An underground experimental mobile platform for soil moisture monitoring

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Abstract
This paper presents an experimental underground pipeline mobile platform that can be used for monitoring soil moisture changes along or across an agricultural field in real time. A modified commercial soil moisture sensor was placed on two circular wheeled bases; each of them being driven by a small electric wheel motor. A single prototyping board allows the user to control the platform by sending commands (move one step forward or backwards) from a remote control. Experiments were carried out in laboratory conditions, on an artificial soil tank 10 m long, 1 m wide, and with a soil depth of 0.4 m. The plastic pipeline was placed horizontally 0.10 and 0.30 m under the soil surface. The results showed that the determination of soil moisture using the proposed method was much more effective than when measuring the soil moisture status at a particular point.

Keywords: irrigation management, soil moisture monitoring, mobile platform

1. Introduction

The key to efficient irrigation water management is good knowledge of both: when to irrigate and how much water to apply. When irrigations are managed prudently and efficiently, sufficient water is available for plant growth and excess water loss is minimized. Yields can suffer if irrigation is delayed and available moisture within the root zone of the crop is appreciably reduced. Similarly, irrigation efficiency is reduced if water is applied in excess of what the soil can infiltrate or retain. Sensor based monitoring of soil moisture status should be an essential part of an integrated management program that will aid farmers to avoid the economical losses on their crop yield and quality that result from either under-irrigation or over-irrigation.

There are three common methods to determine soil moisture status: gravimetric soil moisture content, volumetric soil moisture content, and soil moisture potential. Gravimetric is the only direct method to determine how much moisture is in the soil. All other techniques rely on indirect methods that measure other properties of the soil that vary with moisture content. All the available soil moisture measuring instruments (sensors and probes) are based on the above indirect methods for measuring soil moisture status. According to Cape (1997) a soil moisture sensor is an instrument which, when placed in soil for a period of time, provides information related to the soil moisture status of that soil. The term "sensor" is used to denote the actual sensing element of a soil moisture measuring instrument, while the expression "probe" is used for the sensor together with embedded electrical circuits, which make the output of the sensor technically manageable (Doležal et al., 2008). Most soil moisture sensors are designed to estimate soil volumetric moisture content based on the dielectric constant of the soil. The dielectric constant can be thought of as the soil's ability to transmit electricity. The dielectric constant of soil increases as the moisture content of the soil increases. This response is due to the fact that the dielectric constant of moisture is much larger than the other soil components. Thus, measurement of the dielectric constant gives a predictable estimation of moisture content. For more information on soil moisture sensors see Topp and Davis (1985), Robinson et al. (1999), Charlesworth (2000), Robinson and Friedman (2000), Evett et al. (2002), Muňoz-Carpena (2004) and Walker et al. (2004).

All the available soil moisture sensors and probes can monitor the soil moisture status at a particular point in the field. Depending on the soil moisture monitoring instrument the number of readings might be limited to only one per few hectares. Usually, besting order to obtain more representative results, it is important that the instrument is placed in the average soil type, next to the average plant, at the depth of average moisture uptake and in the zone of average soil moisture application. The installation of an underground pipeline network along or across an agricultural field; and the utilisation of a sensor-based mobile platform that travels through the piping system and monitors the soil moisture changes in real time, is considered as a new attractive solution for efficient irrigation water management.

Mobile robotic platforms are frequently used for automated inspection of the inner surface of piping systems. Examples of such robotic platforms include advanced pipeline inspection techniques such as visual inspection, magnetic leakage detection, ultrasonic inspection, etc. These methods are useful in detecting corrosion, leakage, collapse, and wear. The complexity and variety of industrial pipeline environments accelerates the innovation of robotic systems, for example, autonomous motion without cable, reliable communication between inside and outside of pipeline, extended time field operation, rapid tracing, and accurate localization (Bright et al,. 1997; Qi et al., 2009). Choi and Ryew (2002) presented a robotic system for in-pipe inspection of underground urban gas pipelines. The robot was configured as an articulated structure, like a snake with a tether cable. Two active driving vehicles were located in the front and the rear of the system, respectively. Passive modules such as a control module and other optional modules were linked between the active vehicles. Moghaddam and Hadi (2005) constructed an inspection robot with the ability to move inside horizontal and vertical pipes. The outer diameter of the robot could be varied and adapted to the pipe interior in order to regulate the contact pressure needed between the robot and the pipe. All functions were controlled by the operator through a joystick while receiving the video signal of the camera on a monitor. Zhang and Yan (2007) described a robotic system for gas pipeline inspection. It was composed by two parts, the first one was the inspection robot running inside the pipeline, and the second one was the ground workstation monitoring the state of the inspection robot. The in-pipe inspection robot consisted of a running mechanism, a pipe diameter adaptive mechanism, a sensing system, a control system etc.

In this paper, the authors present a sensor-based mobile platform, which travels through an underground piping system for soil moisture monitoring. The whole design and manufacturing of the mechanism aims to provide a mobile platform which could access the underground horizontal pipeline network with 52 mm diameter, and make use of the soil moisture sensor placed inside the platform.

2. Materials and methods

The sensor-based platform design criteria can be summarized in three major sections: a) the mechanical design of the circular wheeled bases and chassis, b) the electronic design of the prototyping board that allows the user to control the platform by sending commands from the remote control and c) the software design of the graphical user interface in the ground station.

The length of sensor-based platform is 220 mm and the exterior diameter is variable between 47 mm and 54 mm. As illustrated in Fig. 1, the proposed mobile platform consists of two articulated circular wheeled bases including sensor case, and cables. The wheeled bases are linked via usual universal joints (Hooke’s joints). They must have equal input and output angles to work correctly. Also, the forks must be assembled so that they will always be in the same plane. The body of wheeled bases is circular in shape (Fig 2), and is adequate to support the driving and sliding wheels. The sliding wheels are supported via bumper suspensions. This simple suspension system allows motion only in the vertical direction and relies on flexible members (compression springs) to hold the bumper loosely in place. The deflection of the bumper suspensions for the sliding wheels which are in contact with the wall of the pipeline to be foldable. Since each wheeled base can move independently of the other, in the elbow and straight pipelines, the mobile platform guided by the wall goes through the pipelines. It is possible to perform steering at corners of pipelines by differentiating the action of the bumpers and the speed of the sliding wheels. A high quality micro stepper motor is installed close to the driving wheel parts. The driving power is transmitted to the wheel by a motor shaft. The motor voltage is 1.5V-3V with a typical rotational speed of 500 rpm. Each wheel module uses elastic wheels with high friction coefficient. This way, the mobile platform is able to hold onto the surface of the pipeline firmly and move smoothly on the pipeline surface.

The rear wheeled base bears a modified commercial soil moisture sensor, specifically the Diviner 2000 probe (Sentek Pty Ltd, 2007). The Diviner 2000 is a portable soil moisture monitoring system. It consists of a data display unit and a portable probe. The probe comprises of a metal rod with a probe cap and a capacitance sensor at the bottom. A modification was applied that consisted of removing the metal rod with cap from the probe. The handheld display unit automatically records the soil moisture at sampling increments of 100 cm.

In order to minimize the size of the mobile platform, the prototyping controlling board hasn't been installed inside the platform structure but instead in the remote ground station. The prototyping board contains all the drivers necessary to drive the stepper motor. It can be operated in free-standing (internal oscillator) or PC-controlled (direction, step) mode. Two L297 and L298 (SGS) chips are employed as drivers. The speed of the motor is controlled using a single potentiometer. This board allows controlling the speed of the motor in both the forward and reverse directions. The direction can be changed by using a SPDT switch. The range is from fully OFF to fully ON in both directions. Turning the switch in one direction causes the motor to start spinning. Turning the switch in the other direction causes the motor to spin in the opposite direction. The centre position on the switch is OFF, forcing the motor to slow down and stop before changing direction of rotation. Light Emmitting Diodes (LED) provide a visual indication of the whole process. Separate supply voltages for the board and the motor are required.

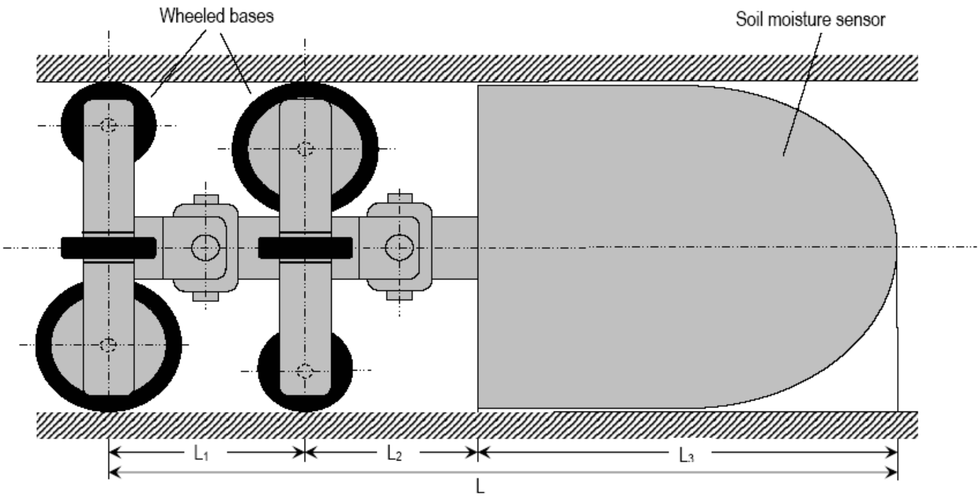

Fig. 1: The mechanical drawing of the mobile platform that monitors soil moisture.

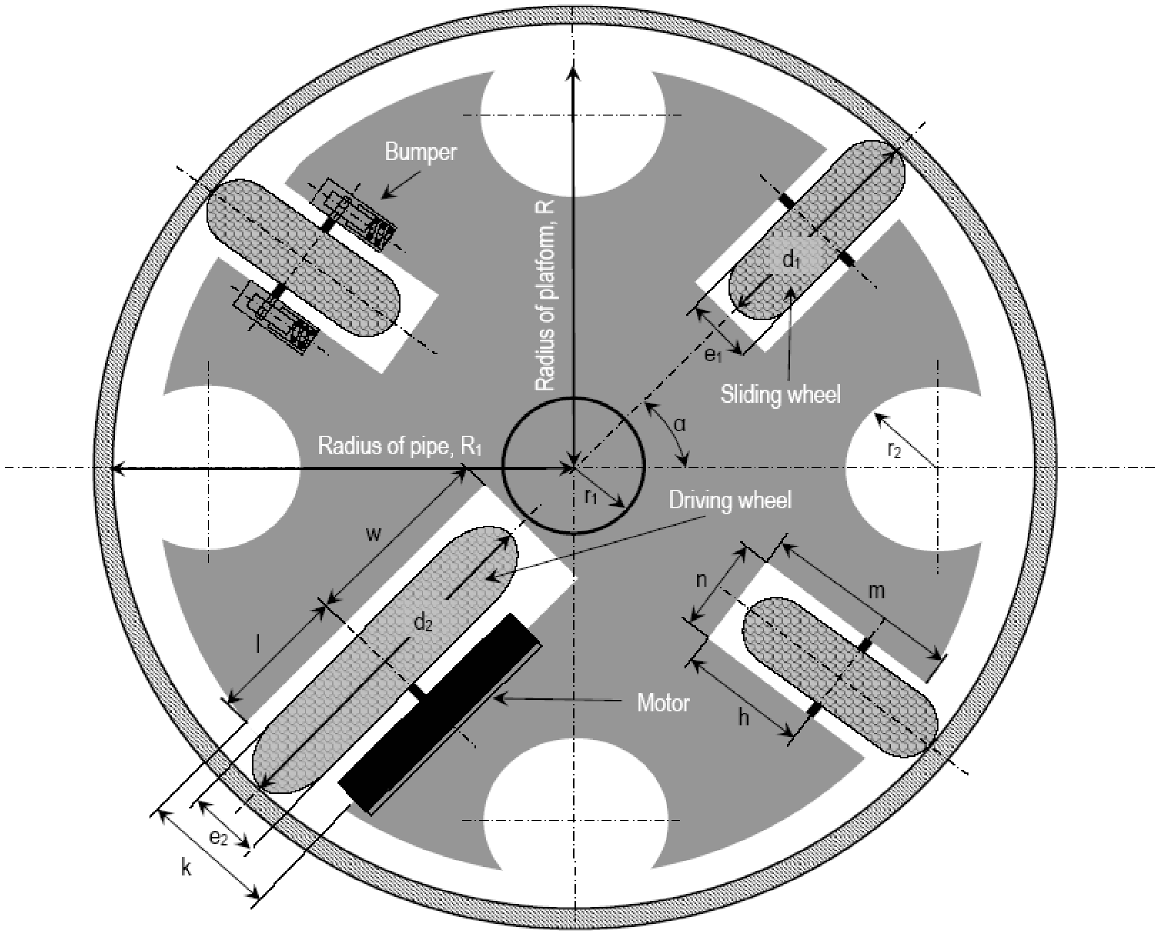

Fig. 2: The mechanical drawing of the circular wheeled base.

Experiments have been carried out in laboratory conditions. A testbed has been constructed for developing and testing the mobile platform for soil moisture monitoring,.Fig. 3 shows the schematic drawing of the experimental testbed, which includes an artificial soil tank, plastic pipelines, remote control unit, display unit, and a computer. The soil tank was made by water resistive wood, 10 m long, 1 m wide, and with a soil depth of 0.4 m. The plastic pipelines were placed horizontally (without elbows or branch) at depths of 0.10 and 0.30 m under the soil surface. In both the smaller sidewalls of the soil tank openings have been made with an internal diameter of 54 mm, to allow the entrance of the mobile platform. The soil classification type that has been used for all experiments was clay loam. The main physical and hydrological properties of this soil type are given in Table 1.

Table 1. Physical and hydrological properties of soil type

Soil type	Sand [%]	Silt [%]	Clay [%]	Bulk Density [g/cm^3]	Field Capacity [% Vol.]	Permanent Wilting Point [% Vol.]	Infiltration rate [cm/h]
Clay loam	41	25	34	1,32	27	13	0,7

Two irrigation methods (i.e. drip and furrow) were simulated. The drip irrigation system was of similar design to that used by commercial growers (using tubes with 16 mm internal diameter, with drippers delivering 4 l/h set at 300 mm apart). For the furrow system, the irrigation water was delivered to furrow in the soil tank by a PVC tube with an internal diameter of 16 mm.

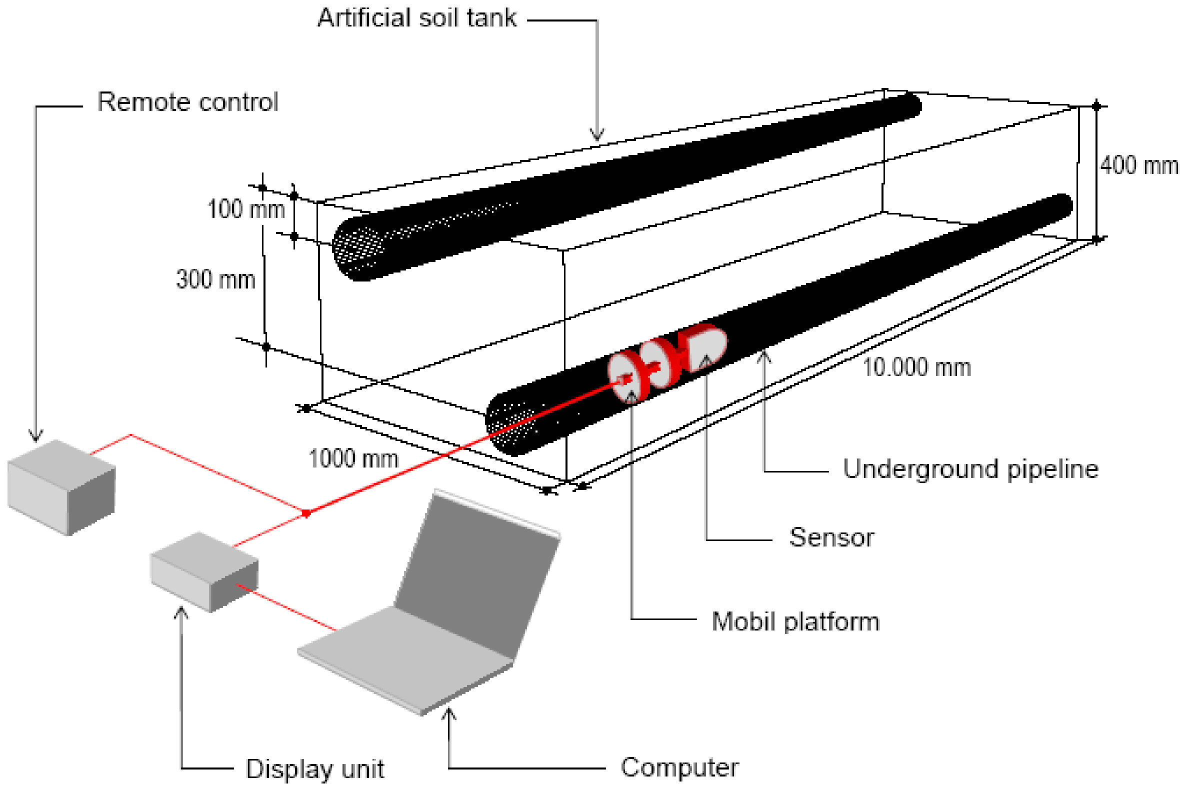

Fig. 3: A schematic of the experimental testbed.

3. Results and discussion

In this section, the experimental results of the evaluation of the performance of the proposed mobile soil moisture monitoring platform are described. The experiments have been carried out in the above testbed for plastic pipelines with ø 52 mm diameter (total length 10 m each horizontal pipeline, without elbows or branches).

In the first task, the ability of the sensor-based platform to pass in horizontal underground pipelines was tested. A very advantageous feature of the in-pipe mobile platform is the wall pressing wheels. Both motors participate in platform movement although in this case the friction is higher. In addition to this, the platform is more stable and the distribution of load on different wheel modules is more uniform. The experiments demonstrated that the proposed platform has excellent mobility. Also, the functionality of the electronic board design was verified. The proposed board can actively modulate the wheeled bases by controlling the motor command. Similar experiments have been performed by varying the speed of the motor in both the forward and reverse direction, respectively.

In the second task, we have tested the platform's ability to monitor the soil moisture changes inside the pipelines and transmit the soil moisture data to the ground station by use of the graphical user interface. Also, we have analysed soil moisture data for irrigation scheduling and we compared plotted data trends between conventional profile moisture content and the proposed horizontal soil moisture content at different depth levels. The experiments showed that the proposed sensor-based mobile platform allows irrigation managers to plot soil moisture changes along or across the agricultural field at different depth levels and as a function of time (Fig. 5, 6, 8 and 9) as an aid in decision making.

In Fig. 4, the soil moisture content changes after furrow irrigation method are presented. The soil moisture dynamics after the second day of the irrigation event are depicted. According to this graph the soil moisture changes are more evident at a 10 cm soil depth than at a 30 cm depth. At a depth of 30 cm the changes are benign. The measurement of the soil moisture content at the bottom of the soil tank has showed a small increase in moisture. This means that the changes of soil moisture at a depth of 30 cm are not sufficiently correlated to the changes at 10 cm. The soil moisture extraction at 10 cm has three important phases. In phase one the soil profile is saturated and still draining. During phase two the draining of the soil profile has stopped and the crop uses freely the available water. In phase three, water consumption by the crop decreases. The soil moisture monitoring in soil profile has been proved to be a good practice for irrigation scheduling. Thus, soil moisture sensors are buried at the active root zone (locations of interest) providing useful information to irrigation managers in the following ways: a) the soil moisture sensor is placed near to the bottom of the root zone so that it can act as a warning signal when over-irrigation is occurring, b) the soil moisture sensor can be used to regulate the amount of irrigation according to the crop's water demand by placing the sensor within the root zone and turning on the irrigation when the soil moisture decreases under a set point, and c) the soil moisture sensors can be designed to collect measurements of soil moisture inputs or outputs from the soil profile. With subsequent analysis these data can provide useful information about managing of irrigation and crop water use.

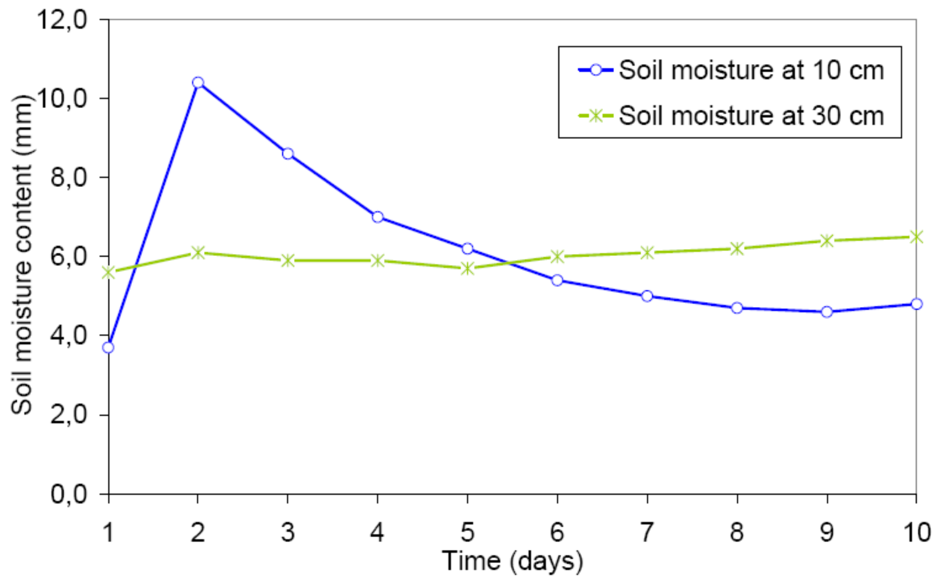

Fig. 4: Soil moisture changes in soil profile of experimental testbed after furrow irrigation method.

Fig. 5 and 6 show the soil moisture changes along experimental testbed at 10 cm and 30 cm depth level after furrow irrigation. At a depth of 10 cm, during the first four days, soil moisture content changes quickly as a function of time and horizontal distance. Eight days after draining the soil moisture content starts to stabilize as a function of time and horizontal distance. At a depth of 30 cm, the soil moisture content increases slowly and firmly with time. The soil moisture content variability as a function of horizontal distance is an interesting feature at this depth. According to the experimental results, the sensor-based mobile platform can give the soil moisture content profile both in the horizontal and vertical direction. This means that it provides the spatial variability of the moisture content, so that precise information about the soil and plant environment is gathered. Comparing this method with the much smaller sampling volumes of most commercial dielectric sensors and probes gives an idea of how many measurements would be needed with conventional technologies in order to get a precise profile of soil moisture content.

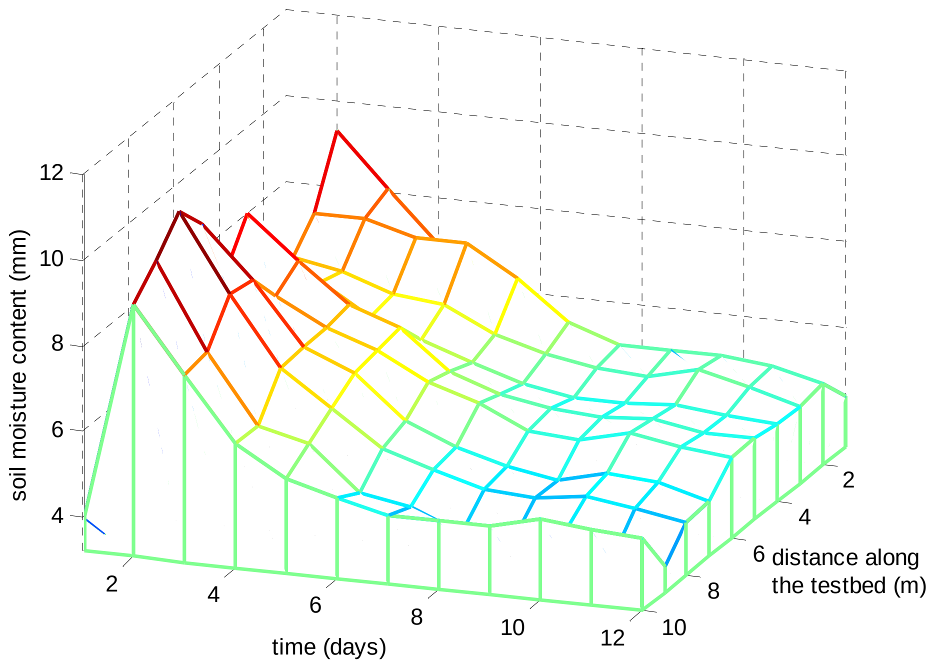

Fig. 5: Soil moisture changes along the experimental testbed at a depth of 10 cm after furrow irrigation method.

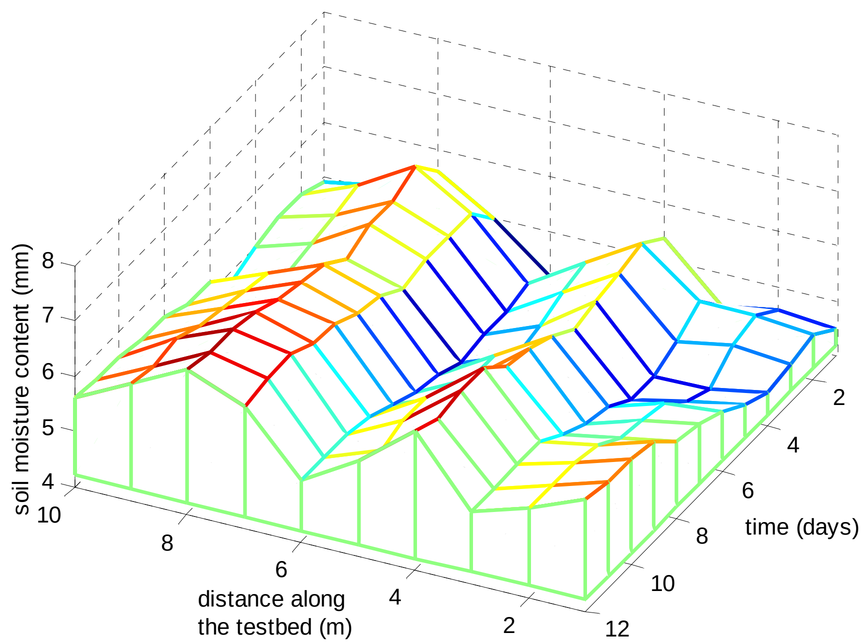

Fig. 6: Soil moisture changes along the experimental testbed at a depth of 30 cm after furrow irrigation method.

In Fig. 7, the soil moisture content changes in soil profile below the first dripper of the experimental testbed after application of drip irrigation are presented. Soil moisture changes are more evident at a soil depth of 10 cm than at 30 cm. Comparing the conventional soil moisture monitoring in soil profile with the results of the proposed sensor-based mobile platform, it is evident that the soil profile moisture monitoring does not provide reliable information about the function of all drippers of the irrigation system. According to the experimental results of the sensor-based mobile platform (Fig. 8 and 9), the soil moisture changes along the experimental testbed at a depth level of 10 cm and 30 cm after drip irrigation shows that the second dripper, which was installed 0.3 m far from the first one, works less efficiently. From the above results, it is quite obvious that the sensor-based mobile platform that travels through the underground pipelines along or across the agricultural field enables more efficient management of irrigation water because it covers densely the whole irrigated area providing a more reliable estimation of soil moisture distribution.

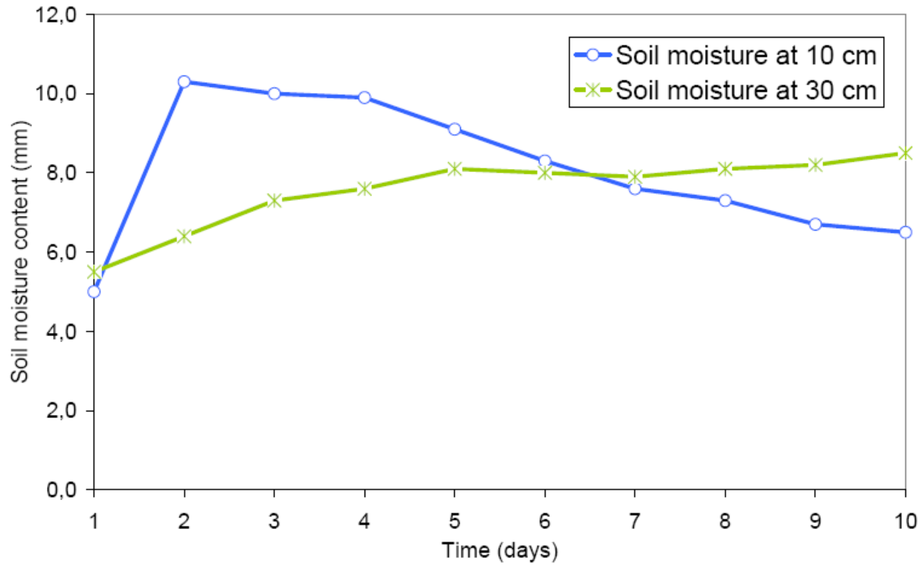

Fig. 7: Soil moisture changes in soil profile of the experimental testbed after drip irrigation method.

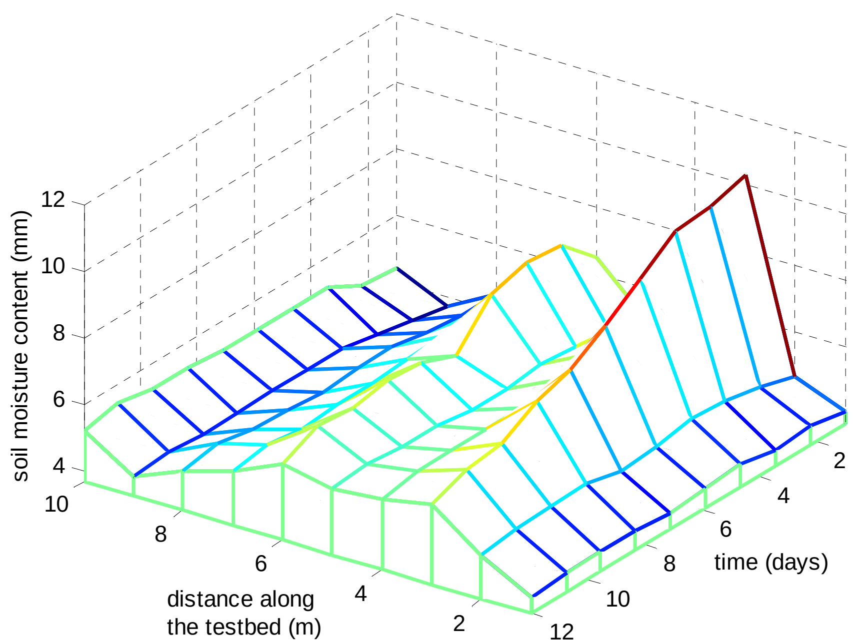

Fig. 8: Soil moisture changes along the experimental testbed at a depth of 10 cm after drip irrigation method .

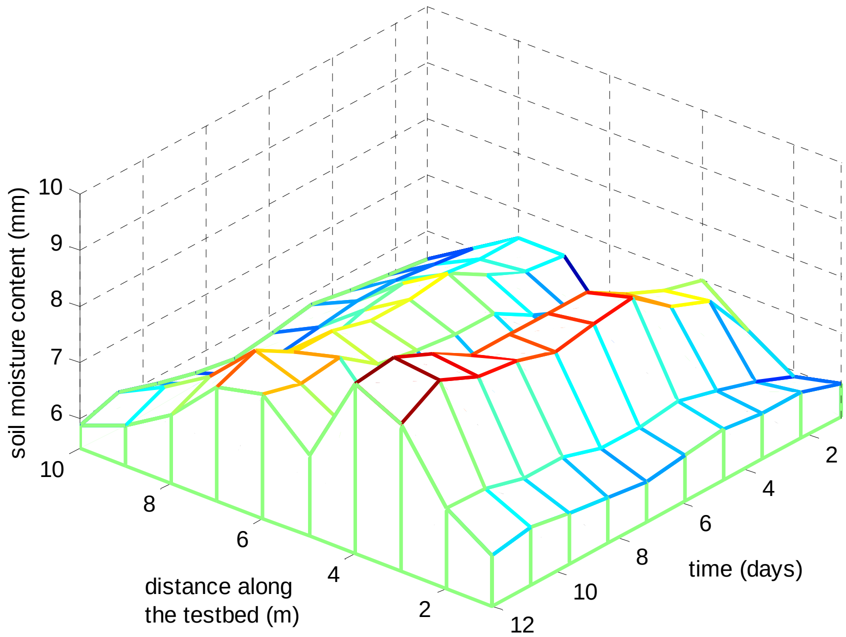

Fig. 9: Soil moisture changes along the experimental testbed at a depth of 30 cm after drip irrigation method.

In order to visualize the soil moisture data collected by the mobile platform a software application has been developed in Visual Basic for Windows. The software has a Graphical User Interface (GUI) with two main windows. One window allows the user to input the soil moisture data. The second window provides information about soil moisture data through the pipelines. It is possible to select data by day by positioning the mouse cursor on the desired date. The specific soil moisture data are then presented in graphical form in a separate window. In this window three horizontal line graphs are shown, each one associated with a specific pipeline. Fig. 10 illustrates the GUI in the ground station.

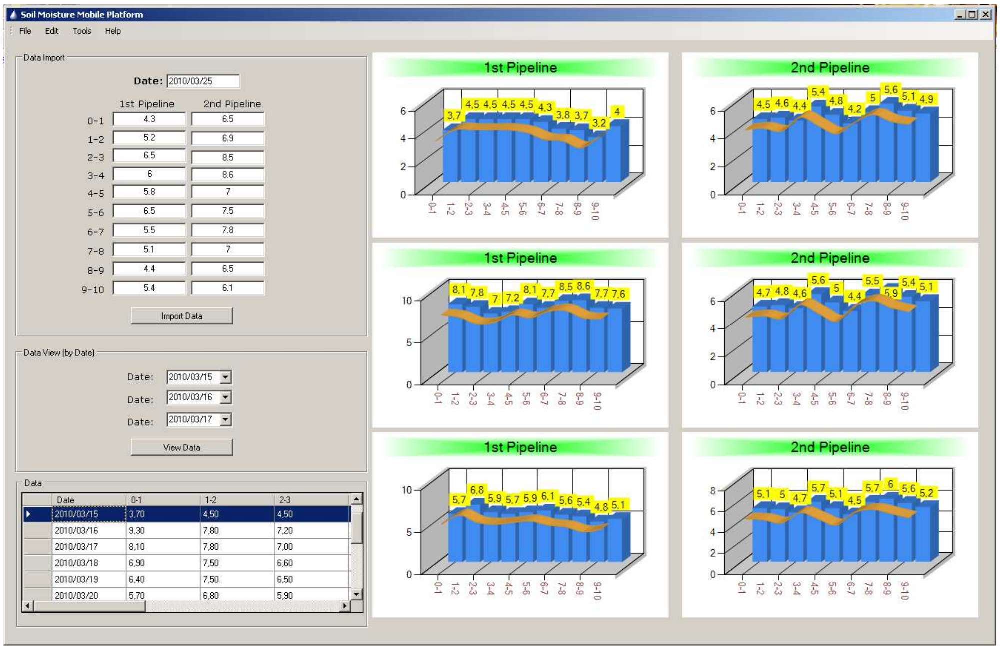

Fig. 10: Graphical User Interface.

Conclusions

A sensor-based mobile platform that travels through the underground pipeline network along or across an agricultural field is a new attractive and economical way for efficient irrigation water management. The proposed method covers a significantly higher percentage of irrigated area, offers rapid and easy moisture measurements, which are not sensitive to the installation details and in addition no special skill is required to interpret the results. Compared to the much smaller sampling volumes of most commercial dielectric sensors and probes, this mobile platform can provide the soil moisture content profile both in the horizontal and vertical directions. The method effectively provides the spatial variability of the moisture content, so that precise information about the soil and plant environment is gathered. Field experiments have proven that the mobile platform can work well inside the underground pipeline. The sensor-based mobile platform provides a convenient platform for continuous development. The combination of mechanical design of the wheel, chassis and motion control allows the exploration of a large number of innovative solutions to be implemented for a number of practical applications.

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