road vehicle data, automatically identify root causes of faults, and eventually provides actionable design enhancement suggestions. We select the vehicle battery rather than other vehicle components as the targeted application due to its critical role in vehicle operation. The proposed data-based scheme and approaches can be easily generalized and applied to other vehicle components.

2. Brief background on vehicle batteries

Without loss of generality, we limit our scope to the most common type of vehicle batteries, the 12 V starting-lighting-ignition (SLI) battery. The primary function of the SLI battery is to drive the starter motor, crank the engine, and start the vehicle. When the battery fails, the vehicle cannot start. In addition, when the vehicle engine is active, the SLI battery serves as an electric power source that is secondary to the alternator. It supplies electric power to the loads when the demand exceeds alternator's maximum output. When the engine is off, the SLI battery is the only electric power source to operate electrical accessories such as the clock and the anti-theft system.

Battery failure is a hardy-perennial problem across the automotive industry, despite of the fact that most SLI batteries are Lead Acid batteries and were invented more than 150 years ago. There are two main failure types for the SLI batteries: low