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Proposal of a simplified monitoring approach of environmental performances of farm tractors through a local telemetry networkFabrizio Mazzetto¹, Marco Bietresato^{1,*}, Aldo Calcante²¹ Free University of Bozen-Bolzano, Faculty of Science and Technology – Fa.S.T.² Università degli Studi di Milano, Dipartimento di Scienze Agrarie e Ambientali – Di.S.A.A.

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ABSTRACT

The TRAKTnet.one project of the Free University of Bolzano aims to identify and develop new solutions to remotely monitor the efficiency of farm-tractors engines included in a local voluntary network all along their lifespan. The knowledge of tractors' efficiency can give important information concerning machines' consumption, emissions and need for servicing, thus contributing to a more environmentally-sustainable agriculture. Engines will be monitored by measuring rpms, exhaust gases' temperature and oxygen content (as indexes indirectly estimating consumption and efficiency) and then analysing and inferring the data through procedures, which algorithms will be an integral part of the project's results. This implies the existence of a service centre controlling all farm machines and managing a Farm-Information-Systems network through simple logical connections according to a client-server approach.

The final outcome of the project is expected to be an automatic system, based on an inference software-engine able to correctly interpreting the sensors outputs. The advantage of this proposal is to exploit a farm monitoring network, previously designed for managing the information related to the automatic compilation of records in the country, by simply equipping data loggers with two additional sensors.

Keywords: Farm tractors; engine performances; system modelling; operational monitoring; engine exhaust gas temperature

1. INTRODUCTION

The necessary condition for developing a sustainable agriculture is to raise the overall efficiency of farm machines by: (1) increasing their annual exploitation, (2) keeping constant their performance over the time. This intensive control on machines must necessarily imply: (a) the implementation of a Farm-Information-System (FIS) based on a client-server approach, to acquire and manage information needed for taking decisions at both farm and territorial scale, through a Farm-Operational-Monitoring, using telemetry and data-loggers on tractors and implements (Sahu and Raheman, 2008; Yule et al.,

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1999; Mazzetto et al., 2009), (b) the proposal of solutions that are economical, simple, robust, reliable and effective in acquiring selected parameters (Singh and Singh, 2011). The TRAKTnet.one project of the Free University of Bolzano (Italy) aims to identify and develop new solutions to remotely control the efficiency of farm-tractors engines included in a local voluntary network all along their lifespan. The knowledge of tractors' efficiency can give important information concerning machines' consumption, emissions and need for servicing, thus contributing to a more environmentally-sustainable agriculture. The proposed solutions will be based on remote measurements of exhaust gases' temperature (Pang et al., 1985; Friso, 1988; De Souza and Milanez, 1987) and oxygen; these parameters will be analysed and inferred through procedures, which algorithms will be an integral part of the project's results. The project includes four steps: (1) preliminary assessment of sensors features (e.g., number, type, position); (2) numeric modelling of a compression-ignition engine to understand the effects of ageing and bad maintenance on its performances; (3) evaluation of possible modifications of commercial sensors (e.g., K- or J-type thermocouples, zirconium-oxide lambda sensor); (4) execution of bench and field tests to validate the system.

Trials will be performed on different engines (e.g., naturally-aspired/turbocharged, with/without EGR/SCR or analogous devices) and at different speeds/loads (full load, partial loads, idle). The choice of the thermocouple type (band/rod) and installation point (manifold/pipe) must be done carefully for not influencing sensor's sensitivity and response time. The combustion quality can be related to the oxygen concentration in exhaust gases (EG), measured through lambda sensors.

Several experiences reported in literature (Friso, 1988; Goering et al., 1986) show that the EG temperature is proportional to the engine torque, thus allowing for an indirect calculation of engine load and related instant power (this is possible only knowing a priori the maximum rated power each engine can provide). The combustion quality, on the other hand, can be related to the oxygen concentration in the EGs, thus enabling a rough estimate of the engine efficiency. Engines will be monitored by measuring rpms, EGs' temperature and oxygen content (as indexes indirectly estimating consumption and efficiency) and then analysing and inferring the data through procedures, which algorithms will be an integral part of the project's results (Alvarez and Huet, 2008). This implies the existence of a service centre controlling all farm machines and managing a FIS network through simple logical connections according to a client-server approach.

1.1 Aims of the research

The final outcome of the project is expected to be an automatic system, based on an inference software-engine able to correctly interpreting the sensors' outputs. It could be used by tractors' owners for being advised about the need for servicing their vehicles but also by local authorities for monitoring tractors' environmental impact in a territory and, maybe, for tailoring the subsidies to the farmers (e.g., on a rewarding-score in accordance to the detected performances).

The advantage of this proposal is to exploit a farm monitoring network, previously de-

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signed for managing the information related to the automatic compilation of records in the country, by simply equipping data loggers with additional sensors.

2. MATERIALS AND METHODS

2.1 Definition of the system components

The system presented here will be fully interfaced with a FIS (Mazzetto et al., 2009) and can be seen as completion of it: some important data collected by the farm monitoring network (e.g., concerning field operations), will be related to the acquisitions of some additional sensors on engines, thus extending the FIS monitoring also to all the involved power units.

The system and its components at every level have been defined by using a *top-down approach*, hence, after formulating the general task(s) of the system, the first-level subsystems, i.e. its main elements, have been specified but not detailed. The detailed refinement of each subsystem is the final task and will be afforded afterwards. The general architecture of the system has hence been defined starting from the following needs/technical requirements: (i) collecting a series of data on vehicles operating in an environment presenting several potential problems for eventual devices (e.g., humidity, dust, heat sources); (ii) interpreting the collected data to give them an informative content, having therefore information concerning the functioning of agricultural farm engines; (iii) putting this information at the disposal of the farmers and/or local authorities.

The monitoring system is composed of three basic elements (Figure 1 *left*):

- *hardware devices*, for collecting and/or storing the data (sensors, data logger - DL with communication capabilities, servers with storage units);
- a set of *automatic computing procedures*, based on several physical models of the engines (one model per each engine) to obtain time-related information about the engine performances from the raw data achieved; the output formats can be both tabular and graphical;
- *interfaces*, to enable the users the access and use of the information.

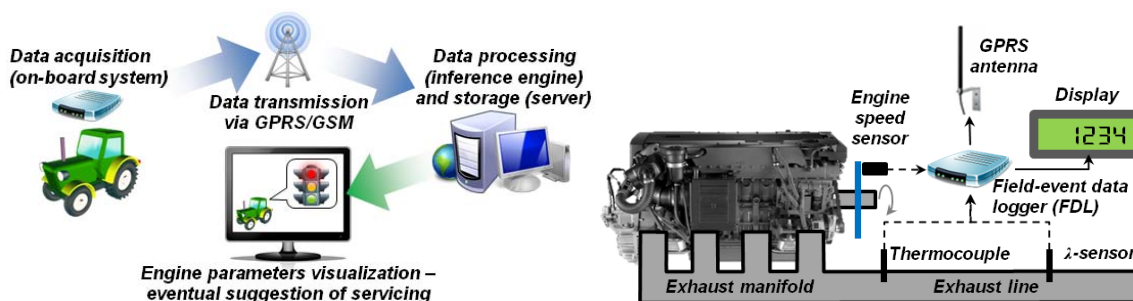


Figure 1 – (*left*) general functioning of the monitoring system for the tractors; (*right*) on-board components involved in the engine monitoring (dashed/continuous arrows indicate raw/interpreted data flows; power-supply connections are not represented).

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In particular, the field-event data-logger (FDL), already present on board all the vehicles connected in a FIS network, will be completed of the following components connected to its input and output ports (Figure 1 *right*):

- two/three input units, i.e. an engine speed sensor, an EG temperature sensor (thermocouple) and, eventually, also a zirconium-oxide lambda sensor;
- one/two output unit(s), i.e. a GPRS antenna and, eventually, a liquid crystals display positioned on the tractor's dashboard.

The FDL, powered by the 12-V-DC electrical system of the tractor, is the kernel of the on-board system and has several functions:

- it is necessary for the power supply of all the connected I/O units, which are typically passive, i.e. not powered independently, and hence they need to receive the power supply from the data acquisition system;
- it collects and stores temporarily the data collected by the sensors, providing to send the raw data (or the interpreted data; see below) to a remote server via GPRS;
- if provided with the correct calibration curves, it is capable to interpret directly the analogue or digital signals of the input sensors as physical quantities (engine speed, EG temperature, EG oxygen concentration) before sending them to a server via GPRS; e.g., the thermocouple and the lambda-sensor are analogue devices and give continuous voltage variations as output, the engine-speed sensor (e.g. a phonic wheel) has a digital output consisting in a wave having the instantaneous frequency of its peaks proportional to the rotational speed.

2.2 Conceptual functioning of the remote-monitoring system

The system operates conceptually in *three different phases*:

1. usage of the OECD test results for tuning a physical model of the engine; usage of the tuned physical model for correlating the EG temperature and the specific consumption/efficiency with the torque and the speed, thus developing some mathematical models with different degrees of detail/complexity;
2. usage of the temperature data, recorded during the normal operating of a tractor, together with the time history of field operations recorded through the FDL for correlating together torque, speed and efficiency of a model of tractor with some hours of operation (Yule et al., 1999; Kolator and Białobrzewski, 2011); integration of this model into the main FDL inference engine to have an estimate of the engine torque or efficiency;
3. comparison of the efficiency values predicted by the two models to quantify the performance decrement of the engine (Alvarez and Huet, 2008) and suggestion to the driver of eventual interventions of extraordinary maintenance to the vehicle.

2.3 Preliminary bench tests

Some preliminary bench tests were carried out at the CRA-ING (formerly ISMA) OECD laboratory centre (Treviglio, BG, Italy). The tests concerned three farm tractors of the same manufacturer but chosen so that to cover a wide range of powers and engines types with a minimum number of trials (Table 1). The experimental procedure

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consisted of several bench tests (163 trials in total, 48-60 per tractor) aimed to record engines' performances (instant torque, power and brake specific fuel consumption-BSFC) and the relative EG temperatures in their engines' full operating ranges (Jahns et al., 1990); each test started only after the engine warmed up and included:

- a classic OECD bench test with the fuel pump rack fully-opened, i.e. a test starting from the maximum engine speed and with a rising brake-force, to obtain the full-load curve and the part-loads curve at the rated engine speed;
- other four tests per engine with the fuel-pump rack at intermediate positions between the maximum and the minimum, i.e. four tests starting from engine speeds lower than the maximum one (each spaced approximately of 200 rpm) and with a rising brake-force, to obtain other "partial-loads" curves.

Table 1 – Tractors' engine main specifications (from OECD technical bulletins).

Engine technical characteristic	Unit	Farm tractor		
		Same Explorer 70 DT	Same Explorer 80 DT	Same Laser 130 DT
Manufacturer/type	-	Same, 1000.4 A	Same, 1000.4 A1	Same, 1056 P
Cylinders/configuration	nr.	4, straight	4, straight	6, straight
Piston bore/stroke	mm, mm	105.0, 115.5	105.0, 115.5	105.0, 120.0
Compression ratio	-	17.1	17.1	n.a.
Total displacement	cm ³	4 000	4 000	6 234
Max power value/engine speed	kW, rpm	47.07@2350	54.20@2509	92.00@2260
Engine speed range	rpm	675-2509	700-2712	n.a.

* at max power engine speed and full load; n.a.: not available data

The BSFC was measured by using a chrono-gravimetric method. During the tests, three thermocouples were used to measure at the same time the EG temperature in three different points of the exhaust pipeline:

- one mineral-insulated *K-type* thermocouple, with its tip inserted inside the exhaust manifold (in direct contact with the gas) and fixed to the manifold through a bayonet coupling (→temperature measured with this thermocouple: TcK);
- two *J-type* thermocouples, respectively fixed in contact with the second cylinder's gas exhaust pipe (→ temperature: TcJ-cyl) and outside of the exhaust manifold through hose clamps (→temperature: TcJ).

In order to have a stable value of the temperature for each operating condition, the EGs' temperature was sampled only after 5 minutes the engine was subjected to a set brake force. This time interval was tuned after the first preliminary surveys: the thermocouples not in direct contact with the gas needed in fact some minutes to reach asymptotically a stable temperature, due to the interposition of the walls of the manifold or of the pipe. The test results were used to test a quick but very effective numeric approach, the *Response Surface Modelling-RSM* (Maheshwari et al., 2011), to be used in the previously outlined first phase of the conceptual functioning of the system (Figure 2), in particular in two different sub-phases:

- to approximate the equations of torque, power, BSFC and efficiency as a function of the engine speed starting from standard OECD test results (full-load curve, part-

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- loads curves at rated engine speed and at PTO speed);
- to build 2-variable models of the EG temperature and engine efficiency as a function of torque and engine speed from the output data coming from a tuned physical model of the engine.

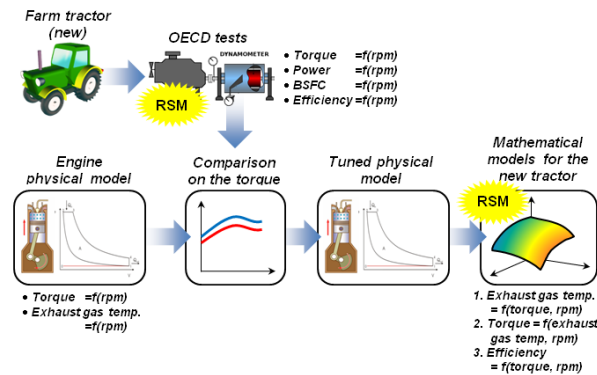


Figure 2 – First phase of the conceptual functioning of the system, concerning the modelling of a new engine; in evidence the sub-phases in which RSM can be used.

Previous works (Friso, 1988; Goering et al., 1986) showed that the relationship existing between torque- M , engine speed- n and EG temperature- T can be numerically approximated by third-degree full-cubic polynomial models. If y_k and $x_{i,k}$ are, respectively, the k -th predicted value of a generic response and the corresponding value of the x_i ($i=1, 2$) generic factor, i.e. independent variable, non-coded, a_0 is the interception coefficient, a_i , a_{ii} , a_{iii} , a_{ij} and a_{ijh} ($i \neq j \neq h$) are the coefficients of the linear, quadratic, cubic, 2nd-order and 3rd-order interaction terms, the generic regression model used in RSM is:

$$y_k(x_i; i=1, 2) = a_0 + \sum_{i=1}^2 a_i x_{i,k} + \sum_{1 \leq i < j \leq 2} a_{ij} x_{i,k} x_{j,k} + \sum_{1 \leq i < j < h \leq 2} a_{ijh} x_{i,k} x_{j,k} x_{h,k} \quad (1)$$

Design-Expert 7.0.0 (Stat-Ease, Minneapolis, MN, USA) was used to analyse the collected data and propose for each response a regression model with only the significant terms (*ANOVA/RSM*). For each response, the terms have been chosen according to RSM-software suggestions.

3. RESULTS

The bench tests and the subsequent RSM confirmed the experiences reported in literature, showing that, for a set engine speed, the EG temperature is positively correlated with the torque ($R^2 \geq 0.9344$; Figure 3; Table 2). The K-thermocouple gave the most statistically-significant measurements (best R^2) and had the higher instrumental sensitivity (or “gain”, here: $\partial T / \partial M$) in the engine torque range ($\Delta T_{TcK} \geq 450^\circ\text{C}$, i.e. more than 3 times ΔT_{TcJ} and up to 34 times $\Delta T_{TcJ-cyl}$ during the same tests), surely due to the absence of an interposed (pipe’s) material, having an its own inertia and thermal conductivity.

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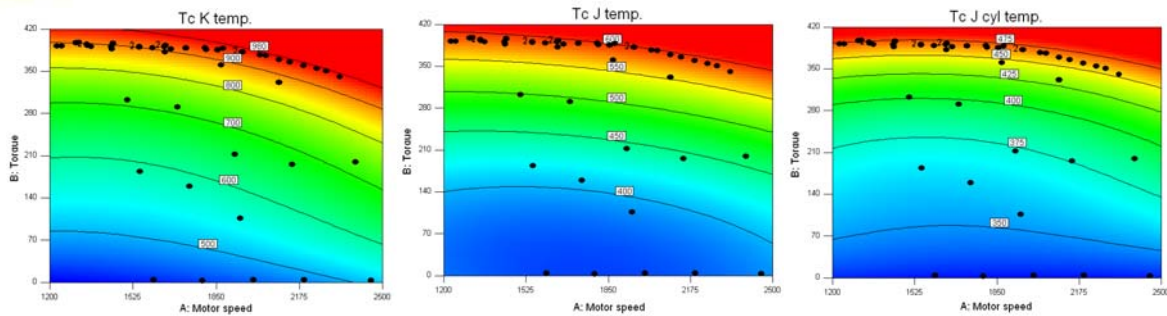


Figure 3 – Contour plots of the temperatures regression models for Same 130.

Table 2 – Main results of bench tests and RSM analyses (M: torque; P: power; S: speed)

Tr.	Operating point	Experimental measurements						R^2 of $T=f(M,n)$ fitting		
		M (Nm)	P (kW)	S (rpm)	TcK (K)	TcJ (K)	TcJ-cyl (K)	TcK	TcJ	TcJ-cyl
SAME 70	Idle	-	-	221	377	336	318	0.9986	0.9968	0.9691
	Max P	423	45	1024	832	449	320			
	Max M	548	34	588	832	492	336			
SAME 80	Idle	-	-	381	413	357	342	0.9960	0.9889	0.9344
	Max P	465	47	956	880	449	346			
	Max M	582	37	613	855	472	356			
SAME 130	Idle	-	-	325	393	407	342	0.9966	0.9738	0.9799
	Max P	804	84	995	981	594	462			
	Max M	913	55	572	923	612	490			

4. CONCLUSIONS

Thanks to the some preliminary bench tests, the correlation of the EG temperature with the torque and engine speed was fully confirmed and hence will be used in the project. Thinking about the monitoring system, the same tests were useful to realize that a thermocouple placed outside the exhaust manifold/pipe, although very easy to install, could be a feasible solution only if stating that the acquisitions can be taken after the engine keeps its speed constant for a certain period. As this situation could rarely happen during the normal operation of a tractor, and considering also the higher sensitivity shown by the thermocouple with the tip inside the exhaust line, this latter solution revealed to be the best one to be applied in the tractors.

The final outcome of the project is expected to be an automatic system for advising tractors' owners about the need for servicing their vehicles, based on an inference software-engine able to correctly interpreting the sensors outputs. At the same time, local authorities could dispose of a tool for controlling the tractors' efficiency in their territory and, maybe, tailoring the subsidies to the farmers (e.g., on a rewarding-score in accordance to the detected performances). The advantage of this proposal is to exploit a farm monitoring network, previously designed for managing the information related to the automatic compilation of records in the country, by simply equipping data loggers with two/three additional sensors.

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