Computers and Electronics in Agriculture 114 (2015) 96–113

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Reducing fuel consumption in weed and pest control using robotic tractors

Mariano Gonzalez-de-Soto[a,b,1,2,*], Luis Emmi[a,1], Isaias Garcia[b,2], Pablo Gonzalez-de-Santos[a,1]

[a] Centre for Automation and Robotics (UPM-CSIC), Ctra CAMPO REAL km 0,2, 28500 Arganda del Rey, Madrid, Spain
[b] Escuela de Ingenierías Industrial e Informática, Universidad de León, Dept. de Ingeniería Eléctrica y de Sistemas y Automática, Campus de Vegazana s/n, 24071 León, Spain

ARTICLE INFO

Article history:
Received 17 September 2014
Received in revised form 31 March 2015
Accepted 3 April 2015

Keywords:
Reducing fuel consumption
Path planning
Energy efficiency
Atmospheric emissions
Digital elevation model (DEM)

ABSTRACT

A significant problem exists concerning contamination of the environment, especially air pollution, and the consequent climatic change. Considering that agricultural vehicles that use fossil fuels emit significant amounts of atmospheric pollutants, the main objective of this paper is to include techniques to reduce the fuel consumption in the controls system of robotic tractors used in agriculture tasks and thereby reduce the atmospheric emissions from these automated applications. To achieve this goal, the first step is to analyze fuel consumption in real time for each of the applications to be improved and to implement the consumption model of a robotic tractor for each task, considering the mechanical energy variations, the performance losses, the energy used to overcome friction and the energy required by the given task. For calculating the mechanical energy, the model considers the potential energy of the system, which is a function of the mass, elevation and gravity. The terrain elevations are estimated from GeoTIFF images of DEM data, which have a pixel size equal to 1 arc second (approximately 30 m at the Equator), and an accuracy of integer meters. Regarding the system mass, the possible loss of mass from applying the treatment is considered. For estimating the frictional forces, the rolling resistance coefficient of the terrain surface conditions is used.

The consumption model has been validated experimentally using real agricultural vehicles and implements within the RHEA project (FP7-NMP 245986), in which the instantaneous fuel consumption was measured.

This fuel reduction method is applied to three different treatments: weed control on herbaceous crops through the spraying of herbicides, weed control on fire-resistant crops with wide furrows through plowing and flame treatment, and pest control on trees through fumigation using insecticides.

Finally, a fuel reduction procedure is applied to each task using the system model implemented to predict the energy requirements. This enables one to find the optimum path plan with respect to fuel consumption. These theoretical results are compared with the experimental results. In addition, the goal is to demonstrate the fuel reduction technique by performing field experiments to show that the use of this method of fuel reduction leads to an reduced fuel consumption and thus reduces atmospheric emissions from agricultural tasks. The results obtained revealed that this fuel reduction method significantly reduces the energy requirements, with the consequent reduction in fuel consumption and atmospheric pollutant emissions.

1. Introduction

It is widely accepted that contamination of the environment, especially air pollution, is an important concern with drastic climatic consequences. Agricultural combustion engine vehicles using fossil fuels emit significant amounts of atmospheric pollutants, primarily carbon dioxide (CO_2) and nitrogen oxide (NO_X), contributing to the increase in the greenhouse effect. Using the concept that the least-polluting energy is the energy that is not used, the objective of this paper is to develop and implement techniques in the control system of robotic tractors to reduce fuel consumption in agricultural tasks; in addition, we can obtain some economic benefits. Fuel consumption is directly related to the energy requirements of agricultural tasks and may be reduced by developing a control system capable of minimizing all energy

* Corresponding author at: Centre for Automation and Robotics (UPM-CSIC), Ctra CAMPO REAL km 0,2, 28500 Arganda del Rey, Madrid, Spain. Tel.: +34 650015576.

E-mail addresses: marianogds@outlook.com (M. Gonzalez-de-Soto), luisemmi@gmail.com (L. Emmi), isaias.garcia@unileon.es (I. Garcia), pablo.gonzalez@car.upm-csic.es (P. Gonzalez-de-Santos).

[1] Tel./fax: +34 650015576, +34 689876367, +34 918711900x221.

[2] Tel./fax: +34 650015576, +34 987291000x5289.

http://dx.doi.org/10.1016/j.compag.2015.04.003
0168-1699/

List of symbols and acronyms

Symbols

A	machine specific parameter function of the soil strength
a	no-load power requirement (kw)
B	machine specific parameter, coefficient of the speed
b	unloaded tire section width (m)
b	PTO power requirement per nozzle (kw/nozzle)
B_n	dimensionless ratio of the *MR*
C	machine specific parameter related to the soil bulk density
c	power per unit of material feed rate (kw h/t)
C_f	fluid flow (L/s).
C_I	cone index for the soil
D	implement draft force (kN)
d	unloaded overall tire diameter (m)
E	electric potential (V)
E_m	mechanical efficiency of the power transmission from the net flywheel to the PTO power
E_t	traction efficiency
F_i	dimensionless soil texture adjustment parameter
g	gravitational acceleration (9.8 m/s^2),
h	tire section height (m)
I	electric current (A)
m	mass (t)
MFR	material feed rate (t/h)
MR	motion resistance
NT	net traction
p	fluid pressure (kPa)
P_{el}	electric energy (kw)
P_{hyd}	hydraulic power (kw)
P_{PTO}	power requirement from the PTO shaft (kw)
P_{PTOeq}	equivalent PTO power (kw)
P_{PTOrated}	rated PTO power (kw)
P_{T_PTOeq}	total equivalent PTO demanded power (kw)
PTM	partial throttle multiplier
T	tillage depth (cm)
TFC	total fuel consumption
v	speed (m/s)
W	number of rows or tools
X	fraction of equivalent PTO power
α	terrain slope (radians)
δ	tire deflection (m),
ρ	*MR* ratio

Acronyms

ASTER	advanced spaceborne thermal emission
DEM	digital elevation model
EGM96	earth gravitational model 1996
GDEM	global digital elevation model
GeoTIFF	georeferenced tagged image file format
GMU	ground mobile unit
NASA	National Aeronautics and Space Administration
PTO	power take-off
RHEA	robotic for highly effective agriculture
RTK	real time kinematic
SFC_v	specific fuel consumption volume
TPH	three-point hitch
UTM	universal transverse mercator
WGS84	world geodetic system of 1984

requirements. In particular, the control system is tasked with choosing the best path to reduce the amount of mechanical and plowing energy used and to reduce friction losses. Additionally, to minimize the amount of energy used, it is also necessary to reduce and improve the usage of the following:

1. the PTO by deactivating it when not used,
2. the hydraulic actuators and
3. the electric actuators.

Finally, the engine operating conditions have to be adapted to achieve the maximum performance.

Currently, energy efficiency is a common concern in all fields; however, in researching this topic for agriculture machinery, we find that the scientific community has dedicated substantial amounts of effort to the topic of energy efficiency in many fields related to agriculture for many years. Grečenko (1968) optimized the plowing energy and analyzed the effect of tractor designs and its combination with implements on field performance and some other operational features. He also developed a method for predicting the performance of tractors in combination with implements. Recently, Mileusnić et al. (2010) presented an analysis and comparison of tillage systems based on fuel consumption. By leveraging the new technical solutions in tillage mechanization systems and the new technological variants in the tillage process, the systems consume significantly less energy compared to the older systems.

Other research efforts focused their activities on the improvement of engine performance. For example, Grogan et al. (1987) based mainly on the results of Larsen (1981) concerning the utilization efficiency of four-wheel-drive tractors, determined that practicing shift-up and throttle-back methods improves engine efficiency and developed a microcomputer algorithm that calculated the optimal gear and engine speeds with respect to fuel consumption and the wheel torque for carrying out a task. Harris (1992) developed a mathematical model to predict the relation between the torque generated by a diesel engine and the fuel that it consumes at any speed. Furthermore, he calculated the optimum operating point of engines. More recently Grisso et al. (2001) discussed how to select a faster gear to maintain travel speed and productivity while reducing the engine revolutions per minute (rpm), which avoids the increase of the engine friction and gases expelled, to reduce fuel consumption.

Recently, optimization has focused more on using path planning to reduce the rolling resistance forces. Bochtis and Vougioukas (2008) and Bochtis and Sørensen (2009) developed an algorithm for path planning that improves the field efficiency of machines by minimizing the total non-working distance traveled, which is the distance traveled when changing tracks (path followed by the vehicle through the treated crop). Oksanen and Visala (2009) presented and analyzed advantages and disadvantages of two algorithms. The first uses a trapezoidal decomposition algorithm based on a top-down approach to split complex-shaped fields into simple ones, and a search for the best driving direction and the selection of subfields was developed. The second algorithm uses a bottom-up approach to cover the field, searching for the best path plan for the whole field using prediction and brute-force methods. Jin and Tang (2010) also presented an algorithm capable of finding the optimal solution for decomposing a field into sub-regions and determining the coverage direction within each sub-region. Other examples of non-working-distance minimization is the algorithm by Hameed et al. (2011), who developed a