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PANSY: A Portable Autonomous Irrigation System

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SUMMARY

Generally, crop in a greenhouse environment is extremely sensitive and responds negatively to even the slightest of climatic changes. As such, an automated system of irrigation is ideal. Deployed effectively, intelligent wireless sensors can efficiently control the environment and irrigate as necessary. Smart wireless sensors provide an avenue to dynamically control the environment with little or no human intervention. In this paper, we introduce a wireless networked sensor system, PANSY, which intends to make crop irrigation efficient and labor un-intensive. PANSY effectively monitors the temperature, humidity, and soil moisture of a certain crop and its surroundings. If desired, sensors can monitor every plant in the greenhouse far more rapidly than traditional techniques, namely, human labor. In addition, each sensor can be calibrated to the specifications of a certain crop making the system universally useful. Such a system promotes highly accurate inventories, simple species location, and the elimination of pot bar codes. More specifically, PANSY provides a portable autonomous irrigation system. Experimental results confirm both PANSY's potential and current ability to produce crops equivalent to those produced by a professional grower. In fact, the plants grown by PANSY consistently out-performed traditional irrigation methods. PANSY is most beneficial when there is a shortage of water or treatment of chemicals as the PANSY system relies upon a more efficient model than the traditional professional and decreases chemical use.

Key words: Portable autonomous irrigation system, Wireless sensor network, Smart wireless sensors, Green house, Monitoring system, Automated system.

1. INTRODUCTION

Agricultural systems are susceptible to dynamic environmental changes which need to be carefully monitored to insure the longevity and health of the crop. In general, crops require sunlight, nutrient rich soil and water for survival, all of which can be controlled within a greenhouse. However, fine-grain control of environmental factors in a modern greenhouse requires both physical labor and expensive monitoring systems. For example, a grower in a medium size greenhouse (about 5 acres) can spend between 4-10 hours irrigating crops every day, even with the assistance from an automated system. In current greenhouse applications human interaction is necessary to setup the irrigation system and may be required to initiate each irrigation cycle. The aim of this paper is to present an irrigation system which reduces human interaction significantly. Intelligent sensors can be programmed to monitor the environment and irrigate crops when needed. This automated irrigation is ideal for a greenhouse application. By introducing smart wireless sensors into a greenhouse environment, the growth of the plants can be controlled with very little human intervention. This paper presents PANSY: a portable autonomous irrigation system that has the ability to monitor a minimal set of environmental elements and irrigate a group of plants depending on environmental conditions. PANSY has two main benefits: it reduces the amount of water given to the crop and reduces, if not eliminates, labor costs required to irrigate crops, thereby reducing a large cost factor in the production of most plants (Bartok 1974, Giacomelli 1994).

Traditional timer based irrigation systems have a set period in which the irrigation occurs. PANSY has the ability to adapt irrigation cycles and their durations relative to environmental conditions within the greenhouse. This adaptation allows the system to more accurately control crop irrigation eliminating under- and over-watering. This method of continuously limiting the quantity of water available to the plant is very effective under climatic conditions that foster slow drying. Watering in this manner effectively regulates growth rates but requires intensive grower management in modern systems (Heins 1994). PANSY can eliminate this expense since it manages the irrigation autonomously.

A drawback of an automated system is the possibility of failure due to power loss or an external catastrophe. Historical data on damage to crops and livestock from the files of a major Dutch insurance company shows that considerable damage to production in agriculture is caused by failures in control equipment (Gieling and Meurs 1984). PANSY reduces this possibility by using redundant sampling devices that can be replaced easily and quickly. On the other hand, a failure of a water controlling device, if gone undetected for an extended period of time, could cause total crop loss within the region it controls.

PANSY has been tested in real world conditions and has shown promising results while only monitoring a minimal amount of environmental factors. When compared to traditional human irrigation, PANSY produced equivalent plants while saving water. As we will show, PANSY can produce high quality plants, however, it is a preliminary design. Addition of other sensors to PANSY could extend its control to the entire climate control system within a greenhouse. Thus, vents, powered walls, fans, heaters, etc. could be controlled by a single fault resistant system.

The rest of this paper is divided into five sections. Background on wireless sensor networks (WSNs) is given in Section 2. The architecture and design of PANSY is described in Section 3. Section 4 talks about the experiment that PANSY participated in followed by the results of the experiment in Section 5. Finally, Section 6 concludes the paper and suggests some future work.

2. BACKGROUND

By exploiting recent advances in MEMS micro-sensors, wireless networking, and embedded systems, wireless sensor networks (WSNs) expand the ability of human to perceive and react to the physical world (Akyildiz *et al.* 2002). Sensor networks are integral to a number of emerging applications, including environmental monitoring (Polastre 2002), Estrin *et al.* 2002, Abdelzaher *et al.* 2003), smart structures (Pescovitz 2001), critical infrastructure protection (He *et al.* 2004), and battlefield awareness (Li *et al.* 2002). Through the use of WSNs fine grained measurements can be gathered quickly and accurately as never before. Extending this work into the field of greenhouse automation is quite natural. Sensing devices used in WSNs are specifically designed to minimize their environmental impact by limiting their physical size while supporting on-device computation and wireless communication between devices. In other words, a device can be attached to a pot within the greenhouse and when the pot is relocated its movement can be detected and system adjustments can be made automatically. In the case of PANSY the irrigation cycles for a region of a greenhouse can be updated as plants are moved within, or introduced to, the greenhouse. There is no longer a need to reprogram the system every time the plant configuration within a greenhouse changes. Furthermore, PANSY has the ability to initially setup irrigation when plants are introduced into the greenhouse.

Programmable WSN devices started to appear in the mid 90s. Research into their design and application was, and is currently, driven by major research and governmental institutions, leading to the design and manufacture of multiple devices of varying sizes and capabilities. The most prevalent of these being the family of Berkeley motes developed at the University of California at Berkeley. A commonly used member of this family, that was used in this study, is the Mica2 mote (Crossbrow Inc. 2003). A Mica2 is comprised of a 8-bit 8 Mhz micro-controller capable of extended operation, non-volitile storage with a capacity of 100,000 measurements, and a wireless transceiver capable of transmitting hundreds of feet. The software used to program the PANSY systems is a freely available operating system called TinyOS (Hill 2000), which is implemented in a programming language named nesC (Gay *et al.* 2003). TinyOS and nesC were developed for WSN applications and have been designed to be accessible to a wide range of users. Using TinyOS and its nesC realization, developers and researchers have implemented a vast array of applications as mentioned previously.

3. PANSY: ARCHITECTURE AND DESIGN

PANSY is a WSN system that is integrated within a greenhouse environment. PANSY monitors dynamic changes in the environment and placement of plants automatically. The autonomy of PANSY reduces labor needed to setup and adjust the irrigation and environmental control systems. PANSY can be extended by integrating more environmental controls into the system. This integration could allow for a greenhouse which is almost completely free of human contact. However, the purpose of this paper is to describe how PANSY can be used as an irrigation system. Fig. 1 shows the inside of a range style greenhouse. The black dots represent where a wireless sampling device or mote could be placed to monitor the crops. As we can see from Fig. 1 the greenhouse is divided into sections. Each section has its own irrigation control and the motes communicate with a watering controller via the wireless network of motes. If the plants are relocated within the greenhouse, the sampling motes will reconfigure themselves to communicate with the proper watering mote. They can retrieve this information by examining other motes within their vicinity. As described so far, PANSY has several parts that are interlinked via a wireless network. Next we describe each part of the system.

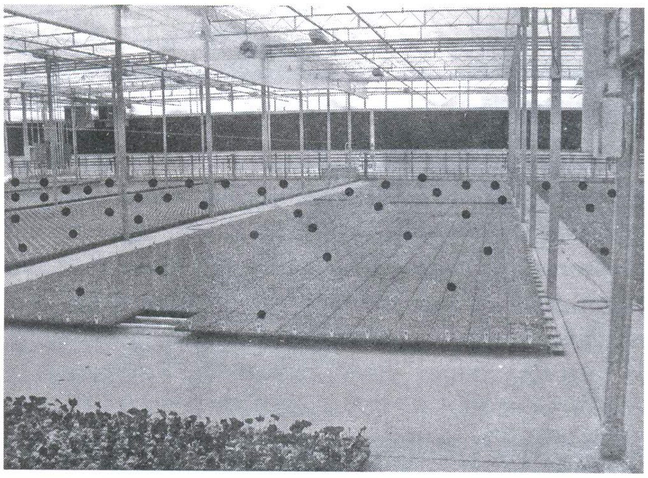


Fig. 1. Example deployment of PANSY

3.1 Motes

PANSY is built with Mica2 motes running TinyOS. The motes handle all of the computation and signal processing. There is no external hardware that is used except for a moisture sensor that is attached to the sampling motes and a simple circuit that is attached to the watering motes both via a data acquisition board (MDA300CA) (Rahimi 2003). The design of the system calls for at least two motes. Fig. 2 shows the implementation of a three mote system. The sampler mote is responsible for periodically monitoring its environment while the watering mote controls all irrigation cycles. A repeater mote can be used, but is not required. The sampler mote is responsible for periodically sampling the moisture in the soil. If the soil moisture is found to be below an acceptable threshold the sampler mote then samples the temperature and humidity of the air around its location. These samples are used to adjust the duration of the next irrigation cycle thereby giving the crop an optimal amount of water. If the current soil moisture is acceptable no watering is necessary and an irrigation cycle is not scheduled.

Each sampler mote is piggy backed with a data acquisition board (MDA300CA) and contains five modules that connect to a central controller. Each module performs a specific set of tasks for the controller. The SamplerC module handles all the communication between the MDA300CA and the controller. It provides the methods necessary for sampling the temperature, humidity and soil moisture via an analog channel. The LedsC module controls the motes onboard LEDs which

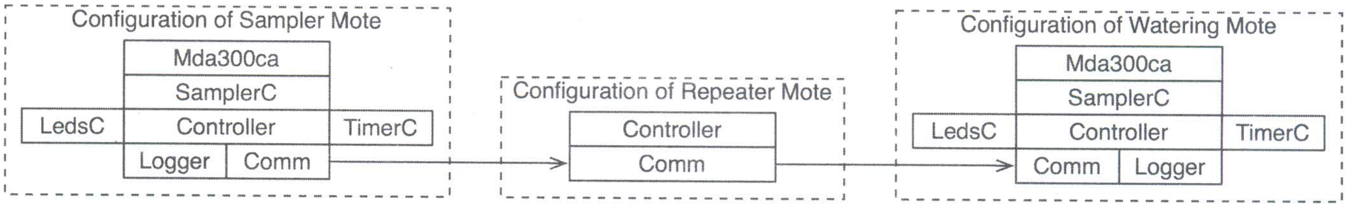


Fig. 2. Three Mote System Design

are used to output external visual signals to the grower. The TimerC module gives the controller access to a timer which fires periodically signaling the start of another sampling cycle. The logger is used to write data received from the SamplerC module to the mote's onboard EEPROM for later retrieval and the Comm handles all radio communication between motes. Each mote allows for messages in the network to be routed through it so that they can reach the watering mote, which controls irrigation cycles. The sampler motes send a packet to the watering mote when irrigation is necessary. Also, included in the sent packet is the duration of the irrigation cycle which is used by the watering mote to set a timer. Irrigation begins when the timer is started and ends after the timer fires an interrupt signaling the specified time has elapsed. If the watering mote does not receive any message to irrigate, it stays idle. Each watering mote uses the same set of modules employed by the sampler motes with a few main differences. The SamplerC module is used to control the water valve and as described above the TimerC module is used to control the irrigation duration. Fig. 2 also shows a repeater mote. This mote is optional and acts as a simple message repeater. It is only necessary when the distance between a sampler mote and a watering mote is too great and message can not be routed through intermediate sampler motes.

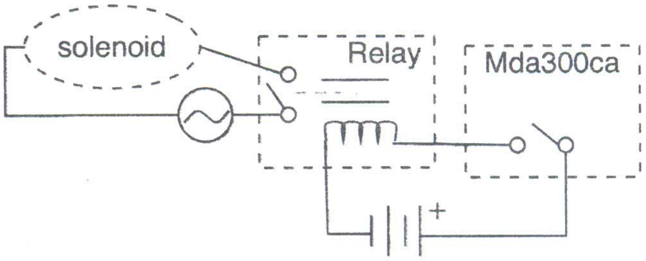
3.2 Soil Moisture Sensor

The soil moisture is sampled periodically by the sampler mote through an analog channel onboard the MDA300CA. The moisture sensor that is employed by PANSY is the Echo EC-10 (D.D. Inc. 2007). The EC-10 measures the dielectric constant which can be normalized and converted to a volumetric water constant. This can then be used to determine if the soil contain a sufficient amount of water. When deploying the EC-10 the sensor should be placed so that it is level and completely underground. This allows sampling to be more precise because water draining through the soil does not affect the readings and it also insures that the contact with the atmosphere does not effect readings. Since the EC-10 is an analog device, normalization of the analog output is required. The MDA300CA offers three voltages for analog execution. In PANSY when sampling occurs the MDA300CA places 5 volts on the execution line of the EC-10. That causes the output of the EC-10 to produce a voltage which is converted to an unsigned 16-bit integer by the MDA300CA. This integer has to be normalized based on the execution voltage level and then is used to compute the ratio of the volumetric water constant. A training phase is required before this ratio can be calculated because for any well-defined soil there is a unique relationship between water potential and water content (Gielig 1994).

3.3 Circuit

The MDA300CA has components that enable it to obtain samples from many different types of devices. It also has two relays that can be used as actuators for external events. Fig. 3 shows a schematic of the circuit used in PANSY to control irrigation.

Fig. 3. Schematic of Circuit



The circuit shown in Fig.3 is made up of five separate entities and two sub circuits. Each of the entities plays a specific role within the circuit. We continue by describing the sub-circuit containing the solenoid followed by the sub-circuit that causes irrigation to occur. When completed the left sub-circuit opens the solenoid. It contains a power source, a solenoid, and a switch that is contained inside a standard relay. When the switch is closed it completes the circuit and causes the solenoid to open. This circuit can be modified to control any electrical device. The only limitation on it, is the power source that is used and the voltage rating of the relay. The working model used by PANSY can handle up to 120 volts of alternating current or 24 volts of direct current. The right sub-circuit, attached to the MDA300CA, controls the left sub-circuit. This circuit contains a power source, an electromagnet contained within a relay, and a relay contained within the MDA300CA. When the relay within the MDA300CA is closed it completes the circuit which causes the electromagnet to produce a small magnetic field that attracts the switch within the other sub-circuit. This attraction closes the left sub-circuit causing the solenoid to open and irrigate the crop. Opening the relay within the MDA300CA stops irrigation. The circuit described in Fig. 3 is simple, scalable and effective. The only limiting factor of the circuit is the amount of power that can move through the MDA300CA. This circuit can be adopted to control most any device with little modification. The entire circuit was constructed for less than forty dollars excluding the price of the MDA300CA from parts obtained at a local electronics store.

4. EXPERIMENT SETUP

In late August to late October 2004 a single Mica2 mote, MDA300CA and EC-10 sensor were integrated into an irrigation system at Esman Greenhouse Inc. in Comstock, Michigan. Fig. 4 shows the physical setup of the system. During the first month of operation, the system was tested with cabbage, kale, and stock plants on a dripper system. This initial testing phase was needed to insure that the systems were working correctly and determine the lifetime of a Mica2 mote when powered by two AA batteries. Once it was concluded that the system was working correctly, six 5 inch pots containing 10 PANSY seedlings each were introduced into the greenhouse containing PANSY. Pansies of varying colors were planted in pairs of pots, one pot from each pair was used as a control while the other was incorporated into the experimental group. The three pots in the experimental group were irrigated by the PANSY system while the other three in the control group were set aside and irrigated by a grower who periodically checked and watered them when appropriate–time permitting. During the experiment the amount of water given to each group and the maximum height of each pot was recorded every few days. These results are discussed in Section 5 along with a visual inspection of the produced crop. The climate within the greenhouse while the experiment was running was controlled by an external climate control system that was preset to give the plants a uniform and stable environment. Therefore, no advantage was given to either the control or the experimental group.

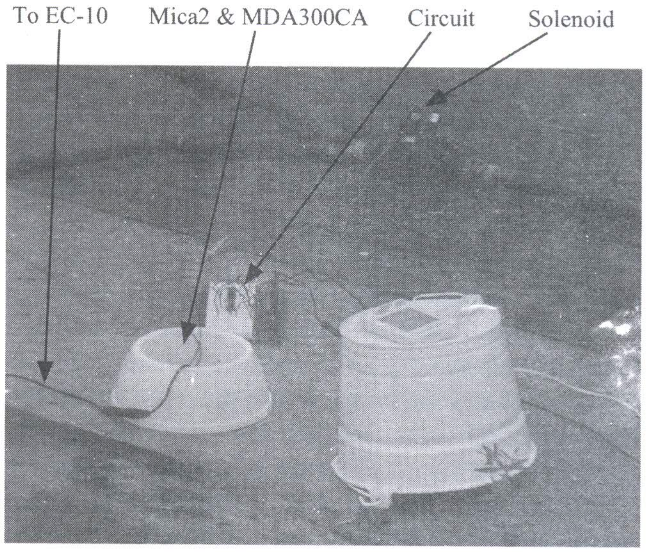


Fig. 4. Physical Setup

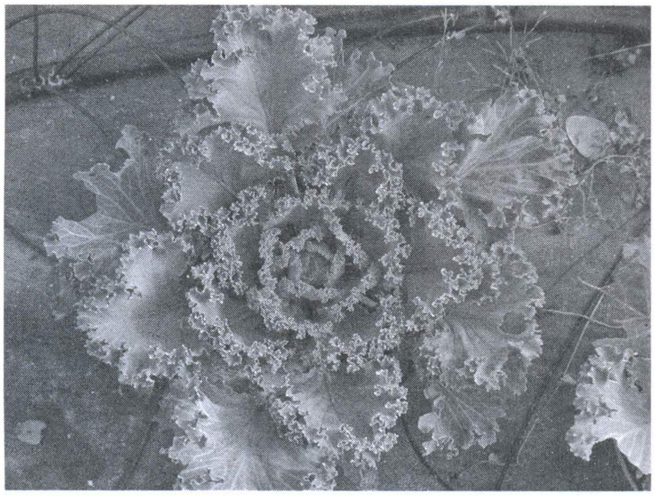
5. EXPERIMENTAL RESULTS

During PANSY's initial testing phase 100 ten-inch stock pots containing various ground cover plants were maintained and cabbage and kale seedlings were grown. Fig. 5(a) shows the state of the stock plants at the beginning of the experiment. Fig. 5(b) shows the final state of the stock plants after having their irrigation solely controlled by the PANSY system for two months. Note that during the two month experiment the stock plants grew enough to require a trimming, and the remains can be seen on the greenhouse floor in Fig. 5(b). Fig. 6 shows the final results of a kale plant grown by PANSY during the initial testing phase. Fig. 6(a) shows the dense foliage

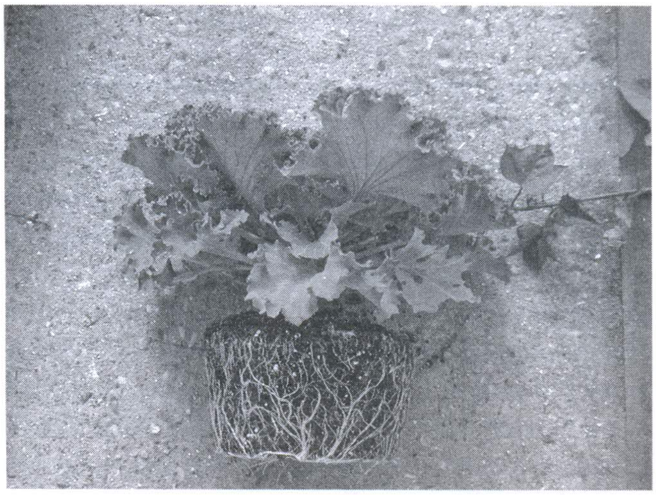
(a) Stock plants before experiment

(b) Stock plants after two months and single trimming

Fig. 5. Stock crops sustained by PANSY



(a) Grown by PANSY from seedling

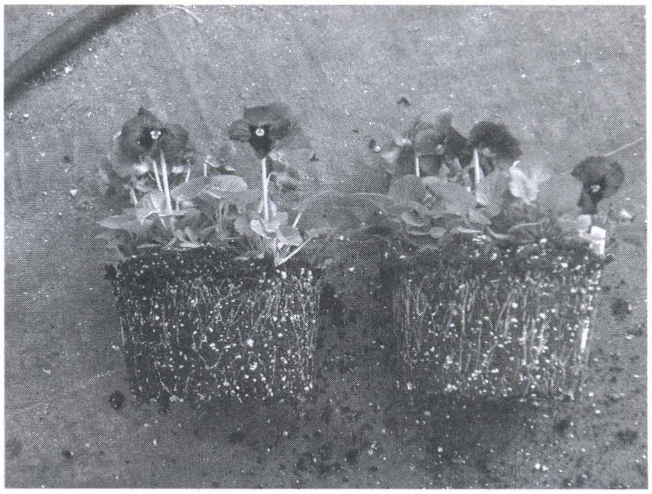


(b) Notice well developed root structure

Fig. 6. Initial Tests of PANSY

of the kale plant and Fig. 6(b) shows a well established root structure which reached the bottom of the pot and proceeded to grow back up. Both of these results give evidence of the success and possible usefulness of PANSY. After the completion of the initial tests, pansies seedlings were introduce into the greenhouse where PANSY was located. We selected pansies because they were in season and their sale would determine the final outcome of the experiment. Fig. 7 shows the final outcome of four five inch pots containing ten pansies each. In both Fig.7(a) and 7(b) there is no noticeable difference in the appearance of the plants except for the color.

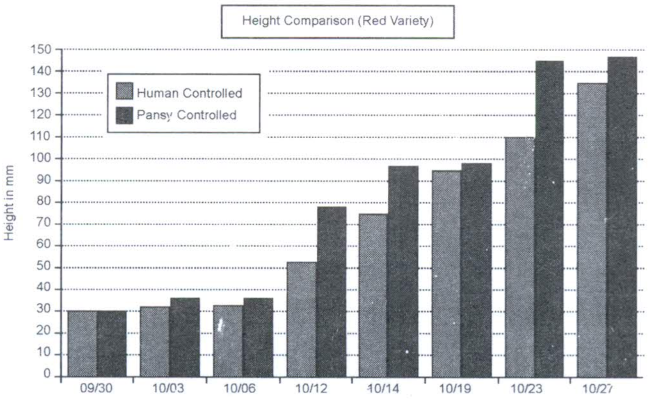
(a) Foliage comparison



(b) Root structure comparison

Fig. 7. Comparison of Pansies Grown from Seedlings by PANSY (left) and Human (right)

Fig. 7(a) shows mature foliage in both pots however one was grown by a human and the other was grown by PANSY. Like Fig. 7(a), Fig. 7(b) again shows mature plants, however, the root structure is displayed. Both pots exhibit root structures which extent to the bottom of the pot and form a solid root ball. It is difficult to differentiate between the plants and select the one grown by PANSY. The plants on the left in both the Fig. 7(a) and 7(b) were grown by PANSY. In addition to the visual inspection of the crop, the maximum height of each plant was recorded as well as the amount of water each group received. Fig. 8 shows the maximum height in millimeters of pansies from the different groups in our experiment over the course of one month. Fig. 8(a) compares the heights of



(a) Height of red pansies

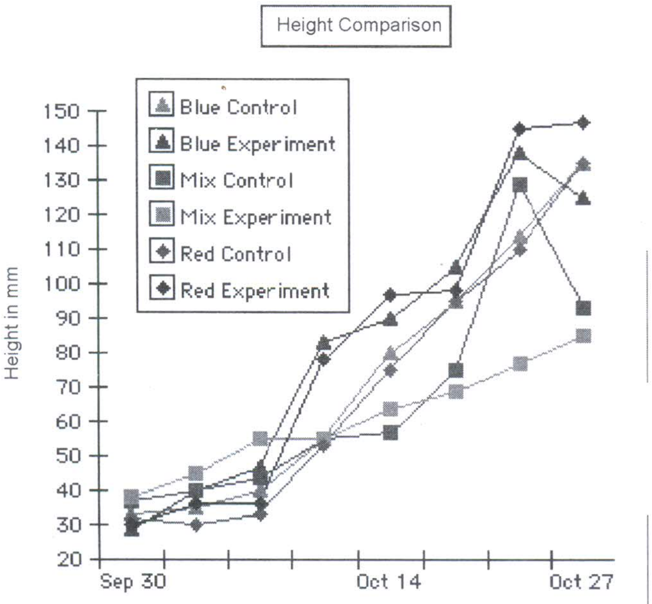


Fig. 8. Growth of pansies

red pansies grown by a human to those grown by PANSY.

As seen in Fig. 8(a), there is very little difference among the two groups. Fig. 8(b) shows that all the three varieties of pansies (namely, red, blue and mixed) grew at similar rates where "Control" refers to the varieties grown by a professional grower and "Experiment" refers to the ones grown by PANSY. The declines in height seen near the end of the experiment are due to plants whose blooms have been spent and the second batch of blooms have not yet matured. The major difference between the traditional grower initiated system of irrigation and PANSY is evident in Fig.9. About 1/3 less water was given to the plants controlled by the PANSY system. This reduction in water consumption will not only reduce water usage and treatment costs, but it will also reduce the amount of maintenance needed to maintain the irrigation system. Obviously, the less an irrigation system is used less degradation occurs resulting in a reduction in the overall operational cost of the greenhouse. From the results shown in Fig. 8, it is evident that the plants grown by PANSY grew equally as well as the plants in the human-controlled group. This result is encouraging because more expert knowledge can be integrated into PANSY allowing for better performance and higher quality crops. From these results it is obvious that PANSY is a feasible alternative to traditional irrigation systems.

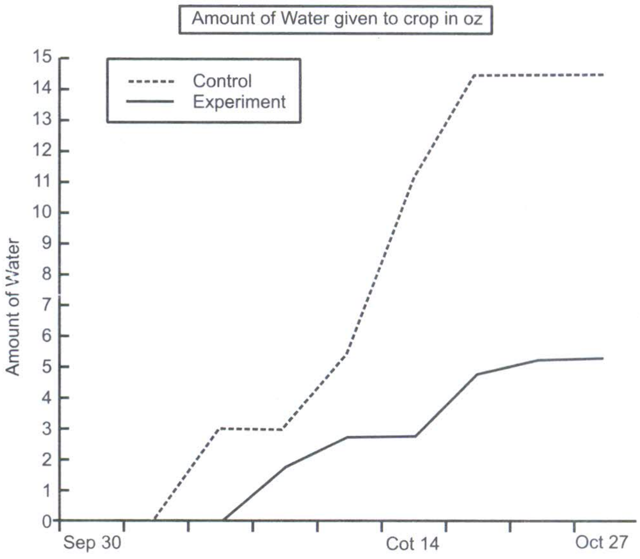


Fig. 9. Total amount of water supplied to each group

PANSY allows for the growers time to be spent on other matters rather than irrigation. This time savings is one of the major advantage of PANSY. By reducing the amount of labor needed to irrigate crops down to almost zero, the total cost of producing crops is also reduced. Thereby increasing the greenhouse's profit.

6. CONCLUSIONS AND FUTURE WORK

PANSY provides a portable autonomous irrigation system through the use of intelligent wireless sensors, which are capable of monitoring and responding to environmental changes frequently and without human intervention. This preliminary implementation of PANSY has shown promising growth results, comparable to traditional methods, as well as substantially decreasing water usage and labor. PANSY can also be extended to monitor and control the climate (vents, heater, fans, etc.) of a greenhouse by incorporating additional sensors and actuators. Through the use of systems like PANSY labor and material costs for operating a greenhouse can be reduced resulting in an overall cost reduction and increased profits while producing equivalent crops.

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