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Automation in the Greenhouse: Challenges, Opportunities, and a Robotics Case Study

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Summary. **The commercial greenhouse operation, with a controlled and structured environment and a large number of highly repetitive tasks, offers many advantages for automation relative to other segments of agriculture. Benefits and incentives to automate are significant and include improving the safety of the work force and the environment, along with ensuring sufficient productivity to compete in today's global market. The use of equipment and computers to assist production also may be particularly important in areas where labor costs and/or availability are a concern. However, automation for greenhouse systems faces very significant challenges in overcoming nonuniformity, cultural practice, and economic problems. As a case study, a robotic workcell for processing geranium cuttings for propagation has been developed. The robot grasps randomly positioned cuttings from a conveyor, performs leaf removal, trims the stems, and inserts the cuttings into plug trays. While the system has been shown to process effectively many plants automatically, the robot is not equipped to handle successfully the wide variety of cuttings that a trained worker handles with aplomb. A key challenge in greenhouse automation will be to develop productive systems that can perform in a reliable and cost-effective way with highly variable biological products.**

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Today's floriculture industry is a vibrant, diverse segment of agriculture that is valued at more than $2 billion per year in the United States (U.S. Dept. Agr., 1988). In these times of global competition, floriculture companies are looking at many methods of improving productivity. Automating labor intensive or hazardous tasks is one example. Robotic systems along with fixed automation machines are being developed for the floriculture industry in an attempt to increase competitiveness and also to improve quality (Neal, 1991).

A robot or robotic system refers to a computer-controlled, general-purpose machine. These machines are different from fixed automation in that robots are programmable and multifunctional. Robotic systems are prevalent in the automotive, electronic, general fabrication, and other industries for conducting repetitive, precise, and/or hazardous operations. Robots are used for large tasks such as handling castings and welding car frames to small tasks such as assembling printed circuit boards and transferring machined parts. The same robotic system, or even the same type of robot, is not always used for such tasks. However, each robot that performs these operations can perform multiple tasks. For example, the same robot that spray paints an automobile can be programmed to paint a child's toy. The term "flexible automation" comes from this proficiency: the ability of a single machine to be flexible enough to perform multiple tasks (Nof, 1985).

With increased emphasis on automation in commercial greenhouse operations, interest in both robotic and fixed automation systems is expanding (Smith, 1991). With this interest in automation comes both challenge and opportunity. In terms of challenge, why is automation particularly difficult for this industry relative to other similarly sized industries? In terms of opportunity, why might it be worthwhile for this industry to pursue automation more vigorously? What types ofgreenhouse tasks are engineers targeting for automation?

This paper attempts to address these questions briefly. The scope includes any system for the moving, processing, or grading of plants and/or containers, whether robotic or fixed automation. The objectives of this paper are: 1) to describe challenges engineers and horticulturists face in developing productive and cost-effective automation systems, 2) to describe the potential benefits and incentives for further automation in the commercial greenhouse, and 3) to describe a greenhouse automation research case study on robotic processing of geranium cuttings for propagation.

Challenges

Current challenges for increased automation can be classified broadly into four groups: nonuniformity, cultural practice, marketing and economics, and funding equipment development.

Nonuniformity. Nonuniformity, or variability, refers to that in which "all entities are not the same." In the floriculture industry, we see tremendous diversity among greenhouse operations including production layout, trays, flats, pots, crops, and of course even within crops. This diversity makes cost-effective, functional automation difficult and time-consuming to develop (Moncaster, 1985). The great majority of current industrial robotic applications, such as the spray painting operation mentioned above, are performed with known items in a known position from day to day. In the greenhouse we frequently do not have this luxury.

Even while performing the most monotonous duties, greenhouse workers are making decisions and modifying their tasks to fit the specific needs of the plants. Whether handling different pot spacings on a bench or processing zonal geranium cuttings, which may vary 300% in stem caliper, 600% in stem length, and have two to 10 leaves, people have the ability to adjust their actions based on the requirements of the situation. Generally, neither fixed nor robotic automation systems are equipped to modify their own operations in this manner. The primary technical constraint for advanced automation systems for the commercial greenhouse is this high degree of nonuniformity.

Cultural practice. Day-to-day operation within most commercial greenhouses does not fit the traditional factory, where economic justification for automating may be simpler. For example, many of the labor-intensive tasks in a greenhouse are not performed daily for ≥8 h, but rather are periodic. This includes work required 2 $h \cdot day^{-1}$, weekly, or even seasonally. An example for some greenhouses would be shipping. If an automated system performed shipping only once per week, it may be sitting idle 80% of the time. Obviously, 20% usage on a machine has a significant effect on break-even costs. A flexible, multipurpose system or a low-cost, single-use alternative may be required in this case.

Other cultural practice challenges to automation include few generally accepted. standards (bench layouts, work areas, and procedures); multiple crops grown within the same range; and the environment (heat, moisture, dust, and dirt). Disorder of propagation stock (e.g., geranium, chrysanthemum, and poinsettia cuttings) is yet another difficulty due to a lack of singularity in equipment for this market. Also, there is the need for retrofitting. Most companies are understandably reluctant to alter their entire operation to accommodate a new machine (L. Carney, personal communication). However, care must be taken to minimize so-called “islands of automation” and the bottlenecks of material flow due to isolated points of automation.

Marketing and economics. Factors related to marketing and economics play a significant role in the challenge to automate. The manner in which demand for a product varies from season to season and year to year, with the accompanying price fluctuations, makes growers very cautious (D. Busch, personal communication). This caution leads to resistance to change. Historically, the plant production industry has preferred operating costs over capital spending. Cost and availability of labor play an important role. Evidence exists that capital intensity may have an inverse relationship to profitability for some industries (Smith, 1991). In a survey in Georgia, nursery and greenhouse growers cited capital as the chieflimiting factor to expansion (Turner and Mixon, 1990).

Few economic studies have been published in the last decade on greenhouse system automation. Fang et al. (1991) evaluated the effects of annual production volume, equipment cost, labor cost, and other characteristics on the economic feasibility of robotic transplanting of bedding plants. Expected payback varied from 2.6 to 6.4 years and return on investment varied from 8% to 61%, depending on the assumptions. vanWaarde (unpublished data) examined the effects ofefficiency, robot number, equipment cycle time, labor cost, and other characteristics on robotic processing of geranium cuttings for propagation. The analysis provided design goals for an economically feasible system with results such as predicting a 100% increase in allowable cost per robot resulting from a 33% decrease in equipment cycle time.

Funding equipment development. Devising and testing new ideas and machines requires funding. Development of new automation equipment for the greenhouse industry is performed both by government researchers and private industry engineers. Unfortunately, all workings in this area are woefully lacking in sufficient funds (Bolusky, 1989). The greenhouse industry has not been willing or able to fund research, as evidenced by the small grants given by the Horticultural Research Institute and the Bedding Plant Foundation. Federal and state government funds for applied research are dropping annually. Few machine/engineering companies are willing to risk corporate funds for innovative automation equipment when the market for specialized equipment is relatively small. And lastly, there are few close grower/manufacturer and researcher/manufacturer relationships, which are essential for producing cost-effective, productive equipment.

Opportunities

Current equipment and research. While there are many challenges to automate in commercial greenhouse operations today, a number of researchers and equipment developers are busy readying new ideas and machines. The most active area of development is transplanting (Neal, 1991). An estimate for 1989 bedding plant production was 60 million flats (Miller, 1990). Equipment for plug or seedling transplanting within a greenhouse is being sold by several companies including Timmer Industries (Jenison, Mich., Plug Transplanter; 10,000 plugs per hour) and Visser (‘s-Gravendeel, The Netherlands, Plant-o-Mat; 10,000 plugs per hour). Transplanting systems under development include those by Bouldin and Lawson (McMinnville, Tenn., Coverplant, a unit initially developed in France, sensors detect poor or empty plugs, 7 to 10,000 plugs per hour); Agrobotics (West Lafayette, Ind., Rotran; handles any standard trays or flats and detects poor or missing plugs); and Rutgers Univ. (New Brunswick, N. J., experimental robotic workcell, innovative gripper for handling plugs). In-field transplanting machines have been developed by the U.S. Dept. of Agriculture, Agricultural Research Service (USDA, ARS), Tifton, Ga., Univ. of Florida, Gainesville, and North Carolina State Univ., Raleigh. Each of these machines has different production rates, efficiencies, support personnel requirements, and flexibility.

Most growers are aware of the impressive pot- and flat-handling equipment developed by Dutch companies such as Visser, Hawe, and Javo, and United States companies such as Bouldin and Lawson and Gleason Equipment. Flexible container-handling systems are being researched by Ohio State Univ. (Columbus, robotic system) and Ecole National d’ Ingenieurs des Travaux Agricoles (E.N.I.T.A) (France; table handling gantry system). Other applications that are under development include spraying by Bouldin and Lawson (mobile, self-guided unit) and cutting propagation by the Univ. of Georgia (robotic workcell for geraniums). Future potential robotic tasks in the greenhouse that may not require direct plant contact include packaging of the outgoing product, unpackaging ofincoming pots and trays, general materials handling in the headhouse, and grading. Those robotic tasks that may require direct plant contact include harvesting (tomatoes and cut flowers), pruning, and grafting/budding.

Benefits and incentives. What are the potential benefits of and incentives for the automation work described above?

1) Improved global market position through increased productivity (Bolusky, 1989).
2) Improved quality for a marketing advantage by providing consistent grading and marketing procedures (U.S. Dept. Agr., 1989).
3) Increased standardization throughout the industry enabling faster machine development as the needs of the industry change.
4) Enhanced commercial-greenhouse operation stability through reduced labor turnover, reduced layoffs and rehires, and promotion of worker retraining (Bolusky, 1989).
5) Improved safety of the workplace through reduction of chemical exposure- to workers (Moncaster, 1985).
6) Improved production practices as related to the environment through reductions in the amount of chemicals required for production and elimination of runoff (U.S. Dept. Agr., 1989).

Other incentives for automation are based on rapidly changing technology. Faster and less expensive computers, more reliable computer networks, improved sensing techniques including machine vision, and improved motors and drives combine to give us better tools with which to design, test, and produce new equipment. Incorporating these tools with innovative software may produce truly cost-effective and productive automation equipment for the industry that can adapt to the changing needs and conditions of the commercial greenhouse.

A Robotics Case Study

Current research. Research in the mechatronics laboratory at the Georgia Station is focused on methods of accommodating nonuniformity as we work to develop reliable, cost-effective flexible automation for agricultural systems. The mechatronics laboratory uses a robotic system, a gripping system, and a supervisory computer. The first case study task for the laboratory has been the preparation of geranium cuttings for vegetative propagation. Geraniums were chosen due to the relatively simple and open structure of the cuttings, a nearby commercial cooperator in Oglevee Products, and the many technical challenges required for successful processing. Our primary goal with this task has been to perform all operations required on the cuttings from the time they are removed from the cooler until they are on the greenhouse bench.

Workcell design for geranium propagation. A robotic workcell may be defined as a unit consisting of machines, sensors, and material transport mechanisms for performing work on one or more products. The robotic workcell for processing geranium cuttings is designed to perform the operations of sizing (i.e., trimming the main stem to a particular size); stripping (i.e., removing those leaves having petiole branches within the rooting zone); and inserting the cutting into a tray. Simple grading based on main-stem caliper also is performed automatically. The primary purpose of the robotic arm is to handle and manipulate the cutting as other mechanisms placed in the robot workspace perform required processing and sensing operations. The robot then inserts the cutting into a selected tray based on grade.

The workcell (Fig. 1) consists of the robot and gripper, a conveyor, a pneumatic cutter, a pneumatic leaf stripping mechanism, a positioning sensor, and a frame supporting three trays. The cutter, leaf stripping mechanism, and sensor are devices

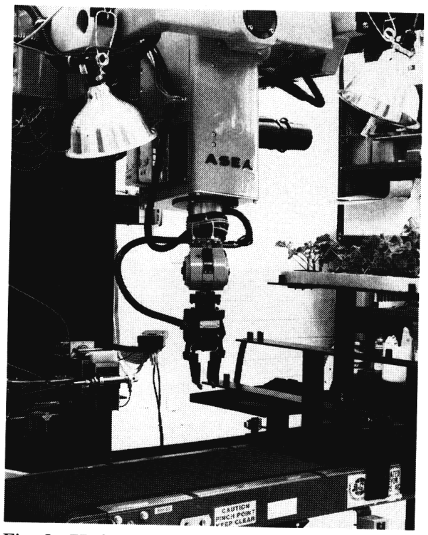

Fig. 1. *Univ. of Georgia robotic workcell for preparing geranium cuttings for propagation.*

developed specifically for the geranium processing workcell. The positioning sensor measures the amount of bend in the stem and allows the robot to successfully stick cuttings with severely bent stems. Trays with a 2 × 19 cell arrangement are used along with Oglevee rubber dirt plugs.

Machine vision. For the robotic system to process a geranium cutting successfully, the plant parts of the cutting must be identified automatically. The system must locate the cutting in the robot workspace and be equipped to distinguish a leaf from a stem, for example, and thus recognize the different sizing, stripping, and sticking actions required for each individual cutting. Handling the wide variability of shapes and sizes ofcuttings is a difficult challenge.

Machine vision, the combination of computer hardware and software that allows a computer to "see," can be a powerful tool for minimizing the effects of variability in automatic agricultural processes. A technique using machine vision has been developed in the mechatronics laboratory that analyzes an image of a geranium cutting on a conveyor surface and identifies all primary plant parts including main stem, petioles, and leaf blades.

We use the vision information to determine a strategy for the processing of an individual cutting. A processing strategy is based on an optimal grasp location and orientation on the main stem and location of leaves to be removed. The most difficult plant part to

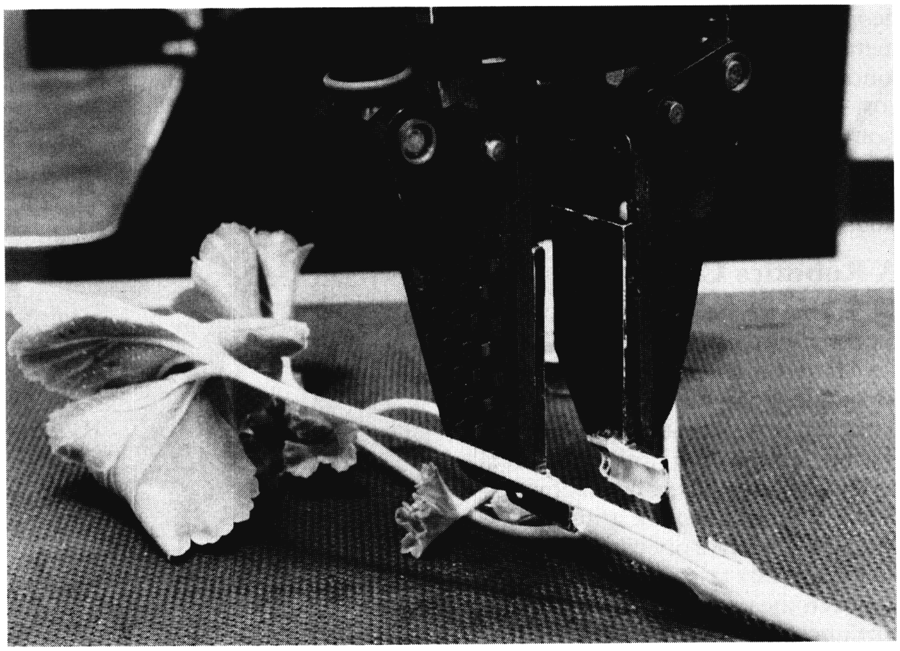

Fig. 2. *The position and force controlled robotic gripper can handlegeranium cuttings from ≈5 to 15 mm in stem caliper.*

analysis of the next cutting on the conveyor by the supervisory computer.

Workcell performance. Many cuttings have been processed in the workcell. Samples from the zonal varieties 'Bridgette', 'Veronica', 'Yours Truly', 'Sincerity', 'Crimson Fire', 'Fame', and several others have been prepared successfully for rooting by the robotic system. Rooting and growth have been shown to be very comparable to manually processed cuttings (Simonton, 1990). The robot can handle a wide range of sizes of geranium cuttings in a time equal to that of one worker. Machine vision, which is used to locate the cutting and identify the details of the cutting's structure, the gripper, which is used to sense and control the force applied to the stem, and the bend sensor, which is used to allow sticking of bent stems, aids the robot in processing the highly nonuniform plant material (Simonton, 1991).

identify is also the most important: the growth tip. Significant errors during location of the growth tip can cause the robot to damage a cutting during processing.

Sequence of operations. A conveyor brings cuttings into the workspace of the robot. A cutting is located using machine vision, and the conveyor is stopped momentarily by the supervisory computer. Cuttings can be in a somewhat random position and orientation (±45 degrees) on the conveyor, but must be kept singular. The supervisory computer analyzes the vision data and determines the grade, position, orientation of the robot grasp point, and leaf removal requirements. This information is passed to the robot, and processing of the cutting begins.

The robot grasps the cutting (Fig. 2), performs leaf removal if required, and trims the main stem. From the trimming mechanism, the robot moves the cutting through a position sensor to determine the amount of bend in the main stem. The robot then moves the cutting to the next available plug in the proper tray and inserts the cutting with an adjusting motion to account for the degree of stem bend (Fig. 3). While the robot processes a cutting, the conveyor is activated and the next cutting is located and analyzed by the supervisory computer. Mechanical processing of a cutting by the robot occurs concurrently with the visual

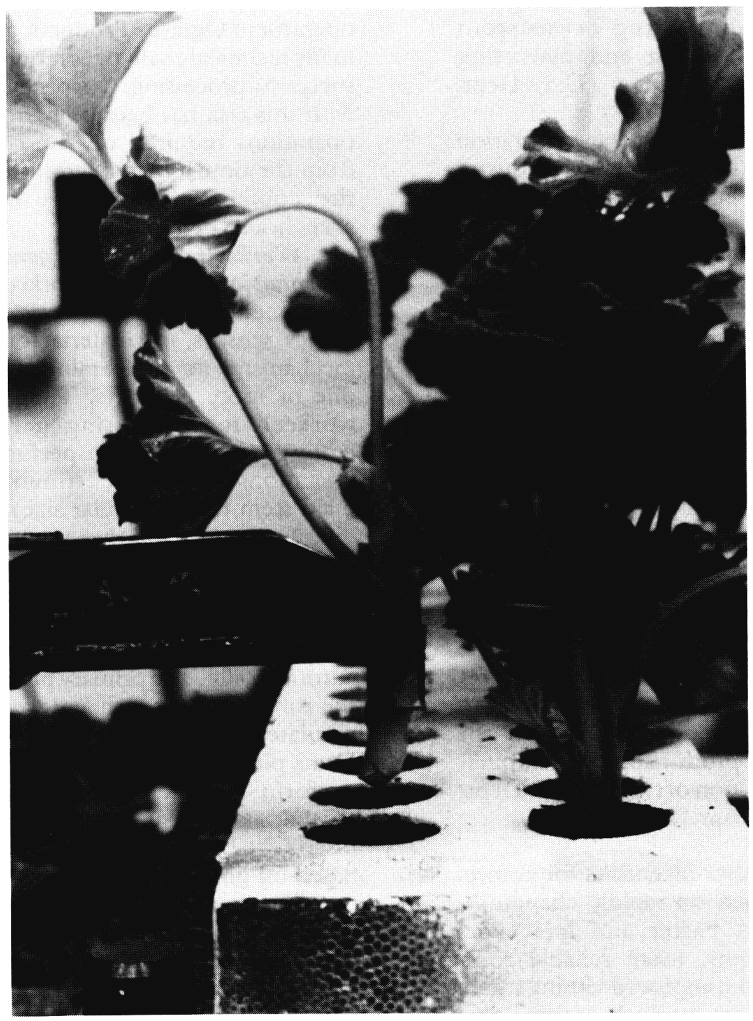

Fig. 3. *The robot can properly insert cuttings into plugs even if the main stem has a significant bend.*

Significant problems exist, however, in the overall performance of the workcell relative to commercial production requirements. Problems include: 1) relatively frequent inaccuracy (15%) of the identification of the growing tip that leads to overly long cuttings inserted into the plugs, 2) inability to selectively remove leaves toward the top of the cutting that causes an increase in foliage density and a corresponding increase in disease and transpiration problems, 3) damage to petioles (3% to 5%) during grasping, and 4) ≈3% of cuttings not being properly inserted into the plugs. Each of these difficulties are due to the robotic system not being equipped to process successfully the wide variety of cuttings that a trained worker handles satisfactorily. Also, two manual preprocessing operations are required: 1) removal of flower buds and 2) removal of leaves within 8 to 10 mm of the base of the unprocessed main stem. Automatic flower-bud removal is not feasible due to difficulties in visual identification and the frequently close proximity to the growth tip. Petioles branching from the lowest portion of an unprocessed main stem can cause significant occlusion problems for the vision system.

Conclusions

The commercial greenhouse system, with a controlled and structured environment and a large number of highly repetitive tasks, offers many advantages for automation relative to many other segments of agriculture. Benefits and incentives to automate are significant, and perhaps none more so than ensuring sufficient productivity to compete in today's global market. However, there are many challenges for the floriculture industry and for equipment developers.

Automation in the greenhouse faces difficulties in nonuniformity, cultural practice, economics, and funding of equipment development. Frequently, a key challenge will be to develop productive robotic or fixed automation systems that can perform tasks dealing with biological products ofvariable size, shape, color, position, orientation, and/or firmness in a reliable and cost-effective way. Just as in the automobile industry, where different robots or fixed automation machines are used for different types of applications, the commercial greenhouse operation will require a number of different systems for its many needs.

The need for successful, near-future automation equipment most likely will be driven by high volume tasks performed frequently, labor shortages, and wage pressures from surrounding industries. Robotics and other automation systems will not be replacing those individuals with significant plant expertise, yet these systems do offer opportunities for improving productivity, quality, and safety. For the industry to progress in automation, researchers and equipment manufacturers will need input on requirements, goals, and priorities from commercial greenhouse growers, propagators, and managers.

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