A System for the Real-Time Geo-Referenced Measurement of Soil Parameters

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Abstract

The aim of this research is to develop a system for accurately measuring in real-time, collecting and processing a high amount of geo-referenced data of soil physical-mechanical parameters, e.g. cone penetrometer resistance, index of soil compaction, and draft force.

The system for measuring the soil cone penetrometer resistance is comprised of a load cell, connected to a rod, ending with a cone, and is mounted on a frame, fixed to the front part of a tractor. The system for measuring the draft force required to till the soil is comprised of a load cell, mounted on the hitch hook of a tool carrier, towed by the tractor. Moreover, in order to test the usefulness of the system with different types of linkage tractor-implement, two other load cells were mounted, respectively, on the top link and the right point of the three-point hitch of the tool carrier. The signals of the load cells and of a DGPS mobile receiver are acquired by a portable computer, by means of a Virtual Instrument developed in LabVIEW environment.

The results of the first tests, carried out in a field in inland Sicily, showed that: the system is able to log data with a sampling frequency adjustable from 1 to 10 Hz; it is able to accurately measure and collect in real-time a large amount of data, which can be easily processed by means of a data sheet, a GIS or another software usable for measuring the within-field spatial variability of soil physical-mechanical parameters; the absolute value of the force measured on the hitch hook of the tool carrier is proportionally correlated to that measured on any point of the three-point hitch of the same one.

Key words: penetrometer, soil compaction, spatial variability, precision agriculture.

Introduction

The correct management of fields according to the principles of precision agriculture also requires the geo-referenced measurement of soil physical-mechanical parameters, e.g. cone penetrometer resistance, index of soil compaction, and shear strength or draft force (according to the implement used for tillage). Whether the soil physical-mechanical parameters were measured by means of sampling and analysis, the very high time and cost should limit the implementation of precision agriculture. Therefore, these parameters must be measured in real-time, by means of specific sensors.

The geo-referenced measurement and, therefore, mapping of soil parameters (and also of crop parameters) can be carried out by means of:

- manual instruments, for most soil parameters;
- on-the-go sensors, only for the soil parameters listed by Adamchuk et al (2004) and based on one of five measurement principles, i.e. electrical and electromagnetic, optical and radiometric, mechanical, acoustic and pneumatic, electrochemical (Table 1).

Table 1. **On-the-go sensors available for measuring soil parameters**

Soil parameters	Electrical and electromagnetic	Optical and radiometric	Mechanical	Acoustic and pneumatic	Electrochemical
Compaction or bulk density			X(c)	X	
Mechanical resistance			X(c)		
Shear strength			X		
Draft force			X(c)		
Depth of topsoil or hard pan detection	X		X	X	
Texture	X(c)	X(c)		X	
pH		X			X(d, c)
Salinity or Na content	X(c)				X
Volumetric moisture content	X(c)	X(c)			
Organic matter or C content	X	X(c)			
Residual nitrate or N content	X(c)	X			X(d)

d = direct measurement sensors (all the others are indirect measurement sensors);
c = commercial sensors (all the others are experimental sensors).

The development of such real-time sensors should increase the efficiency of precision agriculture (Pierce & Novak, 1999), through a higher density and lower cost of measured data (Sonka et al, 1997).

In the future an adequate mapping of the compacted areas will enable spatially variable depth soil tillage. The tillage depth will be optimized according to the compaction depth: variable depth soil tillage could be applied by working just beneath the compacted layer and only where it is needed. The spatially variable setting up of working depth, aimed at avoiding or removing soil pans, should increase farmer's profit. Yet, until now a little amount of research results aimed at assessing the benefits of spatially variable soil tillage is available (Comparetti et al, 2009).

In the above perspective the aim of this research is to develop a system for accurately measuring in real-time, collecting and processing a high amount of geo-referenced data of soil parameters, e.g. cone penetrometer resistance and draft force.

Research materials and methods

The system for measuring the geo-referenced soil cone penetrometer resistance is comprised of a load cell Tekkal ABA 300 (maximum measurable force of 3 kN), moved by a hydraulic jack and connected to a rod, ending with a cone (diameter of 20.27 mm, base area of 323 mm^2 and vertex angle of 30 degrees, according to the ASAE standard 313.3), and is mounted on a metal frame, fixed to the front part of a wheeled tractor (Fig. 1). Such a system is able to carry out measurements at a constant operating speed. Other two hydraulic jacks are used for setting up the tilt of the above frame, in order to keep the penetration rod normal to the field plane. Moreover, a rectilinear position transducer with potentiometric technology Gefran LT 400 and a switch, able to indicate the null depth were mounted on the above frame, in order to measure cone penetrometer resistance values referenced to the depth.

Figure 1. **The system for measuring the geo-referenced soil cone penetrometer resistance: 1) load cell; 2) cone; 3) rectilinear position transducer**

Figure 2. **The system for measuring the geo-referenced draft force required to till the soil, comprising the load cell mounted on the hitch hook of tool carrier (1) and those mounted on the top link (2) and the right point of the three-point hitch (3)**

The system for measuring the geo-referenced draft force required to till the soil is comprised of a load cell DS Europe LT50 (maximum measureable force of 50 kN), mounted on the hitch hook of a tool carrier, towed by a tracked tractor (Fig. 2).

Moreover, in order to test the usefulness of the system with different types of linkage tractor-implement, two other load cells HBM U2A (maximum measurable force of 20 kN) were mounted, respectively, on the top link and the right point of the three-point hitch of the tool carrier.

The signals of the load cells and of a DGPS mobile receiver DSNP Scorpio 6502MK are acquired by a portable computer, by means of a Virtual Instrument, developed in LabVIEW environment. The scheme of the system for data acquisition is described in Fig. 3.

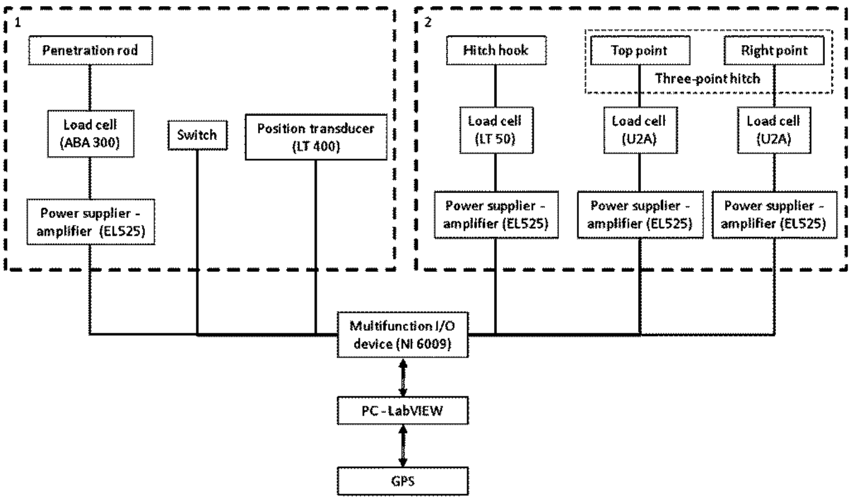

Figure 3. **The scheme of the system for data acquisition: 1) system for acquiring the cone penetrometer resistance; 2) system for acquiring the draft force required to till the soil**

The Virtual Instrument, able to control the multifunction input/output device and serial and/or USB ports and, then, data acquisition, sampling and saving, is constituted by the following three modules:

1) module for decoding the GPS string (NMEA protocol, GGA format) and extracting the data of GPS Time, Latitude, Longitude, Altitude and GPS quality factor;

2) module for acquiring soil cone penetrometer resistance values (expressed in volts), coming from the related load cell and the position transducer, and on/off values, coming from the switch;

3) module for acquiring draft force values (expressed in volts), coming from the related load cells.

Therefore, in every work session the data are logged in only one file, having the following structure: GPS Time, Latitude, Longitude, Altitude, GPS quality factor, value of each signal.

The setting up of the two systems was carried out at both the Laboratory of the Department of Agricultural and Environmental Systems and the Laboratory of Measurements and Tests on Materials of Mechanics Department (DI.MA.) of Palermo University: the force values resulted highly correlated to the signal ones, measured in volts (R^2=1).

Two tests (named test 1 and 2) were carried out in a field in inland Sicily, in the territory of Ventimiglia di Sicilia (Palermo), on a soil having a clay texture according to Miller triangle (clay 58.5%, silt 25.5%, and sand 16.0%), a water content of 13% and a high spatial variability of compaction and draft force.

In order to test the above two systems, the traffic of agricultural machines was simulated: the soil was compacted using a Lamborghini 674-70 N wheeled tractor of 52 kW, having a wheelbase of 2 m, a track of 2.29 m and a total mass of 2,820 kg and mounting the above system for measuring the geo-referenced soil cone penetrometer resistance. The front axle was fitted with 12.2 R24 tyres, inflated at 140 kPa, and the rear axle with 14.9 R30 tyres, inflated at 140 kPa. The soil compaction was obtained after 20 passes of this tractor, at a mean forward speed of about 1.5 m s^{-1}, along a path 30 m long.

Fig. 4 shows the field experimental scheme.

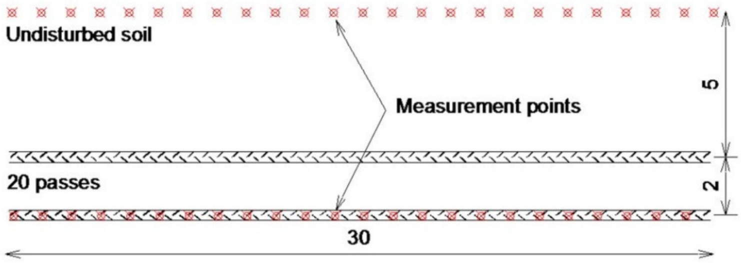

Figure 4. **The field experimental scheme (the distances are expressed in meters)**

During test 1 the soil cone penetrometer resistance was measured every 2 m along each of the two paths 30 m long (on the undisturbed soil and on the soil compacted after 20 tractor passes, respectively) in 16 points, along a soil profile 0–500 mm.

During test 2 the above system for measuring the draft force required to till the soil was used along the two paths, using a subsoiler with only one tine at a working depth of about 400 mm (Fig. 5).

Figure 5. **The subsoiler with only one tine used during the geo-referenced measurement of the draft force required to till the soil**

Results of research

The results of the first tests showed that the system for the real-time geo-referenced measurement of soil parameters is able to log data with a sampling frequency adjustable from 1 to 10 Hz.

Therefore, during the measurement of the soil cone penetrometer resistance, using operating speeds up to 50 mm s^{-1}, this system allowed a spatial resolution of one datum every 5 mm.

Moreover, during the measurement of the draft force required to till the soil, using machine forward speeds up to 5 m s^{-1}, it allowed a spatial resolution of one datum every 0.5 m (considered as the accuracy achievable by an inexpensive DGPS receiver), so that this system can be used during any soil tillage.

Fig. 6 shows the results of soil cone penetrometer resistance (acquired using a sampling frequency of 2 Hz and an operating speed of 10 mm s^{-1}) on the soil compacted after 20 tractor passes.

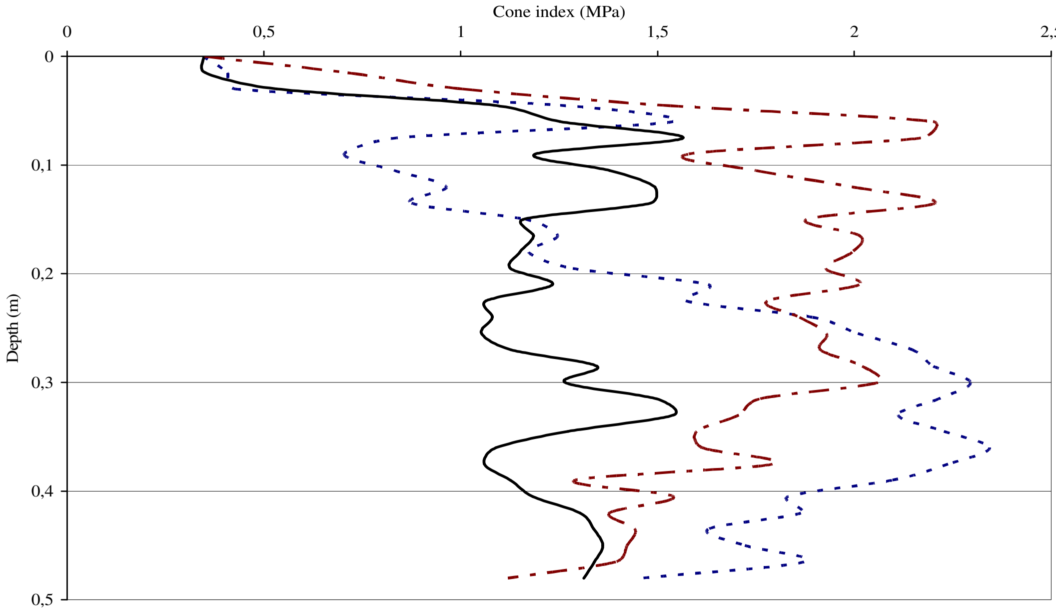

Figure 6. **The results of soil cone penetrometer resistance (cone index) in three measurement point (acquired using a sampling frequency of 2 Hz and a operating speed of 10 mm s^{-1}) on the soil compacted after 20 tractor passes**

Fig. 7 shows the results of the draft force required to till the soil, measured both on the hitch hook of the tool carrier and the top link (whose absolute value resulted almost equal to that measured on the right side point) of the three-point hitch of the same one (acquired using a sampling frequency of 2 Hz and a machine forward speed of 1 m s^{-1}) on the soil compacted after 20 tractor passes.

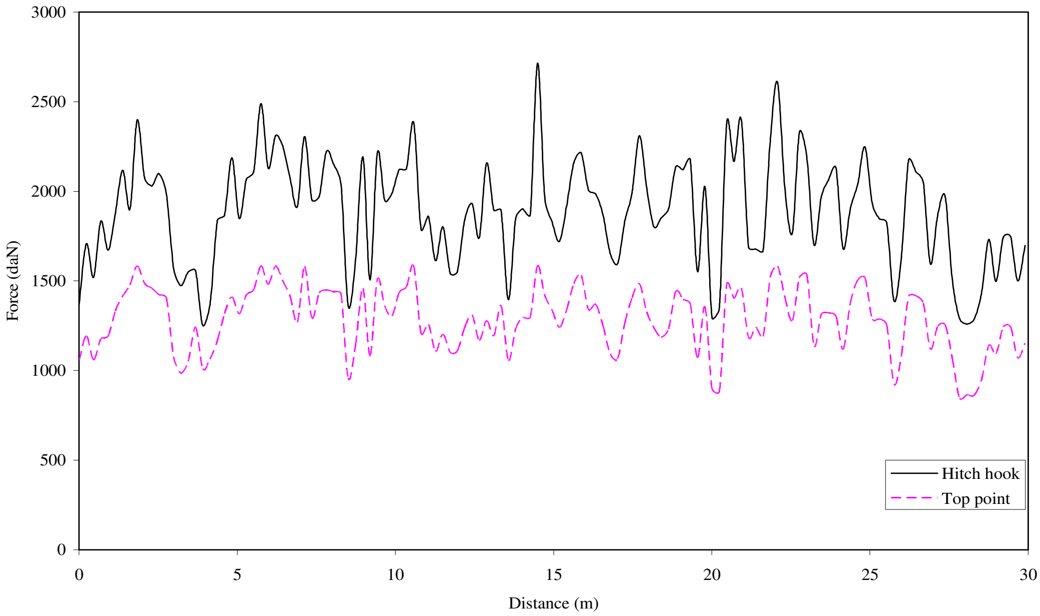

Figure 7. **The results of draft force required to till the soil, measured both on the hitch hook of the tool carrier and the top link of the three-point hitch of the same one (acquired using a sampling frequency of 2 Hz and a machine forward speed of 1 m s^{-1}) on the soil compacted after 20 tractor passes**

Conclusions

The results of the first tests showed that the system is able to accurately measure in real-time and collect a large amount of data, which can be easily processed by means of a data sheet, a GIS or another software usable for measuring the within-field spatial variability of soil physical-mechanical parameters.

At the same time the results showed an absolute value of the force measured on the hitch hook of the tool carrier (draft one) proportionally correlated to that measured on any point of the three-point hitch of the same one (draft one on the two side points, compression one on the top link). Therefore, whether the ratio between the draft force measured on the hitch hook and that measured on any point of the three-point hitch is known, it is possible to measure the draft force required to till the soil by using only one load cell.

In the next future the tested system, relying on the required spatial resolution, will be able to automatically adjust in real-time the sampling frequency as function of the penetrometer operating speed or machine forward speed, in order to acquire the amount of data strictly needed for mapping the considered soil parameter.

Moreover, the test results of many instruments for the real-time measurement of soil physical-mechanical parameters show a high correlation between the soil shear strength or draft force (depending on the implement used for tillage) and the cone penetrometer resistance, index of soil compaction (Hummel et al, 1996; Sudduth et al, 1997; Adamchuk et al, 2004; Comparetti et al, 2008). Therefore, further tests will be carried out in the same field, in order to verify the effect of the water content on the soil cone penetrometer resistance and the draft force required to till the soil. Whether the two above soil parameters will be highly correlated, it will be possible to indirectly determine the cone penetrometer resistance by using only the system for the geo-referenced measurement of the draft force or vice versa.

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