# SOIL MOISTURE REMOTE MONITORING FROM AN AGRICULTURAL TRACTOR

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**Abstract.** Soil moisture monitoring using sensors and wireless technologies is a relatively new concept for farm management information systems (FMIS) and irrigation alerting services. This work describes the hardware and software components of the wireless system monitoring soil moisture from an agricultural tractor. The structure of the wireless soil moisture system is made of remote terminal units (RTU's) properly suited to transmit lots of sensors data, a wireless modem connected to a gateway, a gateway which is the core of monitoring, a wireless network system and the tractor server. The developed software integrates data management, analysis and visualization in a user friendly graphical user interface (GUI). Although it was designed for soil moisture data, it can be used for any other data as well. Each time the tractor entered within the coverage area of the wireless network the transmission of data was started to the central server of the tractor. The developed software running on laptop analyzes data and checks it for abrupt changes in soil moisture status. If the sensed readings are below the defined threshold values then an alarm is sent to the farmer so as to decide on required irrigation management actions. Simultaneously, it supports a management information system for spatial analysis of tractor-implement draft forces that are related to the soil properties of the field in terms of soil moisture status. This analysis could be useful for optimizing tillage operations.

**Keywords:** Remote monitoring, soil moisture, sensor, precision agriculture

## 1 Introduction

Modern irrigation management is based on instrumentation (soil moisture sensors) that provides accurate estimations of soil moisture conditions. According to Fares and Polyakov (2006), installation of soil moisture sensors should begin with a careful selection of monitoring sites, which are subdivided into macro- and micro-zones. Macro-zone refers to the selection of one or several locations in an agricultural field characterized by dominant topography, soil type, vegetation, and management practices. Micro-zone selection aims at determining the position of the sensor in relation to individual points/locations, soil depths (shallow vs. deep) or irrigation delivery points (drip or sprinkler emitter). The most common single sensors are based on two electrodes measuring the resistance of the soil. Also, there are probes with bare wires embedded in gypsum (gypsum probes). The bare wire sensors are extremely affected by soil salinity and pH. Gypsum probes do not dry at the same time with the soil surrounding it, and they are plagued by clogging from small soil particles (Eldredge et al., 1993). Heat dissipative sensor using exact heating and cooling profiles provides another accurate method of soil moisture detection that is not affected by soil salinity, pH, soil compaction and temperature (Phene et al., 1971). Time domain reflectometry (TDR) is also used to measure soil moisture; a higher moisture concentration causes a higher average dielectric constant for the soil. The average dielectric constant can be sensed by measuring the speed of electromagnetic wave propagation along a burried transmission probe (Ledieu et al., 1986). Other common type of soil moisture sensors in agricultural use is a frequency domain reflectometry (FDR) such as a capacitance sensor (Eller and Denoth, 1996).

Since the early 1990s, Wireless Sensor Networks (WSNs) have been an area of active research. Wireless technologies refer to standardized set of radio technologies that allow computers and electronic devices (sensors) to communicate and access the internet without being connected via cable (Vellidis et al., 2007). WSN is a collection of a large number of sensors distributed logically, spatially over an environment and connected through a high speed network. WSNs perform three basic tasks: (a) sensors continuously collect data from the surrounding environment; (b) data are processed by an associated processing element; and (c) transfer them through wireless communications to a data collection point called sink node or base station (Anastasi et al., 2009). According to Chatzigiannakis et al. (2006), the static WSNs are based on the assumption that the network is dense, so that any two nodes can communicate with each other through multi-hop paths. More recently, mobility has also been introduced to WSNs. In fact, mobility in WSNs is useful for several reasons (e.g., connectivity, cost, reliability, and energy efficiency). In addition, mobility in WSNs also introduces significant challenges which do not arise in static WSNs (e.g., contact detection, mobility-aware power management, reliable data transfer, and mobility control). Sensors may be distributed in a two-dimensional (2-D) or a three-dimensional (3-D) environment. The environment in which the sensors are deployed varies with applications. For example, it may be an agricultural field for soil moisture data gathering. Each sensor node may consist of one or more soil moisture sensors installed within the field at same or at different depths. Wireless sensors monitor soil moisture and transmit the data back to the data server.

Soil moisture detection using sensors and wireless technologies is a relatively new concept for farm management information systems (FMIS) and irrigation management programs. FMIS is defined as a planned system for collecting, processing, storing and disseminating of data in the form of information needed to carry out the operations and functions of the farm (Sørensen et al., 2010). During the last years a number of studies have shown the potential to use wireless technologies and sensors for the detection of soil moisture status. Vellidis et al. (2008) present a prototype real-time, wireless smart sensor array for scheduling irrigation in cotton. The array consists of a centrally located receiver connected to a laptop and multiple sensor nodes installed in the field. It is a low cost system that allows dense installation of soil water sensors and it offers reliable monitoring of soil moisture status in crops. Bogena et al. (2010) investigate the potential of wireless sensor network technology for the near real-time monitoring of soil moisture at the large scales using the developed wireless sensor network (SoilNet). A forest area (27 ha) was instrumented with 150 end devices and 600 capacitance sensors. In a period of four months, more than six million soil moisture measurements were obtained. Zhang et al. (2012) present an advanced Wireless Underground Sensor Networks (WUSN) for monitoring of soil moisture at multiple depths. WUSN consists of wireless devices that are burried completely under the ground surface. It is a specialized kind of wireless sensor network that mainly focuses on the use of sensors that communicate through soil. Majone et al. (2013) describe a Wireless Sensor Network (WSN), composed of 135 soil moisture sensors (capacitance sensors) organized in 27 nodes (5 sensors per node) and 27 temperature sensors, in an apple tree orchard of about 5000 $m^2$, located in northeastern Italy. WSN is based on totally independent sensor nodes, which allow both real time and historic data management and are connected through an input/output interface to a WSN platform.

In recent years, a wireless sensor network with mobile elements is a promising approach because of its potential for enabling full of novel applications and services. An agricultural tractor can be used as a mobile element that allows data collection from remote agricultural field sensors (Polojärvi et al., 2012). It was assumed that sensors and tractor are connected with short-range radio communication devices. Farmer uses tractor to visit the remote sites constantly (e.g., every day or every week). The radio device on tractor contacts with sensors at the remote sites, and data returns to the tractor position (Ochiai et al., 2011). As a consequence, three main phases associated with the data collection in WSNs emerge: discovery, data transfer and routing to tractor server. In addition, the correct location of sensor nodes is known. On the other hand, the tractor movements can be designed and recorded so as to achieve specific goals and optimize given performance parameters. Mobility can be demonstrated by means of trajectory, the path followed by the tractor during its movements, and speed (Somasundara et al., 2007). Mobile sensing vehicles have been proposed by other researchers in different applications (Lee et al., 2009; Eisenman et al., 2009; Liu et al., 2004).

This study demonstrates data gathering from remote soil moisture sensors using an agricultural tractor as mobile element of the wireless monitoring system. The automatically transferred soil moisture data: (a) support a management information system for spatial analysis of tractor-implement draft forces, which is useful for tillage operations analysis, soil conservation, and fuel saving, and (b) offer irrigation alerting services on agricultural tractor.

## 2 Materials and Method

An agricultural tractor (Lamborghini R6. 130 Hi-Profile) moves between remote nodes (i.e., tractor as mobile base station and soil moisture sensors as remote nodes). Thus, when tractor comes into radio communication range with sensors (1000 m), they contact each other and start exchange data. The experimental site (almost 25000 $m^2$) was located at the campus of the Technological Educational Institute of Thessaly, Greece. The soil characteristics determined by laboratory analysis: soil texture was sandy loam, porosity was 0.44 and dry bulk density was 1.42 g $cm^{-3}$.

## 2.1 General description of wireless soil moisture monitoring system

This section describes the hardware and software design of the wireless soil moisture monitoring system that automatically gathers and transfers field data, as well as routing to the agricultural tractor server. The architecture of the wireless soil moisture monitoring system is shown in Figure 1. It consists of three granular matrix sensors (GMS) Watermark Model 200SS (Irrometer Co. Inc., Riverside, CA, USA), and the commercially available wireless monitoring system Adcon Telemetry (Adcon Telemetry GmbH, Klosterneuburg, Austria).

The three granular matrix sensors (Watermark, Model 200SS) are used for soil moisture monitoring. These types of sensors have been chosen due to the low unit cost and simple installation procedure. Each sensor is installed in its own hole in representative points of the experimental field, to measure soil moisture at a depth of 0.25 m. Because the relationship between soil moisture potential and resistance of Watermark 200SS sensors has been observed adequately by Shock et al. (1998) and Allen (2000b) no other method was evaluated in this study.

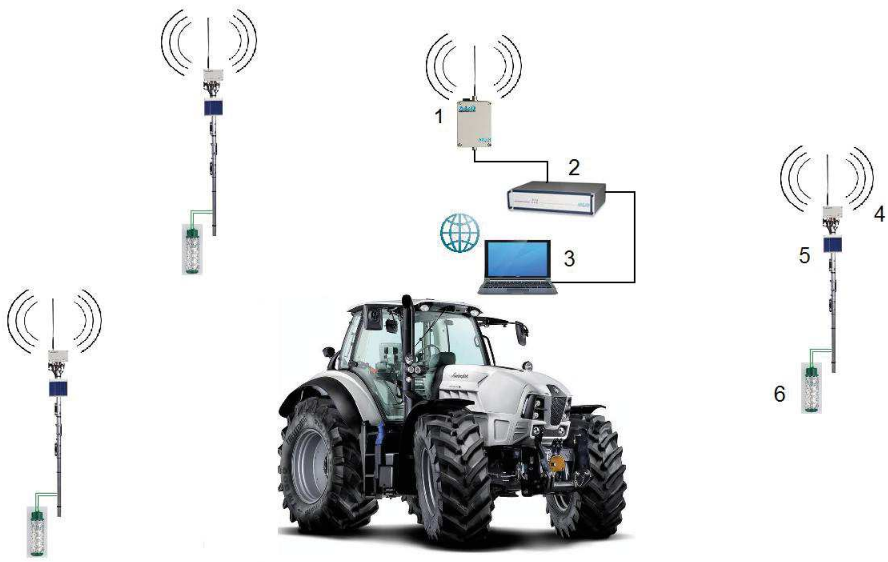


**Fig. 1.** Remote monitoring of soil moisture from an agricultural tractor: (1) Wireless modem, (2) Gateway, (3) Laptop Computer, (4) Remote Terminal Unit, (5) Solar Panel, and (6) Soil moisture Sensor.

The wireless monitoring system Adcon Telemetry consists of three remote terminal units (RTU's), a wireless modem, a telemetry gateway, and the tractor server. The RTU (A723 addIT Series 4) is a short range remote telemetry unit with an integrated 10mW radio, allowing reliable data collection and transfer. It has 6 analogue, 2 pulse and 2 digital inputs and supports up to 40 SDI-12 values. Logging and transmission intervals are customizable over all around the environment. A robust IP-66 rated aluminum housing ensures year round operation, even in harsh environments.

Waterproof Binder connectors are used for sensor and solar panel connections, making field installation quick and simple. It is powered by a small permanent solar panel. The A850 telemetry gateway is the core (base station) of the Adcon radio network. An internal memory of 256MB on CF card stores data of RTUs for approx. 1 week or 1 million reads per write cycle. In our study it was set to record 100 measurements per day. The gateway software can enforce some limitations that can be inserted (e.g., the number of RTUs, the number of sensors, the number of wireless modems, etc.). It communicates with the three radios RTUs (A723) via the A440 Wireless Modem (outdoor unit) installed on the rooftop of the tractor's cabin. Wireless Modem A440 has two connectors, one for the antenna, and a second that accommodates the connection cable, which not only provides communication link to the A850 telemetry gateway (indoor unit), but power as well to the A440. Furthermore, the telemetry gateway unit is connected directly, via a serial null modem cable, to a laptop PC running MS Windows XP as an operating system which has been used as a tractor server. The amount of collected data is send to the web-based FMIS application through a wireless or GPRS connection. The tractor server provides the user with a graphical interface at the laptop desktop. Finally, the A850 telemetry gateway is a low-power device, a built-in rechargeable battery which maintains the function also in case of temporary outages of the primary power source for up to 24 hours preventing any data loss. Telemetry gateway and laptop PC are powered by tractor's battery via an inverter DC 12V to AC 220V.

### 2.2 Topology of wireless network

The topology of a wireless network describes the physical layout of RTUs, and gateways, as well as the data flow paths between them. In this study, it was used a traditional star topology architecture. Star topology is a point-to-point or line-of-sight architecture where individual RTUs, communicate directly with a gateway. The gateway transmits the data to a central collection point, such as the tractor laptop PC. Each RTU cannot communicate directly with one another; all communications must be routed through the centralized gateway. Each RTU is then a "client" while the tractor laptop PC is the "server". The star topology potentially uses the least amount of power of the other architectures because of the simple, direct wireless connections. But the distance the data can be transmitted from the RTUs to the gateway is limited. Communication may be hindered or data lost if something disrupts the transmission path between a RTU and gateway. In case there is a need to monitor the soil moisture of a much larger area, then it is suggested to use different infrastructures and wireless network topologies. Three of the most common wireless topologies for agricultural and environmental applications are long range networks, short long range networks, and UHF plus GPRS networks.

### 2.3 Software design of Farm Management Information System

The Farm Management Information System (FMIS) was developed by Tsiropoulos et al. (2013) to handle draft forces data and generate spatial performance maps. It could be useful in order to analyze tillage operations, to maintain soil quality, and reduce energy consumption. The FMIS consists of a windows and a web based application. The FMIS software was written in C# which is a multi-paradigm programming language. The data was stored in 2 MS – SQL databases, one for windows-based application (laptop) and one for the web application (web – server), which have been synchronized.

The windows-based application has six basic tools. These are: (a) the Data Logger Tool in which the data of the three data sources (portable dynamometer, tractor ISOBUS, and GPS receiver) have been recorded, (b) A850 Telemetry Gateway that acts as a mid-term storage device for soil moisture data collected from RTUs, (c) the Spatial Analyst Tool where spatial maps have been created, (d) the Calibration Tool where the response of each load cell to known weights have been stored, (e) the Statistics Tool where recorded data and charts could be viewed, and (f) the Synchronization Tool, which is responsible for the synchronization between the two application databases.

The web application has three basic tools. These are: (a) the Farm Information Tool where data about the farm has been stored (fields, tractors, implements, etc.), (b) the Real Time Tool where the data of the instrumented tractor and implements, as well as soil moisture sensors data have been shown in real time, (c) Spatial Analyst Tool where spatial maps have been created, and (d) the Statistics Tool where recorded data and charts can be viewed.

Finally, the FMIS hardware equipment for tractor-implement combination is described very analytically at the work of Tsiropoulos et al. (2013), therefore no more information are given in this study.

## 3 Results

The design of the soil moisture monitoring system faced two significant challenges: to offer irrigation alerting services on agricultural tractor and to support a management information system for spatial analysis of tractor-implement draft forces.

As mentioned above, the web application can display the data in real time. User has the option to select which info and tools can be viewed at the Real Time Tool of the web application. The basic tools that always exist at the Real Time Tool are: (a) basic tractor data (engine speed, fuel consumption, tractor speed), (b) soil moisture data, (c) sensor nodes position and (d) tractor route. Figure 2 shows the Graphical User Interface (GUI) of the Real Time Tool. Basic tractor data and soil moisture data is displayed as gauges for helping FMIS users to understand in a very easy and fast way all the values. Tractor route, sensor nodes position and field boundaries are displayed on a real time map. Tractor route is shown as a red line, field boundaries as a blue translucent polygon and nodes position as green dots. The number over the green dots is the sensors ID number. Additionally, the chart displays the engine torque, fuel consumption, traction, and soil moisture potential. The GUI of Figure 2 shows that the sensor array was able to successfully monitor soil moisture as measured by the three Watermarks and can indicate soil moisture tensions at the field before and after an irrigation event.

If an action is needed or there is a system alert (e.g. soil moisture is low at one of the sensors), a pop up window will appear at the web application, and a short message service (sms) will be send to the farmer mobile phone. The automatic alerts and the way the GUI is displaying the data (e.g. range colors on gauges) helps the farmer to decide when and how long the irrigation cycles should be.


**Fig. 2.** Graphical User Interface (GUI) of the web Real Time Tool.

Field experimental results show that all measured FMIS parameters were closely related and showed in similar patterns. Fuel consumption and torque are related to engine speed and forward velocity. Fuel consumption was 20% higher at 2200 rpm compared to 1800 rpm at all velocities, and 25% higher at 5km/h compared to 9km/h at both engine speeds. Soil moisture status was 13-15 kPa which means that the soil is adequately wet.

## 4 Discussion

In this work it is demonstrated an application of WSN that allows soil moisture data gathering from a mobile base station (agricultural tractor). Our goal was to offer irrigation alerting services on agricultural tractor and support a FMIS (windows-based and web-based) for spatial analysis of tractor-implement draft forces. This technology embedded on agricultural tractors offers new capabilities and computational tools. The pilot deployment of this wireless soil moisture monitoring system took place at the Technological Educational Institute of Thessaly, Greece. It was carried-out through small-scale experiments with three nodes. However, experiments turn out with success. In the future, this study will be extended to full deployment with increased number of sensor nodes for any other type of data, optimal placement strategy for the sensor nodes, and enhanced the computational capabilities of the management information system.

## 5 Conclusions

- This soil moisture wireless monitoring system promotes new services on tractor including irrigation alerting and support a FMIS (windows-based and web-based) for spatial analysis of tractor-implement draft forces.
- According to the results, soil moisture data from sensor nodes were transferred to the tractor server successfully.
- While the current project has concentrated on soil moisture sensing, it could be used for any other field data gathering. In addition, this wireless monitoring system could be implemented on other self-propelled machines of the farm.

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