A Minimal Cost, Soil Moisture Measurement System
Logging Wenner Array Resistivity with a Microcontroller for Less than 10 Euros

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Abstract: Where water is a scarce resource, efficient use of irrigation systems is an absolute requirement for crop management. Whilst there are many commercial systems available on the market, units typically cost hundreds of dollars or are lacking in basic data-logging capabilities. This paper describes results from trials of a minimal cost microcontroller based monitoring system designed for large scale deployment or highly cost sensitive monitoring. The system can easily be expanded to meet differing socio-economic situations.

1 INTRODUCTION

There is a wide range of electrically based soil moisture measurement techniques well established in the fields of geophysical surveying (Dobrin, 1988), (Parasnis, 1986) and agronomy (Edlefsen,1941) These include resistivity based methods such as the Wenner (Wenner, 1915) and Schlumberger Arrays (Lark-Horovitz, 1959), and capacitive based methods such as Frequency Domain Reflectometry (FDR) (Wobschall, 1978) and Time Domain Reflectometry (TDR) (Topp,1980) as well as Radiation based techniques such as the Neutron Probe (Bell,1973). Whilst low cost implementations have been suggested in the past (Rhoades, 1979), (Igboama, 2011), commercial implementations of these units (for example the Landviser Landmapper) are expensive (typically $500 to $1600), lack integrated data-logging capabilities, or are simply unavailable. By far the simplest of these are the resistivity based techniques, which whilst suffering from a susceptibility to a variety of differing soil conditions such as composition (Table 1), texture (Nadler, 1991), varying pH (Ishada, 1999), salinity (Austin, 1979), (Read, 1979) and temperature (Hanson, 2000), can still be highly effective in detecting relative changes in soil moisture levels

Table 1: Measured soil resistances (at 6cm separation) and resistivity under dry and moist conditions at 25C.

Soil Type	Observed Resistance (Ohms)	Effective Resistivity (Ohm m)
Dry Clay	560	211
Dry Mulch	690	260
Dry Sand	>10K	>4K
Wet Clay	95	36
Wet Mulch	90	34
Wet Sand	60	23

In particular, the temperature of the soil is significant (Afa, 2010) as this can affect the electrochemical properties of the soil being sampled.

This paper presents results from field trials of a low cost minature Wenner Array based system in both a mulch enriched research vineyard and a hi-silica, clay based almond field, typical of the farmland and campo of the Vega Baja region of Eastern Spain.

2 METHOD

The Wenner Array was implemented using a PIC18F family (Microchip, 2000) microcontroller with a multi-channel, 10 bit Analogue to Digital convertor, and four metal rods (culinary grade steel) of up to 23cm length and 2mm diameter held 6cm apart. Five PIC pins were required for the implementation of each array, the first to act as a current source, the second as a current measurement point and insertion point into the soil, the third and fourth as voltage measurement points in the soil and the fifth as a current extraction point from the soil

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(see Figure 1). A reference resistor of known value was used between the first and second pins, and by measuring the voltage difference across this resistor, the current flowing through the soil was determined. The third and fourth pins provide a high input impedance voltage measurement and given the known current, the resistance of the soil between these two points can be determined. As the voltage measurements require extremely small currents, this measurement technique is relatively immune to irregularities in probe to soil impedance.

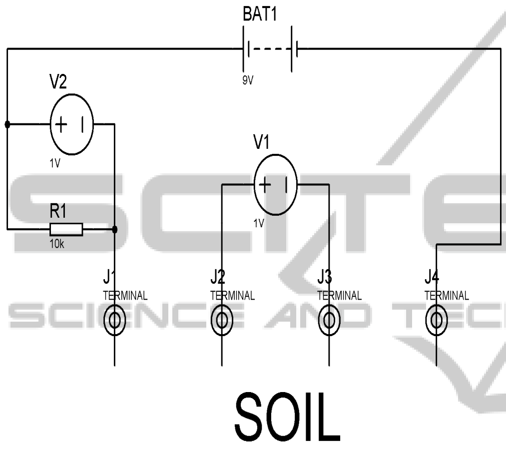

Figure 1: Schematic diagram of Wenner Array.

To minimise ground field, capacitive and electrochemical effects, the system used a square wave oscillating voltage, first passing the current in one direction, then reversing polarity to pass the current in the opposite direction. A frequency of 20Hz was used, as suggested by US Geophysical Surveys (Environmental Geophysics, 2011), with a processor voltage of 3.3v (regulated).

Given the range of observed soil resistance values shown in Table 1, the reference resistor value of 330 Ohms was chosen to maximise measurement resolution. This gave an absolute current limit of 10mA, well within the PIC limit of 25mA, but in effect, typical observed currents were of the order of 2 to 3mA.

The system used 4 cycles, each of 50ms, taking voltage and current readings 24ms into each half cycle, and averaging the results. Readings taken earlier in the cycle demonstrated differing capacitive effects within different types of soil, but these were typically found to be minimised towards the end of the 25ms half cycles.

The temperature readings were made using probe heads consisting of two, 1N4148 diodes in series, forward biased by a known, fixed, small current (nominally 8.8uA), provided by the PIC CTMU constant current source. The forward voltage developed by the diodes under these circumstances is linearly proportional to the temperature (Yedamale, 2009) but with a negative slope co-efficient. These were buried in the soil at a depth of approximately 5cm and readings taken every 15 to 21 minutes. Resolution was in the region of 0.2´C.

To reduce random noise, each stated reading is the average of 64 readings taken approximately 20uS apart. A 1K Ohm resistor was used in series at the PIC end to limit the current in the event of a short circuit in the probe or its wiring.

The system was powered from three 1.5V alkaline AA cells. Whilst the PIC is in sleep mode, current consumption (including regulator leakage) is less than 100uA. Current consumption peaks at around 4mA for around 1 second every 15 minutes, thus, based on a nominal capacity of 1200mAh, the power source can be sustained in excess of a year provided the unit is not subjected to wide extremes of temperature which would reduce battery life. The MCP1700-330 regulator was chosen for low drop out and low quiescent current reasons.

All the electronics and batteries were housed in a small IP56 rated ABS box, with an LED protruding from the top, connected to the PIC via a 1K resistor. This allowed both status indication and monitoring of the external brightness level, providing a convenient day/night reference channel.

A typical PIC18F family member has 64Kbytes of flash memory, with the program code taking less than 2K, this leaves more than adequate storage space for over 7000 readings to be logged. At 3 minute intervals, this allowed readings to be logged for experiments in excess of 14 days. For longer term field use, with readings taken every 20 minutes, these units could be deployed in trials of up to 3 months. For larger data storage capacity options see Section 4.

Total component cost of each unit was less than 10 Euros including probes, casing and batteries, making the units ideal for large scale deployment both for research and practical agronomic use. The choice of materials and components was made to improve the likelihood of availability in third world countries, the main PCB being pre-manufactured, whilst final assembly would be performed locally.

Three experimental trials were performed. The first over a four day period in a clay based soil, during which several bouts of heavy rainfall occurred.

For the second trial the unit was repositioned into a recently prepared almond orchard, again in a

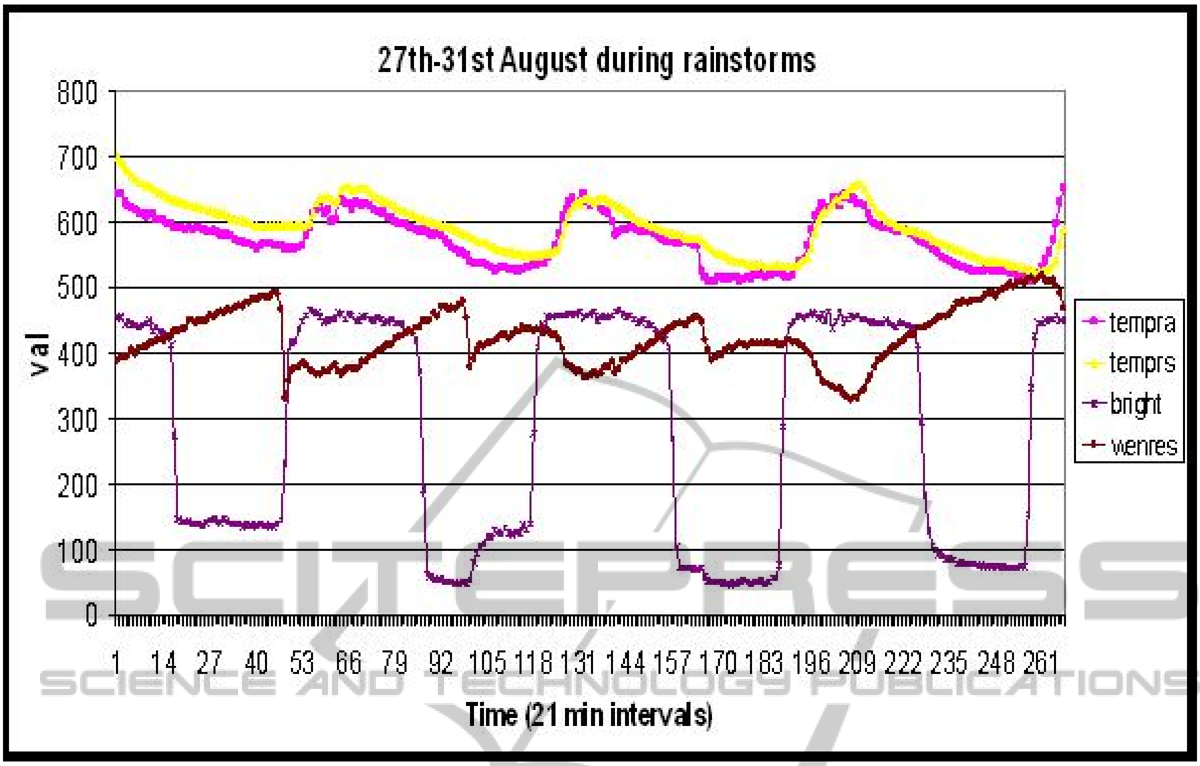

Figure 2: First trial of the system during rainstorms.

clay based soil. The unit was left to record data for 6 days.

The third trial was conducted with a second unit installed at a Research Vineyard facility, where individual vines are placed in separate pots in a mulch based soil. These pots were raised off the ground and attached to a sophisticated crop management and irrigation system consisting of lysimeters and automatic soil drainage systems. The pots were shielded from direct rainfall. This trial was run for 4 days.

3 RESULTS

Table 1 shows the calculated resistance values for typical samples of clay, mulch and sand media, both after drying, and after typical horticultural irrigation. These values were calculated from the measured values of current and voltage observed by the sensor.

Also given are their normalised resistivity equivalents. These values were found to be consistent with established values typical of these soil types (Dobrin, 1988).

Figure 2 shows the temperature of the air (Pink trace), the temperature of the soil (Yellow), the brightness level (Maroon) and the measured Wenner resistance (Brown) of the soil.

The 4 daily cycles are immediately apparent in the brightness plot, showing that the system was activated early in the afternoon and was deactivated mid morning.

It is assumed that the irregularities seen at the troughs of the brightness plot correspond to differing cloud conditions and moonlight.

The temperature plots also follow a daily cycle showing warming in the morning and steady cooling from mid afternoon until the following morning.

The temperature of the soil can be clearly seen to lag the temperature of the air as would be expected.

The Wenner resistance plot shows an initial period of drying (indicated by increasing resistance), which stops abruptly at dawn as a particularly heavy shower of rain soaked the ground at this time. This plot then levels out as the bulk of the moisture sinks in the soil, passing the length of the rod and then the plot rises again as moisture levels close to the surface fall and thus resistance increases.

A second period of heavy rainfall then occurs around midnight of the second night, followed by a lighter, but more persistent shower mid morning of the next day and again during the following night, where a sudden drop in brightness level, Wenner

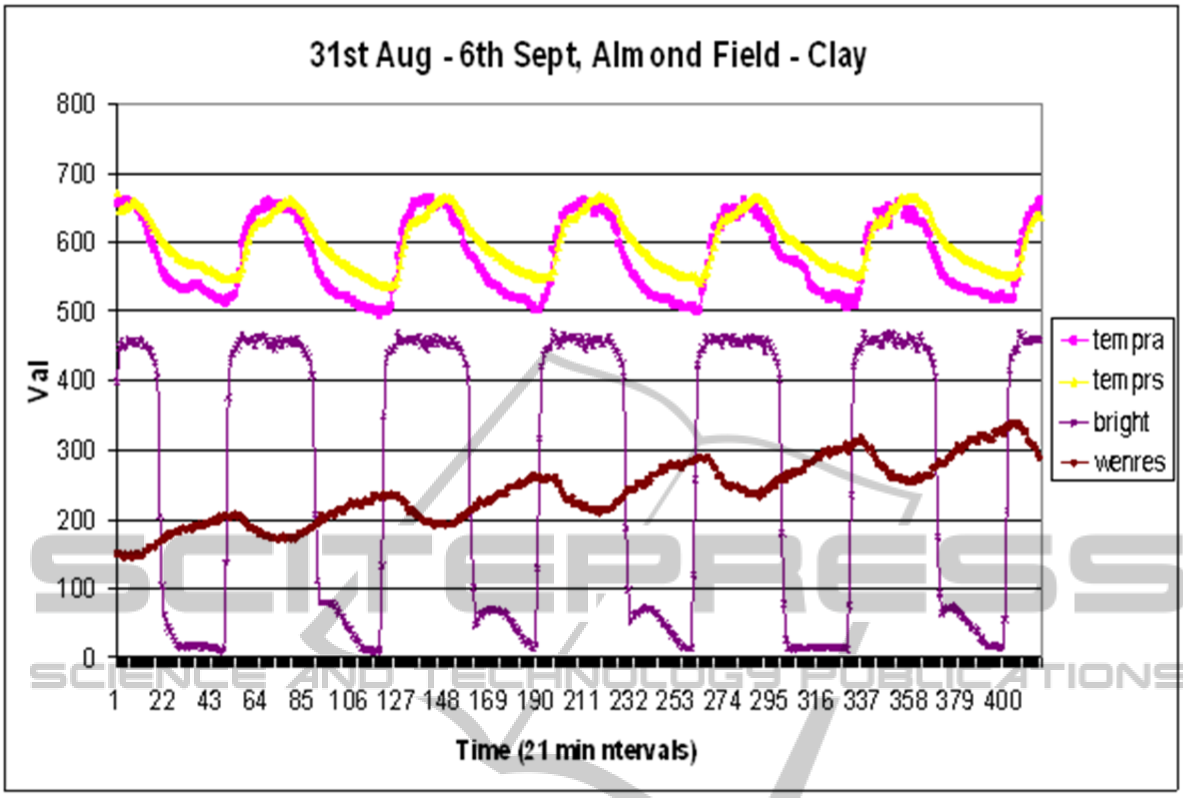

Figure 3: Six day trial in Almond Field with no rainfall.

resistance and air temperature is recorded. This is possibly due to sudden reduction in cloud cover giving reduced reflected light pollution and greater air cooling.

The final full day experienced further long lasting but light rainfall, after which no further rainfall was observed until the following morning just before the unit was retrieved.

Figure 3 shows the results from the second trial, after the unit was moved to be situated in a clay based almond orchard fitted with a slow release dripper pipe irrigation system.

Once again, the daily brightness cycles are clearly apparent, together with the daily heating and cooling cycles of the air and the soil. Again the temperature lag is seen between air and soil.

Although the moistening effect of the daytime slow release irrigation is clearly visible, commencing in the morning and stopping mid afternoon, this irrigation is unable to compete with the overall loss of moisture seen in the orchard. This loss is due to natural drainage, evaporation from the soil surface and moisture taken in by the almond trees themselves. Given the high levels of rainfall observed in the preceding week however, this is to be expected and moisture levels remained at levels required to sustain healthy growth of the trees.

This trend is clearly visible by the steady upward inclination of the resistance plot.

The results for the final trial are shown in Figure 4. Unlike the other trials, this was conducted in a highly managed research vineyard as described in section 2. For clarity purposes, the Brightness plot has been artificially raised in the figure.

Shading of the LED brightness sensor by the leaves of the vine as the sun passed overhead are clearly visible and form a daily repeating pattern. Once again the daily temperature cycles are apparent.

The vines are clearly irrigated four times a day at 2 hour intervals. Irrigation intensity is obviously high for a short period, and the system is clearly carefully managed as despite the long overnight periods of drainage, the vine pot returns to preset moisture levels each day during the irrigation.

4 FURTHER DISCUSSION

The probes used in this implementation were low

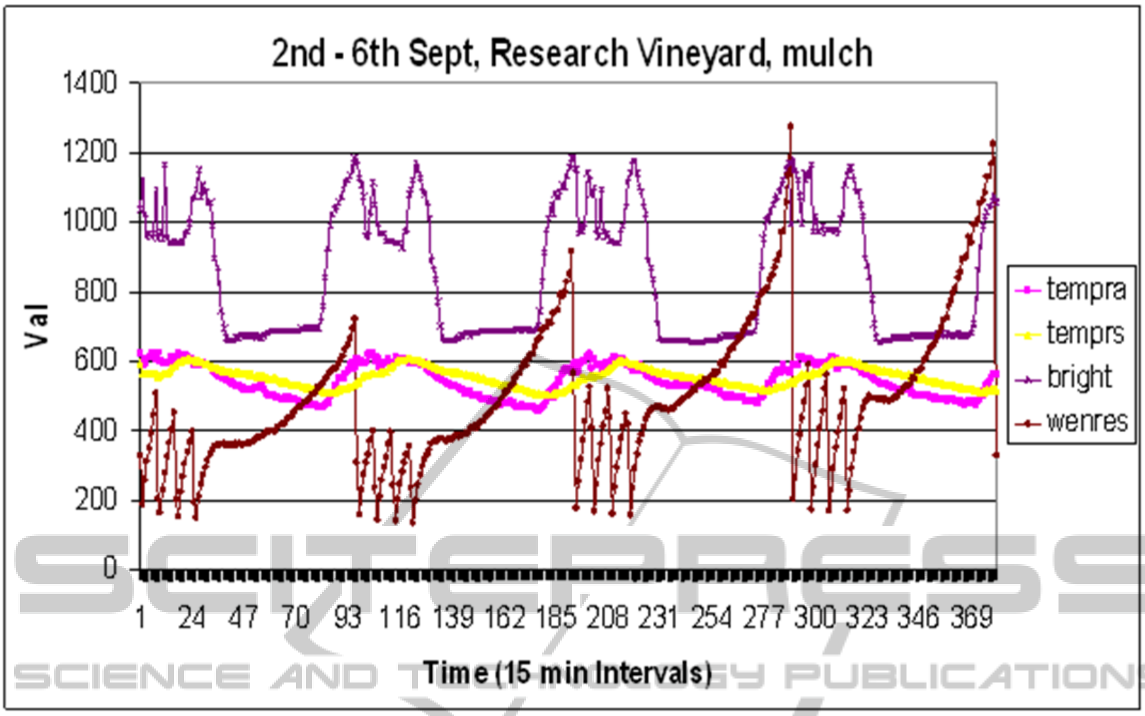

Figure 4: Four day trial in Research Vineyard.

cost culinary grade steel. Over time, and in a variety of soil types and conditions, these can be expected to corrode. This will of course have some impact on the soil however resistance measurement impact is minimised by the nature of the Wenner Array. In theory this eliminates effects caused by changes in probe to soil resistance, however if current levels become too low, insufficient resolution within the PIC Analogue to Digital Converter will present accuracy problems.

The resistivity of the soil is also known to be affected by the temperature of the soil. For simple, relative moisture logging, this is not an important consideration, however if more accurate or absolute soil moisture measurement is required, the soil temperature reading can be used to compensate for this.

The primary design objective for this system was a minimal cost solution making large scale deployment in third world countries practical. Where labour costs are low, it can be more cost effective to use manpower to deploy and retrieve such devices, than to increase equipment costs by adding sophisticated communications capabilities.

However where the socio-economic conditions permit, the system is extendable by the addition of low cost (circa 5 Euros) integrated RF transceivers such as the Hope Alpha TRX module operating in either 433MHz or 868MHz frequency ranges (dependent on local legislation). Initial trials with these modules suggest an effective line of sight range of around 100m.

These RF units significantly increase current consumption (using around 25mA during transmission) but the use of burst transmissions keeps the average consumption to a minimum.

The local RF transmissions are collected at a central point (See Figure 5), and collated. Were local conditions and legislation permit, these can then be passed on via GSM communications using low cost cell phone technology such as the OLIMEX PIC-GSM module (costing less than 100 Euros), which, shared across 10 to 20 sensors, remains a low cost solution. Other options include ANT and ANT+ low power radio technologies, where units are closely co-located.

The fact that each unit logs its own readings allows for tolerance of failure in the communications network. Individual results, or many thousands of results can be re-sent on demand, once reliable communications have been re-established.

Alternatively, where monitoring of individual plants and/or tress is required, the system can be connected in a wired multi-drop bus arrangement (See Figure 6), with the communications cable following the line of the irrigation pipes to reduce

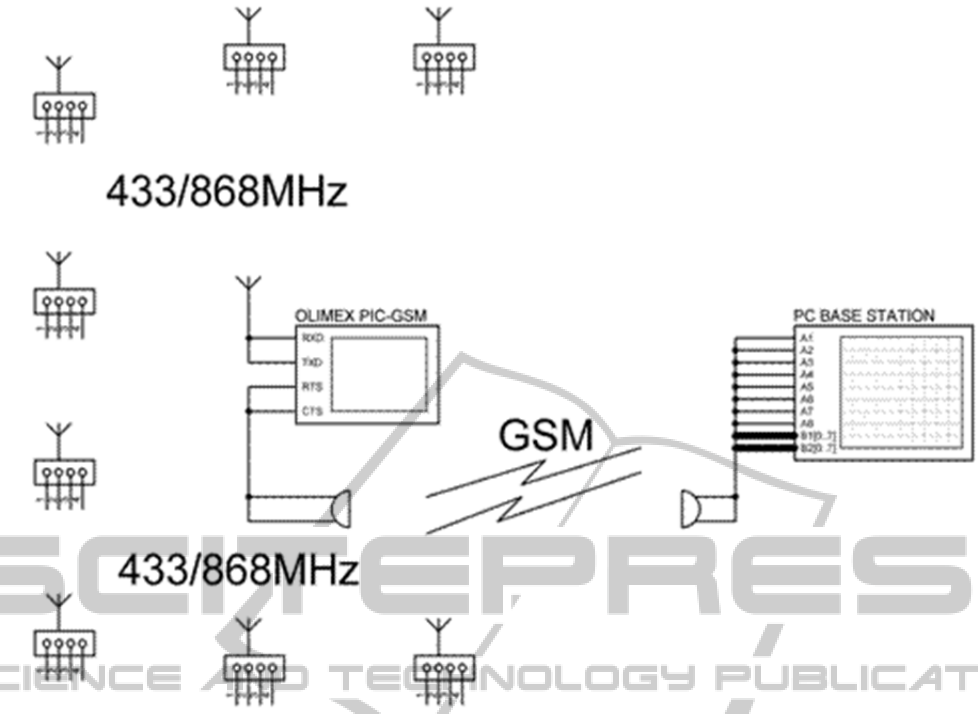

Figure 5: Local RF sensor network with GSM communications to remote management centre.

the risk of damage. In this configuration, the unit can be resin encased and powered by separate battery packs distributed along the cable (see Figure 6).

This would provide further unit cost reduction as the IP56 box and battery holder represent 30% of the unit component cost, and the wiring through the moisture resistant ports of the box represent a significant manufacturing labour cost. The chosen PIC supports both UART and MSSP communications ports to facilitate this.

Once this basic platform is established, the intention is to provide a range of expansion options including lateral facing Infra-Red LEDs for fire detection, ultra-sonic water flow detection in irrigation pipes and multi-depth temperature and moisture arrays for moisture profile analysis.

Further uses of the system include tracking water movement / drainage on slopes and across areas where changing subsoil topography leads to irregular irrigation, absorption, runoff and drainage.

The system can also be interfaced to traditional irrigation systems, turning a simple timer based on/off irrigation system into a more water efficient system only irrigating when necessary, and reducing the risk of over-watering during periods of heavy rainfall.

Where more detailed measurements are required over longer timescales, each unit is expandable via SPI bus using the SPANSION 32Mbit CMOS Flash Memory chip (costing less than 1 Euro).

For commercial reasons, certain aspects of implementation, accuracy, sensitivity and calibration have had to be omitted from this publication.

5 CONCLUSIONS

This paper has presented results from initial field trials of a highly cost efficient soil moisture measurement system.

The system has been demonstrated to provide useful data in differing soil types.

Local data-logging provides resilience against communications network failures.

The system is also capable of low cost expansion to provide a range of additional data and services.

The system can also be used for a range of topographical analysis applications.

The system can be used to enhance traditional irrigation systems providing a more efficient use of scarce water resources.

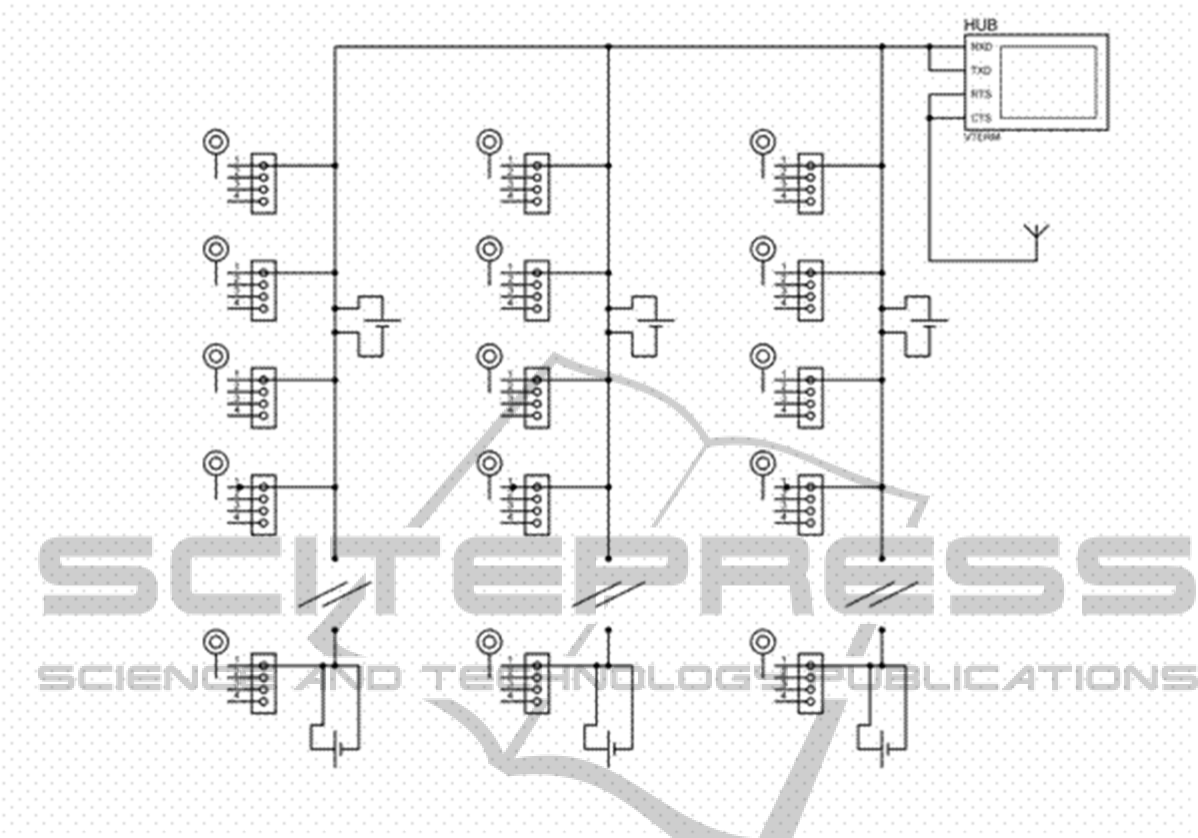

Figure 6: Multi-drop bus configuration for individual plant monitoring.

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