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A neural network approach for indirectly estimating farm tractors engine performances

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HIGHLIGHTS

- ANNs are used to predict instant torque and BSFC of farm tractor diesel engines.
- ANNs were trained with exhaust gas (EG) temperature and motor oil temperature data.
- Different ANNs (with 1/2 hidden layers, Sigmoidal/Gaussian algorithms) were compared.
- Lubricant temperature resulted to be unsuitable (very low and diversified R^2).
- ANNs using EG temp. give reliable predictions ($R^2 > 0.993$ for torque estimations).

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ABSTRACT

The instant torque and brake specific fuel consumption (BSFC) of a farm-tractor engine are very interesting parameters from a technical and economical point of view and allow advancing many considerations in the Engineering and Farm-mechanization fields related to the optimization of the engine power and consumptions. A direct access to the CAN-BUS system, where present, can be difficult; as a consequence, some practical solutions (sensors, numerical methodologies) aimed to deduce continuously but indirectly the engine performances are therefore proposed and discussed.

In particular, the focus of this study is to evaluate the possibility of using artificial neural networks (ANNs) trained with exhaust gas (EG) and motor oil temperature data, easy to be measured. Hence, the above-mentioned temperatures and several network architectures (different for neurons and hidden layers number, neuronal transfer functions) were evaluated in their reliability in estimating the torque and BSFC of different tractor diesel motors, giving also the readers some useful indications: determination coefficients were calculated with reference to the line "*predicted values = experimental values*".

Lubricant temperature resulted to be totally unsuitable (very low and diversified R^2).

ANNs using the EG temperature for torque estimations achieved higher average R^2 than ANNs predicting BSFC, both in the training (>0.996 vs. >0.889) and in the prediction phase (>0.993 vs. >0.621). Consequently, EG temperature is strongly recommended for estimating both parameters even if preliminary evaluations should be performed for BSFC (engine characteristics have a significant influence on the predictions).

Finally, best R^2 can be scored by using the Gaussian neuronal transfer function.

1. Introduction

1.1. Technical background

One of the main paths leading to the development of a sustainable agriculture is to waste as little (fossil) energy as possible. Therefore, farm machines should be as much efficient as possible both in their power trains [1,2] and in their power units. Besides having high efficiencies, it is equally important to keep constant over the time the thermodynamic performances of engines but this implies the availability of a monitoring system capable of acquiring data and elaborating useful information concerning the engines of the machines under control. A possibility is surely the interfacing of such a system directly with the electronic engine management system or the CAN-BUS system of the machine and the direct acquisition of engine-related data [3–6]. Unfortunately, the

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CAN-BUS system, i.e. a serial high-speed wired data network connection among vehicle on-board electronic devices [7] developed on the basis of ISO 11898:2003 standard [8], could have its signals coded with proprietary algorithms and, often, it is not present on all the agricultural machines currently in use. In particular, the latter outlined problem is typical of all the countries with a high mechanization of agriculture over the last decades. In Italy, for example, there are a lot of tractors, almost 2 million units at the last official survey of 2012 [9], and the turnover rate (new tractors divided by total tractors) is very low and decreasing from 1960 until today (Fig. 1). In fact, the turnover of tractors has been around 2% from 1995 to today and in 2012 was even below 1% (precisely: 0.98%). This caused the tractor pool has actually an average age of 25 years, therefore half of the tractors was surely built before the first issue of ISO 11898 standard (1993) and some of them were built even before the first ever introduction of the CAN serial bus system by Robert Bosch GmbH at the Society of Automotive Engineers (SAE) congress of 1986 [10]. If the turnover rate remains at 2% also for the next years, a complete replacement of all the tractors with new machines, surely equipped with CAN BUS, will occur in 50 years: in a situation like this, the actual average age is destined to increase and a high penetration of machines equipped with CAN BUS is yet to come. Therefore, some practical and quick retrofit solutions (based on sensors and numerical methodologies) aimed to deduce continuously the performances of an engine (in particular, its *torque* and *brake specific fuel consumption – BSFC*) even if the tractor is not equipped with CAN BUS, are proposed and discussed in this study.

The measurement of the *torque* provided by a motor is always a parameter of extreme interest, in fact:

- the manufacturer of the engine (or of the whole vehicle) has the possibility to study real and not estimated data concerning the engine operating conditions, thus being able to infer the maximum and mean effective workloads that an engine deals with during his lifetime and in different conditions of use; the so-collected data can also be used to optimize the propulsion unit architecture and settings, and maybe to propose some major improvements, thanks to this increased level of knowledge;
- the user of the engine (or the driver of the vehicle) can formulate some economic considerations related to the engine effective exploitation and the opportunity to perform preventive maintenance, maybe at intervals more or less frequent than those provided for a standard use [11].

Another very interesting parameter is the instantaneous *BSFC* of an engine. By knowing it, in fact, it is possible to build the "engine performances maps" (or "BSFC contour maps"), i.e. the most important graphical instrument to describe the performances of tractor engines, in which the lines of equal BSFC (in g $(\mathrm{kW\,h})^{-1}$) are plotted as a function of (absolute or relative) engine speed and torque/engine load [12]. The engine performance maps, if known (they are not part of the OECD standard tests), can be used:

(a) as a support to set up some simulations aimed at predicting the engine performances and reducing fuel consumptions [13,14]; specifically, the BSFC can be calculated by using mathematical models based on historical data collected during tractor tests [15,16];
(b) as a tool to optimize the tractor-implement coupling from a dynamic point of view, i.e. considering different operating conditions (e.g., tractor and implement specifications, tires, soil conditions, speed of operation) [5,17];
(c) as a basis for realizing a tractor-implement monitoring system provided with a decision support system [18–21], eventually able to carry out a diagnosis about the engine operation and identify potential critical states of the engine [22]; this is a very interesting possibility in order to avoid breakages or damages, considering that engine is a part frequently subjected to breakage (25.0% and 12.5% of total breakages in tractors and combine harvesters respectively) [23,24].

Several experiences reported in the literature [25–28] show that the exhaust gas (EG) temperature in the exhaust manifold (T_{em}) is related to the engine speed n and to the torque M, thus allowing for an indirect calculation of it (and, hence, of the instant power):

$$T_{em} = f_1(M; n) \Longleftrightarrow M = f_2(T_{em}; n) \tag{1}$$

The measurement of the EG temperature, although not free from metrological problems [29,30], is however practically viable and economically cheap, requiring only a thermocouple and a data-logging system. Rather, the real challenge is disposing of a relatively simple but effective mathematical tool to describe the correlations between the EG temperature and engine speed with the torque and BSFC of a motor. In some examples found in the literature [25–27], engine data are fitted on mathematical models by using statistical software. Another possible approach is the

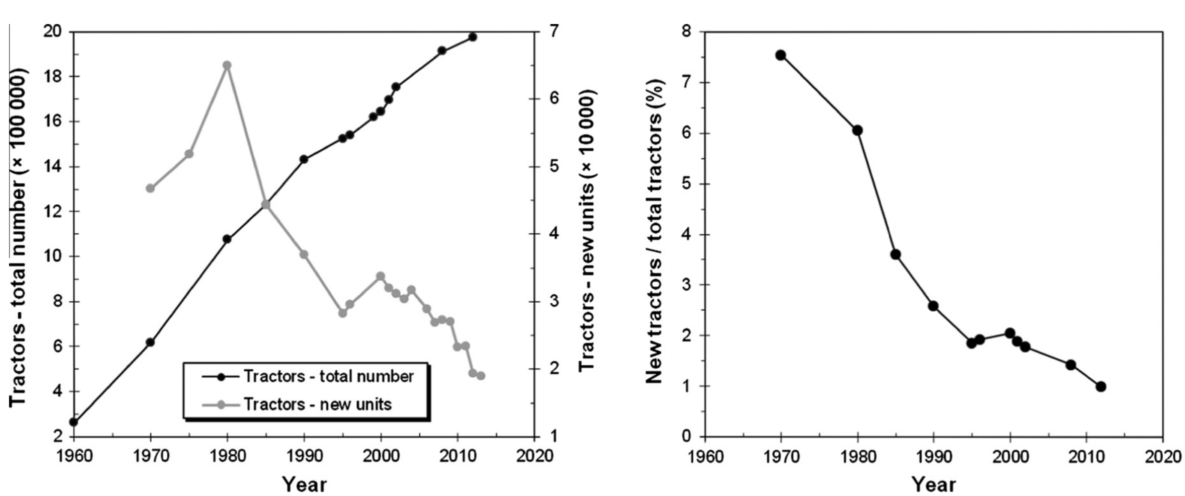

Fig. 1. (Left) situation of tractors in Italy in the last 60 years (total number of tractors, registration of new units); graphical trend of the turnover rate (ratio new tractors/total tractors) in the same period (right).