

Automated Container-Handling System for Container Production Nurseries

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I. ABSTRACT

Production of nursery crops in the US is accomplished in container- and field-growing conditions, with propagation and seedling-rearing carried out in greenhouses. Container-grown crops represent 60% of the US market and represent a highly labor-intensive and thus costly segment of ornamental crop production. The USDA, NASA and the ANLA have collaborated to develop an automated in-field container-handling system for reducing dependence on foreign labor while also increasing productivity. A first-generation system was developed at CMU, capable of automatically lifting and conveying plants from the ground (in a variety of regular patterns) onto trailers, and vice-versa. The system is capable of handling a vast array of container-designs from different manufacturers, and spans the size-range from #1 to #5 (approximate equivalence to gallons). The system is designed to handle 45,000 containers per 8-hour day with one to two operators. Testing currently underway indicates that the system approach is valid, with the next incarnation requiring reduction in size and weight, as well as reduction in manufacturing costs; a new design is currently underway, with as-built designs and experimental results for the first prototype's performance presented herein.

II. INDUSTRY OVERVIEW

US ornamental horticulture is a rapidly growing, \$11 billion dollar a year industry (about 10% of the gross agricultural output of the US alone), tied to a dwindling migrant work force, working in outdoor conditions in very large acreage areas (see Figure 1).

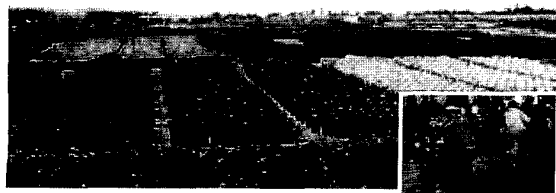


Figure 1 : Typical container nursery view & labor task

Unskilled labor is becoming more costly and harder to find, while it is still needed to move potted plants - this represents a manual handling task of at least 450 million units per year, each handled 3 to 4 times a year. The nursery industry must address this problem if it is to survive and continue to flourish in the next millennium.

Nursery production automation is a growing field worldwide. At the highest level there are three main areas, namely greenhouse operations, container yards and field nurseries. Within these groupings, there are several areas that lend themselves to automation (see Table 1):

AREA	AUTOMATION-FRIENDLY
Greenhouse	<i>Seed/Propagate, Pick/Ship, Gather, Transplant/Set</i>
Container Yard	<i>Field Movement, Upshifting, Order-Picking, Shipping</i>
Field Nursery	<i>Dig, Plant, Stake, Harvest, Container Handling</i>

Table 1 : Automation Areas for Nursery Industry

In these areas it was judged [2] that automation has achieved different levels of automation-penetration worldwide - the levels are expressed in the histogram shown in Figure 2:

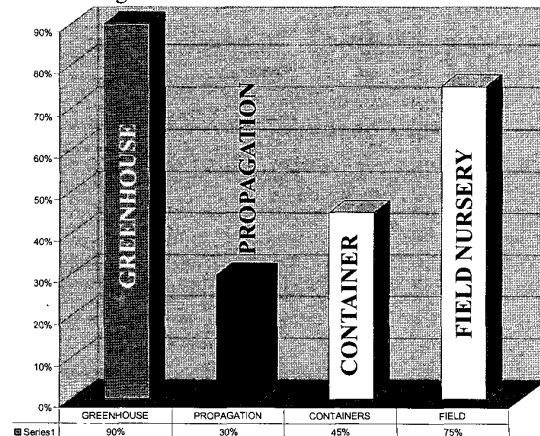


Figure 2 : Automation Levels in Nursery Industry

Current automation in the nursery production field worldwide are very wide-scattered, depending on the specialty-area. Holland [1], Germany, Italy and England are world leaders in the automation of greenhouse production, whether that be for woody ornamentals, flowers or even vegetables. Equipment from suppliers in these countries, and the associated infrastructure, are in use worldwide. Equipment ranges in variety from plug-planting machines, potting machines and flower imaging and quality segregation to automated soil-mixers, -fertilizers and washing machines (excerpt in Figure 3).

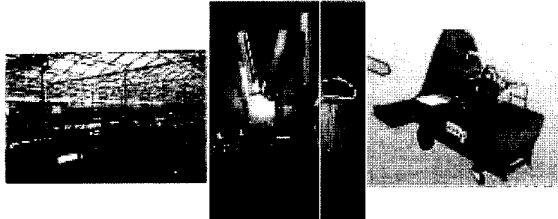


Figure 3 : Greenhouse automation equipment

Field-nursery production automation is primarily limited to the development of assistive tools, which assist in the excavation of field-grown trees and inventorying systems for such trees (see Figure 4).



Figure 4 : Field Nursery automation equipment

Container-handling devices for field-use, which is where

most of the labor-costs are expended, have not seen any intensive development in the US nor abroad - for good reasons; systems that are available are shown in Figure 5.

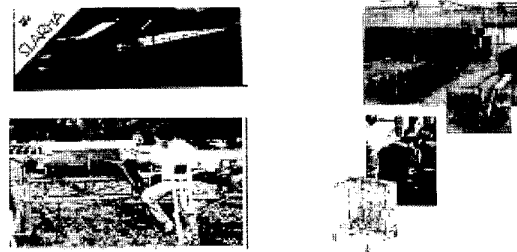


Figure 5 : Container Nursery automation equipment

The variety in container-types and surface-conditions and nursery layouts is vast - they way greenhouse automation was made successful is through standardization of the infrastructure (containers, conveyors, irrigation, etc.), which is still sorely lacking in the US. Talks about standardized containers has been ongoing for many years, but due to the nature of the business, has not taken a foothold in the US. Differentiation amongst growers, climatic conditions and simple opinion-variability amongst growers results in methods and principles that make it hard to apply automation broadly in this vast market, without requiring dozens of various dedicated machines for different growers/growing-regions (thereby reducing the attractiveness to equipment developers).

III. PERFORMANCE REQUIREMENTS

The motivation to automate being obvious, it becomes important to realize that the US market has a high affinity to price and performance. The performance requirements that were derived for the proposed container-handling

DESCRIPTOR	TARGET	VALUE
Containers moved in the field per hour	Meet/Exceed 4-person daily rate	25,000/day ^a
System Design	Stand-alone System	N/A
Trailer Compatibility	Compatible with typical trailer	4' x 10'
Operator Reduction	Single-operator for system	1 Operator
Quality and Control Assurance	No extra plant/container damage	N/A
Multi-container usability	Adaptable ^b to #1, 2, 3 & #5s	Yes
Container Configurations	Can-to-Can, Can-tight, Spaced ^c	Yes ^c
Multi-surface operability	Gravel, Geotextile - NO Poly!	Yes
Cold-Frame Compatibility	Access into/sideways frames	Yes ^d
Cost-Effectiveness	Typical stand-alone system	\$50K to \$75K

a. Refers to #1 containers in an 8-hour workday with a single operator, or about 2,500 containers/hour!

b. manually adjustable over a range or usage of a different tool-head

c. in a follow on system adapted based on the baseline system

d. possibly with minor modifications in the door and/or hoop-structure and irrigation-location

Table 2: Performance Metrics

system, focussed around several key areas, namely (i) throughput (containers/day), (ii) applicability to existing infrastructure (containers, groundcover), (iii) compatibility with existing equipment (trailers, cold-frames), (iv) manpower reduction, (v) job-quality (compared to manual), and (vi) cost-effectiveness (ROI-based). The system has to be able to pick-up and drop-off in can-to-can and can-tight, as well as diamond-spaced configurations, and do so at a rate to pay back for the system in terms of labor-savings within as few seasons as possible. Performance variables and the expected value for each are shown in Table 2.

IV. SYSTEM DESCRIPTION

The design developed for the automated field-container handling system represents a self-mobile outdoor platform powered by an IC engine, perceiving containers through a set of ranging IR-sensors, controlled through on-board PLC-based ladder-logic computers, and actuated through a set of electro-hydraulic actuation systems. A CAD-rendering of the developed system is shown below in Figure 6:

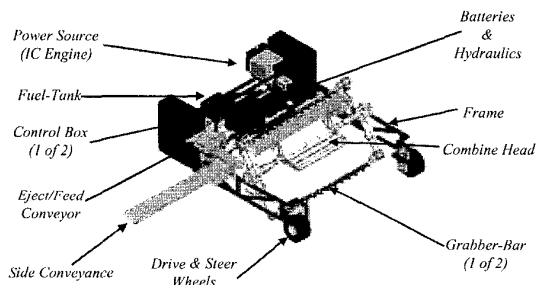


Figure 6 : CAD image of the container handling system

The above design relies on a self-powered skid-steered platform with rear floating rocker-arm caster-axle. The containers are now grabbed using a squeeze-pinch and moved in a circular arc fashion to a conveyor that speeds them off to the side (onto a waiting trailer); the operation is run in reverse for setting down and spacing out containers. Two grabbers ensure that a full 6-foot wide row of containers is moved every 8 seconds. Sensor-guided driving aligns the frame to pick up or drop off in any desirable configuration.

The overall system can thus be seen to consist of several major elements, including (i) frame, (ii) drive & steer, (iii) container grabber & handler, (iv), and power & control systems. The roles and interconnections of each of the above modules can be generically described as detailed below:

FRAME: The frame consist of an open U-shaped weldment, upon which rest the IC power-plant, hydraulic drive system, power and control electronics, locomotion and steering system, as well as the container grabbing and handling head and its associated conveyors. The system

was oversized so as to allow for laboratory testing of all possibly useful features, which are then to be evaluated for inclusion in the commercial prototype (see Figure 7):

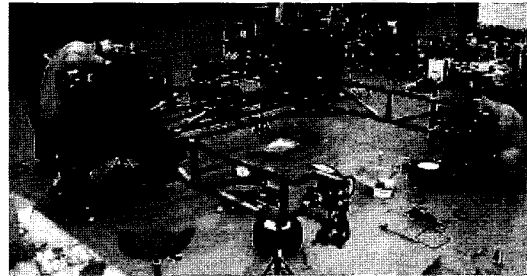


Figure 7 : Frame undergoing assembly

POWER & CONTROL: The main power source for the system consists of an internal combustion-engine mounted on the frame, providing both electrical power via a generator, and hydraulic power through a direct-coupled pump. The power is regulated through a dedicated cabinet, while the electronics and controls for the PLC and the relays and valves are housed in a separate compartment. Fuel-tanks and cooling radiators are mounted on the frame as well. A picture of the subsystems is shown in Figure 8:

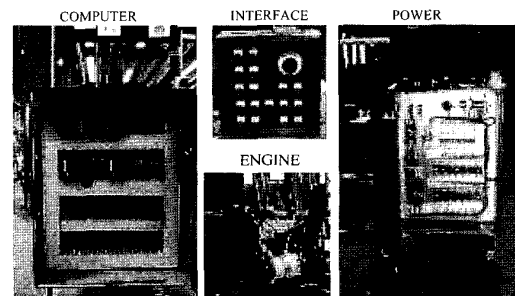


Figure 8 : Power & Control Subsystems

HYDRAULIC DRIVE & STEERING: The hydraulic system is used to provide driving/steering power to the wheels, as well as articulating the grabber arms and pinching endeffectors. The drive and steering for the handling system is achieved by driving the two front wheels in a differential manner, while letting the system follow based on a simple rear-mounted rocker-arm caster-axle. The individual systems are shown in Figure 9 in different stages of assembly.

CONTAINER GRABBER: The method used to grab containers reliably, without requiring any dedicated container design, is based on a simple double half-moon friction-clamp design. By ganging these pinch-grabbers along an actuated rail, a whole row of containers can be grabbed at once and moved around. The bar-mounted pinch-grabber arms are mounted on a set of two rotating side-arms, allowing a combine-like full rotation of each row that has been grabbed; and internal gearing-pass ensures that the containers remain level during any part of

the rotation. The sensory system used to control the machine-heading, combine-head rotational position, arm-extension and pincher open-close states, is based on the processing of infrared range-measurements from embedded sensors [3].

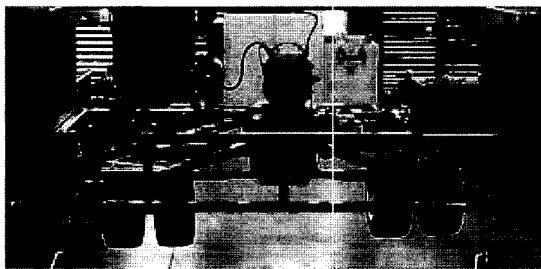
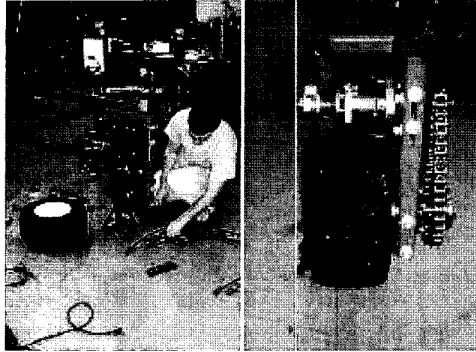


Figure 9 : Locomotion and Steering Subsystems

Preliminary testing on a single pincher and a full pincher-grabber bar basis have determined that this approach is reliable and robust to container types and outdoor conditions. Images depicting the pincher system during indoor testing, are shown in Figure 10.

PINCH-GRABBER ARM ARRANGEMENT IN LABORATORY TESTING

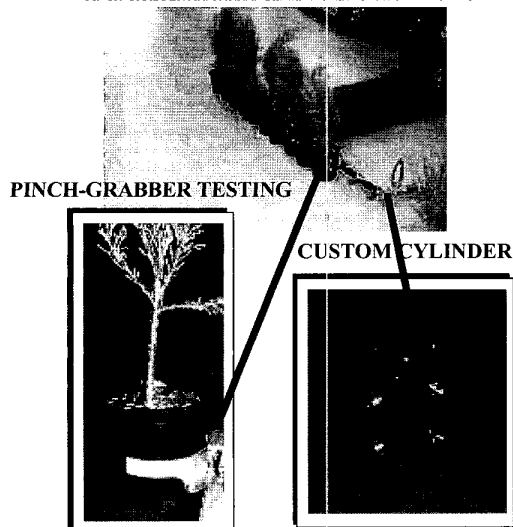


Figure 10 : Container Grabber Subsystems

ELECTRONICS: The electronics and control system is based on commercial-off-the-shelf industrial automation hardware. The hardware architecture is shown in Figure 11. The control system hardware consists of an Allen-Bradley SLC-500 PLC, two Delta Computer Systems motion controllers and a variety of other components (e.g. sensors, relays, and contactors, etc.). As noted in Figure 11, the PLC communicates with the motion controllers via Ethernet. The PLC performs all supervisory and discrete device control. The PLC chassis houses the CPU and several I/O modules for: a) discrete and analog sensors inputs (e.g. proximity switches, IR sensors for container localization, etc.), and b) discrete outputs (e.g. solenoid valves, indicator lights, etc.). The motion controllers coordinate and control all 10 axes. The ten axes include: (i) two (2) drive wheels for locomotion, (ii) combine head rotation, (iii) four (4) hydraulic cylinders for the telescoping tubes, and (iv) the three conveyors. The system operator will interact and control the system via buttons, switches, and a joystick (see Figure 8).

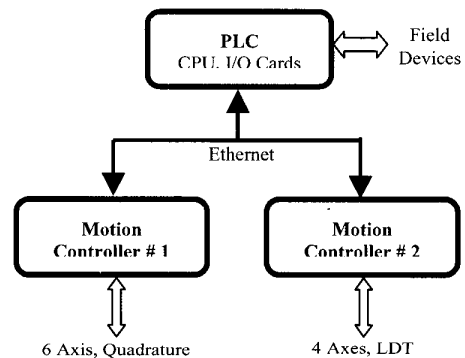


Figure 11 :High-Level Electronics Architecture

CONTAINER SENSING: In order to perform up-close positioning of the grabber-head so as to achieve 'proper' alignment with the containers for a full-row pick-up, despite the potential misalignment of the tool system itself, the misplacement of containers, etc., requires the use of an integrated sensing system. The most suitable candidate for simplicity, ruggedness and reliability turned out to be a non-contact infrared ranging system (see Figure 12). To build the range-imager, we integrated several of these relatively short-range (4 inches to 2 feet depending on IR diode-power) sensors onto the side of the frame along the pickup-line. This allows us to not only achieve a good 'average' sensory-alignment reading, but to also have a much better idea of the alignment of the container-row in the field, which will be useful if we are to properly space containers in the field. The test-setup we used (see Figure 12), includes a suite of several IR sensors, which are multiplexed through a computers' I/O port (parallel in the experimental setup's case) to obtain range-readings from each sensor at a rate of 10 per second. These readings are then processed based on the

calibration-curve for each sensor, and then a range-map is built.

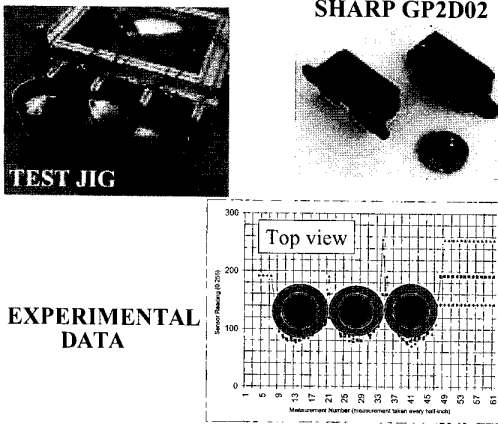


Figure 12 : IR Sensing System & Setup

If the sensor-array is moved laterally and in front of a row of pots, an image can be generated which a computer interprets so as to determine the inter-container spacing, which in turn can be used to determine the proper location of the gaps between the containers. This process makes the accurate placement of the grabber-head possible so as to provide final alignment through heading control and grabber-arm extensions. The block-diagram of the software that was developed in order to perform the ranging, computation and grabber-head alignment (including gross alignment by way of heading and displacement of the entire system), can be depicted as shown in Figure 13:

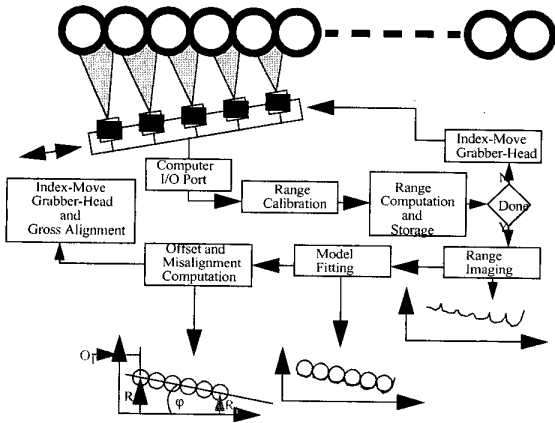


Figure 13 : Software Sensor-Control Diagram

SOFTWARE: The control system logic is implemented via Allen-Bradley's ladder-logic programming language. The RSlogix development environment was the primary tool for development of the ladder-logic control program. Unlike most industrial ladder logic programs, the software/control program was written using a modular, systematic approach. This systematic approach makes the

code more reliable and easier to debug and maintain. The software architecture is shown in Figure 14. The program consists of a main program, device control, input references, output references and several processes. The main program provides overall control. The device control is the only place where devices are controlled. The input and output references map all internal software variables to the I/O hardware. The processes are where the majority of the control logic is implemented. These processes represent basic functionality of the system's various sub systems and are where the machine operation is sequenced. For example, one of the processes is for loading/queuing of the transfer conveyor so a grabber arm can pick up the containerized plants and set them on the ground. Another process, for example, is for unloading the conveyors after a grabber arm has placed containerized plants on the conveyor.

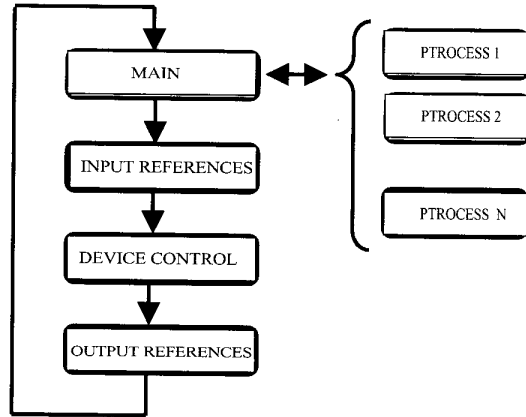


Figure 14 : Software Architecture Layout

SYSTEM: A fully assembled locomotion platform of the container handling system is shown in Figure 15 during locomotion trials on the experimental nursery at CMU's National Robotics Engineering Consortium experimental nursery:

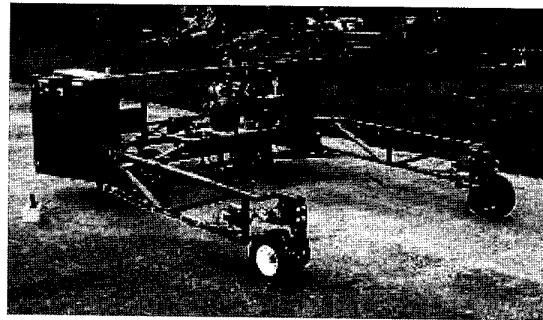


Figure 15 : Fully integrated container handling system

V. FIELD TESTING

The handling system shown in Figure 15, was tested at REC's experimental nursery. The system performance was measured over a 6-foot wide and 50 foot long bed

using a variety of #1 containers and different plant-types and weights. Initial testing indicates that the sensing scheme was able to position the system accurately enough (to within 0.15m), yet the closed-loop speed needs to be increased to achieve a productivity increase of about 30% (currently at ~ 20,000 containers per 8-hour day). The time spent between grabbing containers off the ground and hand-off onto the conveyor needs to be sped up to increase cycle-time as well. Large steering corrections did not result in expected behavior, due to the variability in traction we re seeing due to different groundcover and the fact that the weight distribution between the front driving wheels and the rear caster-axle is 30/70. The operator interface was found to be simple enough to use, even when manual reset and resumption of automated handling was required. Minor improvements in mounting and cooling for certain subsystems are being undertaken to complete the testing program before the onset of winter.

VI. SUMMARY & CONCLUSIONS

The container handling system presented herein represents a major step towards automation of labor-intensive container-handling tasks in medium to large-sized container nurseries in the US. The system represents a new class of smart outdoor automation systems utilizing existing hard-automation components, aided by smart sensors, intelligent software and innovative mechanism design. Testing of the system has shown its potential to achieve the desirable productivity of 25,000 to 45,000 #1 containers per day with one to two operators, without regard to the type of hauling-trailer. The system is capable of handling a large variety of containers available through US manufacturers. Groundcovers suitable for the machine and tested to date, include gravel and stone/asphalt/concrete. The current system needs to be reduced in weight and size (mostly width), as well as re-engineered for lower manufacturing costs. System maintenance requirements are expected to be reduced by switching to exclusively electrical power on board.

VII. FUTURE WORK

The system presented herein represents the first generation of field-container handling systems. We are currently simplifying and shrinking the system design, and expect to prototype an improved commercial prototype by the end of 2001. In addition, CMU is developing other more simple manual tools for assisting growers that have switched to growing trees in the ground in large containers (pot-in-pot) and those retailers involved in the landscape

and garden-center sectors in this industry. Licensing arrangements are being sought to ensure the technology gains wide acceptance in the US and abroad.

VIII. ACKNOWLEDGEMENTS

The container handling system was jointly funded at Carnegie Mellon University (CMU), by NASA under research-grant #NCC5-223, the US Dept. of Agriculture's (USDA) Agricultural Research Office (ARS) under a SCA (#58-1230-8-101/58-3607-0-130), and a grant from the Horticultural Research Institute (#1999-128/2000-163), the research-arm of the American Nursery and Landscape Association (ANLA). We wish to further acknowledge the help from many growers and nursery/agricultural equipment/supply providers (MidWest Groundcover, John Deere, Toro, Lerio, Nursery Supplies, etc.) in the industry, that have gone out of their way to assist in the development through advice and equipment and supplies donations.

The above-described system and process has been described to the USPTO as part of a patent-filing - it has a patent-pending status.

IX. REFERENCES

- [1] "*VISSER - Product Descriptions.*", Company Catalog and CD, November 1999
- [2] Schempf, H., "*Automation and Mechanization: The Future of the Nursery Industry in the US*", NEGrows Conference, Boston, MA, January 21-27, 2000
- [3] Dias, B., Stentz, A., Schempf, H., '*Sensory-based nursery container detection*', RI Tech Report Draft, Carnegie Mellon Univ., Pittsburgh, September 2000
- [4] Product Literature for various companies: Bouldin-Lawson, Javo, Baertschi-FOBRO, Goetsch, Urdinatti, etc.
- [5] '*Systems for Success*', by D. Hughes, Jr., Cedar Rapids, IA, ISBN 0-9655037-0-4
- [6] "*New Ideas*", Bi-monthly Newsletter, Wholesale Nursery Growers of America, 1991 - 1999.
- [7] Jagers, F. et al, "*Hi-Tech take-over of pot-plant grading*", FlowerTECH 1998, Vol.1/No.1
- [8] Adrain, J.L., et al, "*Cost Comparisons for Infield, Above Ground Container and Pot-in-Pot Production Systems*", Journal of Environmental Horticulture, Vol.16, No.2, June 1998, p.65
- [9] '*American Standard for Nursery Stock*', American Association of Nurserymen, ANSI Z60.1-1996, Nov. 6, 1996