BARD

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On-Line Fault Detection and Diagnosis for Greenhouse Environmental Control

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Project Title:

On-line fault detection and diagnosis for greenhouse environmental control

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Research Authority, Principal Institution

Publication Summary (numbers)

	Joint IS/US authorship	US Authors only	Israeli Authors only	Total
Refereed (published, in press, accepted)			1	1
Submitted, in review, in preparation		1		1
Invited review papers				
Book chapters				
Books				
Master theses		1		1
Ph.D. theses			1	1
Abstracts				
Not refereed (proceedings, reports, etc.)		4	5	9

Patent Summary (numbers)

	Israeli inventor only	US inventor only	Joint IS/US inventors	Total
Submitted				
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Licensed				

Cooperation Summary (numbers)

	From US to Israel	From Israel to US	Together, elsewhere	Total
Visits/Meetings	1	3	1	5
Sabbaticals				
Postdoctorates				

- **Cooperation**, briefly explain whether synergistic, complementary or supportive.

Mainly complementary: the Israeli team dealt with the shoot environment and the Cornell team with the root environment.

ON-LINE FAULT DETECTION AND DIAGNOSIS FOR GREENHOUSE ENVIRONMENTAL CONTROL

Ido Seginer, Louis D Albright, Robert W Langhans

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ABSTRACT

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Background

Early detection and identification of faulty greenhouse operation is essential, if losses are to be minimized by taking immediate corrective actions. Automatic detection and identification would also free the greenhouse manager to tend to his other business.

Original objectives

The general objective was *to develop a method, or methods, for the detection, identification and accommodation of faults in the greenhouse*. More specific objectives were as follows:

- 1 *Develop accurate systems **models**, which will enable the detection of small deviations from normal behavior (of sensors, control, structure and crop).*
- 2 *Using these models, develop algorithms for an early **detection** of deviations from the normal.*
- 3 *Develop **identifying** procedures for the most important faults.*
- 4 *Develop **accommodation** procedures while awaiting a repair.*

The Technion team focused on the shoot environment and the Cornell University team focused on the root environment.

Achievements

Models: Accurate models were developed for both shoot and root environment in the greenhouse, utilizing neural networks, sometimes combined with robust physical models (hybrid models). Suitable adaptation methods were also successfully developed. The accuracy was sufficient to allow detection of frequently occurring sensor and equipment faults from common measurements. A large data base, covering a wide range of weather conditions, is required for best results. This data base can be created from in-situ routine measurements.

Detection and isolation: A robust detection and isolation (formerly referred to as 'identification') method has been developed, which is capable of separating the effect of faults from model inaccuracies and disturbance effects.

Sensor and equipment faults: Good detection capabilities have been demonstrated for sensor and equipment failures in both the shoot and root environment.

Water stress detection: An excitation method of the shoot environment has been developed, which successfully detected water stress, as soon as the transpiration rate dropped from its normal level. Due to unavailability of suitable monitoring equipment for the root environment, crop faults could not be detected from measurements in the root zone.

Dust: The effect of screen clogging by dust has been quantified.

Implications

Sensor and equipment fault detection and isolation is at a stage where it could be introduced into well equipped and maintained commercial greenhouses on a trial basis. Detection of crop problems requires further work.

ACHIEVEMENTS

Ido Seginer	Technion, Haifa, Israel
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Shoot environment. Technion.

The first four paragraphs below describe methodological developments that are pre-requisite to successful fault detection and isolation. The next three paragraphs refer to particular types of faults. Generally speaking, we were able to achieve all the objectives of the research, except for the initial field survey.

Hybrid models of the greenhouse environment (Sections A1, A2, A3, T2)

Early fault detection requires accurate and robust models of the normal (fault-free) greenhouse. A hybrid model consisting of a robust simple physical model in parallel with accurate local 'black-box' corrections, ensures the desired properties. Radial basis function (RBF) neural-networks have been used for the correction in regions of the domain where experimental data were available. Generally speaking the hybrid models are more robust but less accurate than sigmoid NN models.

Model adaptation (A3, T2, T3)

The models need to be adapted to changes in the weather, control policy and crop. Adaptation to weather was done on-line: Starting with the physical model, RBF centers were added over the domain, at rectangular grid points, whenever new data points were sufficiently far from the previous data. In this fashion, by the end of one annual cycle most of the feasible domain has been covered. Adaptation to the developing crop was done off-line, by inputting the crop cover, which did have an effect on the results when the ventilation rate was low.

Wide domain versus narrow domain models (T2)

Separate models were trained for the different seasons (spring, summer etc.) and compared to models based on all the available data. Although a spring model could be used in a later year at spring with some confidence, it is better to train a single model with all available data and use it for all seasons.

Robust model detection and isolation (A2, A4, A6, T4)

The unknown input observer method (UIO) fault diagnosis method was adapted to the non-linear greenhouse system. This robust method is capable of separating the effect of faults (to be detected) from model inaccuracies and disturbance effects.

Sensor, actuator and structure fault detection (A2, A4, T4)

Utilizing the methodology described in the preceding paragraphs, we were able to detect and identify (isolate) six frequently occurring faults: two sensor faults, two equipment faults and two faults of structure and crop. In particular: (1) the loss of aspiration of temperature and humidity sensors, (2) changes in the ventilation rate and (3) abnormally low evaporation rate (water stress). A similar approach can be used to detect changes in the heating operation.

Water stress detection by dynamic excitation (A5, T5)

Water stress affects the transpiration rate and hence the greenhouse aerial environment. Around noon time, this effect is strongly diluted by the large volume of ventilation air and the signals become too small for reliable fault detection. This problem has been solved by stopping the ventilation for periods of 30 min while monitoring the transient responses of the system. Comparison of on line measurements of these transients with model predictions for an unstressed crop, made it possible to detect water stress as soon as the transpiration rate dropped from its normal level.

Dust clogging and its detection (T6)

Dust accumulates rather quickly on the insect screens used to protect a greenhouse from invading pests. Over a period of several weeks we measured a 20 fold increase in the loss coefficient of a 50 mesh insect screen. While this is not critical for well designed fan ventilated greenhouses, naturally ventilated greenhouses may suffer a considerable reduction of air exchange rate, resulting in a significant increase of the greenhouse air temperature. Simple calculations showed that this temperature increase could be detected by the methods developed in this study.

Root environment. Cornell University

The first two paragraphs below describe the instrumentation of the experiments and the last two – the successful prediction of normal plant dynamics and the detection of certain equipment faults. Unfortunately, difficulties were encountered

during the installation work, for we were unable to find a commercial system to measure nitrate continuously, accurately and reliably, for useful periods of time. In addition, our neural network models were not sufficiently reliable under the circumstances to detect faults imposed on the plants in the hydroponic system, by monitoring pH, EC and nitrate concentration changes. It appears that the plant responses are sufficiently closely coupled with environmental parameters that root zone dynamics with stressed plants did not differ in detectable ways from root zone dynamics with unstressed plants.

Instrumentation of deep-trough hydroponic system (C1)

A system of three small deep trough hydroponic units were developed and instrumented. Instrumentation for pH, EC, DO, temperature, and nitrate concentration were developed, as well as scales for two of the three ponds to quantify evapotranspiration. The complete system will remain available for active research for the foreseeable future.

Method to measure transpiration in deep-trough, hydroponic culture (C1)

The scales included for two of the three deep-trough systems provide sensitivity of 50 g of water evaporated out of each tank, which contain more than 100 kg of water. This corresponds to transpiration of approximately 50 ml of water. Typical daily crop transpiration was 3000 ml; thus, sensitivity was on the order of hourly transpiration, permitting the tracking of short-term plant responses and diurnal transpiration patterns.

Neural network prediction of pH and EC changes indicting unstressed lettuce (C2)

A neural network model to predict pH and electrical conductivity (EC) dynamics in a deep-trough hydroponic system was developed, with unstressed lettuce as the crop of interest. A feed forward neural network model with nine inputs and two outputs (pH and EC at the next time step) proved to be the best predictor. Predictions of the pH and EC values for the next time step (twenty minutes) were within 0.01 pH units and $5 \mu\text{S cm}^{-1}$, respectively.

Neural network detection of mechanical faults in deep-trough hydroponic systems (C3)

A neural network model to predict mechanical and sensor faults in deep-trough hydroponic systems was developed. The optimum network had fifteen inputs. Faults tested included sensor failure, and acid and nutrient solution circulation pump failures. The network proved able to detect single failures, generally within one hour of the fault occurring.

LIST OF PUBLICATIONS

- ✓ Linker R, Seginer I, Gutman PO. 1998. Neural network and hybrid adaptive modeling of greenhouse air temperature. Proceedings AgEng98, Paper B006 (Oslo).
- ✓ Linker R, Gutman PO, Seginer I. 1998. Robust failure detection and identification in a greenhouse modeled with hybrid physical/neural-network models. 1st IFAC Workshop on Control Applications and Ergonomics in Agriculture (Athens). Preprints, pp. 171-176.
- ✓ Linker R, Seginer I, Gutman PO. 1999. Adaptive hybrid physical/neural network modeling, and its application to greenhouse climate optimization. Proceedings of the 7th IEEE Mediterranean Conference on Control & Automation (MED99), Haifa, Israel, pages 695-715.
- ✓ Linker R, Gutman PO, I Seginer. 2000. Robust model-based failure detection and identification in greenhouses. Computers and Electronics in Agriculture 26(3):255-270.
- ✓ Linker R, Seginer I. 2000. Greenhouse crop water stress detection via dynamic excitation. Proceedings AgEng2000, Paper 00-SW-011 (Warwick).
- ✓ Linker R, Seginer I. 2000. Fault detection and isolation in greenhouses. Proceedings of "Greenhouse techniques towards the 3rd millenium". Acta Horticulturae 534:367-374.
- ✓ Mathieu JJ, Kurata K, Goto E, Albright LD. 1999. A discussion of nutrient uptake equations in hydroponic culture, and their use in computer simulation. Acta Horticulturae 507:205-213.
- ✓ Ferentinos KP, Albright LD, Scott NR. 2000. Modeling pH and electrical conductivity in hydroponics using artificial neural network. To be presented in: Agricontrol 2000, July 10-12 2000, Wageningen, the Netherlands.
- ✓ Mathieu JJ, Albright LD. 1999. Water and nutrient uptake in hydroponic crop production. ASAE Paper 99-4122, 11 pp.

Journal and symposia papers A

- ✓A1 Linker R, Seginer I, Gutman PO. 1998. Neural network and hybrid adaptive modeling of greenhouse air temperature. Proceedings AgEng98, Paper B006 (Oslo).
- ✓A2 Linker R, Gutman PO, Seginer I. 1998. Robust failure detection and identification in a greenhouse modeled with hybrid physical/neural-network models. 1st IFAC Workshop on Control Applications and Ergonomics in Agriculture (Athens). Preprints, pp. 171-176.
- ✓A3 Linker R, Seginer I, Gutman PO. 1999. Adaptive hybrid physical/neural network modeling, and its application to greenhouse climate optimization. Proceedings of the 7th IEEE Mediterranean Conference on Control & Automation (MED99), Haifa, Israel, pages 695-715.
- ✓A4 Linker R, Gutman PO, I Seginer. 2000. Robust model-based failure detection and identification in greenhouses. Computers and Electronics in Agriculture 26(3):255-270.
- ✓A5 Linker R, Seginer I. 2000. Greenhouse crop water stress detection via dynamic excitation. Proceedings AgEng2000, Paper 00-SW-011 (Warwick).
- ✓A6 Linker R, Seginer I. 2000. Fault detection and isolation in greenhouses. Proceedings of "Greenhouse techniques towards the 3rd millenium". Acta Horticulturae 534:367-374.
- ✓A7 Mathieu JJ, Kurata K, Goto E, Albright LD. 1999. A discussion of nutrient uptake equations in hydroponic culture, and their use in computer simulation. Acta Horticulturae 507:205-213.
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- ✓A9 Mathieu JJ, Albright LD. 1999. Water and nutrient uptake in hydroponic crop production. ASAE Paper 99-4122, 11 pp.