Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 126 (201709) 907–914

Energy Procedia

www.elsevier.com/locate/procedia

72nd Conference of the Italian Thermal Machines Engineering Association, ATI2017, 6-8 September 2017, Lecce, Italy

Internal Combustion Engine sensor network analysis using graph modeling

A. Corsini[a], F. Bonacina[a]*, S. Feudo[a], A. Marchegiani[a], P. Venturini[a]

[a]*Department Mechanical and Aerospace Engineering, Sapienza University of Rome, Via Eudossiana 18, I00184 Rome, Italy**

Abstract

In recent years there has been a rapid development in technologies for smart monitoring applied to many different areas (e.g. building automation, photovoltaic systems, etc.). An intelligent monitoring system employs multiple sensors distributed within a network to extract useful information for decision-making. The management and the analysis of the raw data derived from the sensor network includes a number of specific challenges still unresolved, related to the different communication standards, the heterogeneous structure and the huge volume of data.

In this paper we propose to apply a method based on complex network theory, to evaluate the performance of an Internal Combustion Engine. Data are gathered from the OBD sensor subset and from the emission analyzer. The method provides for the graph modeling of the sensor network, where the nodes are represented by the sensors and the edge are evaluated with non-linear statistical correlation functions applied to the time series pairs.

The resulting functional graph is then analyzed with the topological metrics of the network, to define characteristic proprieties representing useful indicator for the maintenance and diagnosis.

Peer-review under responsibility of the scientific committee of the 72nd Conference of the Italian Thermal Machines Engineering Association

Keywords: Sensor Network, Graph Modeling, Big Data Analytics, Complex Systems.

* Corresponding author. Tel.:+39 0773476521.
E-mail address: fabrizio.bonacina@uniroma1.it

1876-6102
Peer-review under responsibility of the scientific committee of the 72nd Conference of the Italian Thermal Machines Engineering Association
10.1016/j.egypro.2017.08.160

1. Introduction

A sensor network (SN) comprises a group of tiny devices and wireless infrastructure that monitor and record conditions in any number of environments. With the recent diffusion of Micro-Electro-Mechanical Systems technology, the SNs has received a significant attention in the real world scenario and several example of their applications are available in multiple fields, such as power grids, smart buildings, industrial process, transport and logistics, military applications, environmental monitoring, human-centric applications, etc. [1,2].

Looking at internal combustion engines, different on-board-diagnostic (OBD) control unit, defined engine control module ECM or alternatively powertrain control module (PCM) are typically installed. Customary OBD system are designed and calibrated to detect single component fault at the required malfunction criteria rather than every combination of multiple component degradations. The basic concept of OBD systems is to result in malfunction indicator light (MIL) illumination after a fault has been detected on two or three consecutive driving cycles [3]. But it is still difficult to detect a fault when the standard operation conditions of any components have only partially reduced its efficiency, especially under critical working conditions (i.e. at high speed and low loads) [4]. In some recent works, multivariate statistical analysis approach to process the monitored variables (i.e. instantaneous engine speed) has been evaluated for detecting the multiple misfire event in multi-cylinder diesel engine [5]. To be able to identify the cause of the fault, multivariate analysis and the principal component analysis (PCA) was used to investigate the relationship between process parameters, energy variables and emissions [6]. Data Analytics for SNs to perform intelligent analysis on sensor-collected data is considered as a complex area where several issues are still unresolved. In fact, these data seem to have the characteristics of the "4 V" (Volume, Velocity, Variety and Value) typical of the big data, due to their massive amount, the speed required for their collection, processing and use, the heterogeneity (variety of communication standards and data formats), their high redundancy and noise [7].

As reported in Zhou et al. [8], traditional data analysis in statistics, data mining, machine learning, data management and data visualization may result inappropriate in dealing with the sensor network big data.

In this paper we propose to apply an analytical procedure to analyze sensor network data gathered from an internal combustion engine (ICE), based on the Complex Network analysis techniques. Similar methods have been successfully applied in biology and biomedicine [9], but in current literature there are no application cases for ICE monitoring systems. For example, in neuroscience, complex networks are used to describe the structure of relationships between the various regions of the brain and create diagnostic models based on recorded measures from functional magnetic resonance imaging (fMRI), electroencephalography (EEG) or magnetoencephalography (MEG) [10].

The main purpose of this paper is to test the effectiveness of these analytical methods to identify different operating conditions of an ICE. For these reason, we performed three different laboratory tests in order to reproduce a standard situation (thus reproducing urban condition) and two possible failures: i) disabling the exhaust gas recirculation (EGR) valve and ii) reducing by 50% the section of the intake air duct.

An accurate description of the proposed method for sensor network data analysis is given in Chapter 2, while in Chapter 3 the case study is defined. Chapter 4 shows the results obtained by applying the method on the case study and finally, in Chapter 5, the conclusions are presented.

2. Data analysis model

The proposed data analysis approach is based on the graph modeling of the sensor network and the subsequent study of the characteristic topological metrics, with the aim of extracting useful information on the analyzed system. Specifically, the method can be summarized in the following steps:

a) Extractions of the time series
b) Data cleaning and recovering
c) Data modeling with an unweighted graph
d) Definition of the functional graph
e) Analysis of the topological metrics of the graph

At the initial stages (a,b), the heterogeneous data acquired by the sensors are temporally re-aligned and any outlier or background noises are removed. In step (c) a fully-connected graph is created in which each monitored