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Intelligent Control in Greenhouses based on Activity Planning

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Abstract

The paper presents a new approach to greenhouse control based on artificial intelligence methods. The intelligent solution is expected to overcome the main limitations of the traditional greenhouse control, namely its dependence on manually selected set-points, the reactive nature of such system and the missing synchronization of the actuators. Set-points can be eliminated by using goals to express the plants' needs in a more abstract, knowledge intensive way. Reactivity is avoided by using predictive models. Two time-series mining methods are introduced for the prediction of the external temperature which strongly affects the internal state of the greenhouse. Black-box modeling is proposed as a method of choice for predicting the internal conditions of the house. The missing synchronization is avoided by creating common control plans for all actuators. The whole control solution is outlined, with the requirement specification of the underlying measurement and control subsystems.

Keywords: greenhouse intelligent control, adaptive modeling, activity planning, time series mining

1 Introduction

Greenhouses have transparent walls and roofs and are widely used for vegetable production and for growing flowers. Solar radiation is essential for photosynthesis of the plants, and useful in the cold season to keep the inner temperature within an acceptable range. In many cases a heating system may also be necessary. In hot weather other actuators, like roof vents, shading systems, exhaust fans or evaporative cooling may be used to avoid overheating. These actuators are in almost all cases automated, and operated by a control system. Traditional control systems are introduced in the following section.

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1.1 Greenhouse Control - Practice vs. Theory

Greenhouses today have very diversified control systems, dependent on the size and structure of the houses, the cultivated plants and the financial limitations of the owners. The majority of smaller simple greenhouses utilize simple microcontroller based solutions, while special purpose or laboratory establishments draw upon theoretically involved, advanced model based solutions. Unfortunately such advanced solutions are usually not used in industrial greenhouse control systems due to the lack of resources, and/or the application know-how.

Control systems usually incorporate some kind of environmental control computer. Computer collects, stores, and visualizes the measurement data for the greenhouse operator, but despite its computing power, almost all systems work with independent, set-point based PID controllers [1]. The main disadvantages of such scenario are:

1. the reactive nature of the control system,
2. the missing synchronization of the actuators,
3. strong dependence on the owner's expertise to find the appropriate set-points.

There is ongoing research to solve the first problem, namely by using model predictive control methods [2][3][4]. It must be however emphasized that model based, knowledge intensive solutions, when set against the variety of industrial setups, would require know-how not present in the majority of the owners, or would develop into an additional financial factor. The model based solutions moreover, even if they produce close to optimal control schemes, do not solve the whole control problem, because the particular temperature or humidity can be influenced with different configurations of heating, shading, draught, or water cooling, with various effectiveness and related costs.

When the number of automated actuators increases (because of the sensitivity of the plants, or the extremity of the external circumstances), the problem of missing synchronization in the control appears. In all cases the set-point selection is the task of the owner of the greenhouse, leaving all responsibility to the operator. In some experimental control system it was allowed to slightly differ from the set-points based on optimization results, but the main constraints were still represented by simple set-points [5].

Despite of the disadvantages of simple solutions, the owners of the greenhouses are satisfied, because the control system eliminates the former need for the constant presence of the human operators. The operation of the control system is easy to understand, and the owner feels completely in control over the system by tuning the set-point values. The actions can also be easily deduced from the set-points, making the system strongly casual and seemingly trustful.

Any new greenhouse control scheme has to retain the above mentioned advantages, while solving necessarily the earlier outlined problems. The hardly used computing power of the control computers is a good basis to develop more sophisticated control schemes with almost no new hardware investment, which is financially appealing and thus easier to be sold to the greenhouse owners, who would perhaps accept the advanced solutions more willingly. In our case the proposed control solutions will be applied to the experimental, industrial size (100 m^2) greenhouse, growing extremely sensitive young plants, in the Western region of Hungary. This establishment is available for collecting measurement data, and for testing intelligent control methods in real production environment. Of important practical value to the presented research is the fact that the greenhouse is realistically equipped (i.e. not too much, not too expensive) in internal and external sensors.

The next section introduces a complex, intelligent control system, which solves the presented problems by the elimination of set-points and by using adaptive modeling and planning.

2 The Concept of the Intelligent Control

An intelligent control system must provide a comfortable interface to the operators, eliminating the need of handling set-points. The system should be able to accept the goals of the control, and to make its decisions conform to the goals specified by the greenhouse owner. To overstep the limitations of the traditional reactive control solutions, the intelligent control system must predict the future state of the greenhouse and its environment (prediction of the external environment improves the quality of the in-house predictions). Prediction requires modeling both the external weather and the greenhouse itself. Because of the difficulties of the model building and the need for an easy model modification (following the changes caused by e.g. the growing plants, changing environment or structure of the house), only adaptive modeling can be applied. The most effective usage of predictive models is to create tentative control plans covering all actuators. If the control actions have associated numerical cost values, then the best tentative plan (fulfilling all the goals with the lowest total cost) can be chosen, and its first step executed.

Different levels of intelligence can be implemented in practical greenhouse control. The first level means a very simple intelligent extension to current systems making them capable to accept goals and to transform them to set-points. At the second level, a more sophisticated control solution would use predictive models without planning, to make the actual control decisions. The third level is the fully intelligent control system, using goals, predictions, and planning together, to ensure the highest service level.

2.1 Goals

Traditional systems require set-points to control the actuators. Such systems measure internal temperature at mostly a single reference point in the house, and compare this value to all set-points to determine the preferred state of the actuators. After this comparison the necessary commands are sent out to the actuators.

Finding the optimal set-point values manually is not easy, due to the large number of the parameters (usually more than 40 set-point values for different actuators) and due to coupled interactions between different actuators. Wrong set point-values or rare weather conditions can easily cause otherwise avoidable oscillations. To require that the greenhouse owner should set these values is far from ideal, because the owner is competent usually only in deciding the optimal environmental conditions for the plants, i.e. the global goals for the control system.

An intelligent greenhouse control system should act to fulfill these goals, instead of responding reactively to the set-point violations. Selecting the goals is neither straightforward, though the correct formulation of the goals is fortunately in the competence of the greenhouse operator. Goals can be set as e.g. the required temperature at different points in the greenhouse, the required humidity interval or the amount of (natural or artificial) light.

The goals can be set as time independent values (e.g. the required level of relative humidity); or can change with the time of the day (e.g. the intensity of light). The effect of violating a goal can be quite different in case of different goals; therefore a penalty function is also necessary to yield numerical values for all possible violating cases. Figure 1 shows example of goal settings and penalty functions.

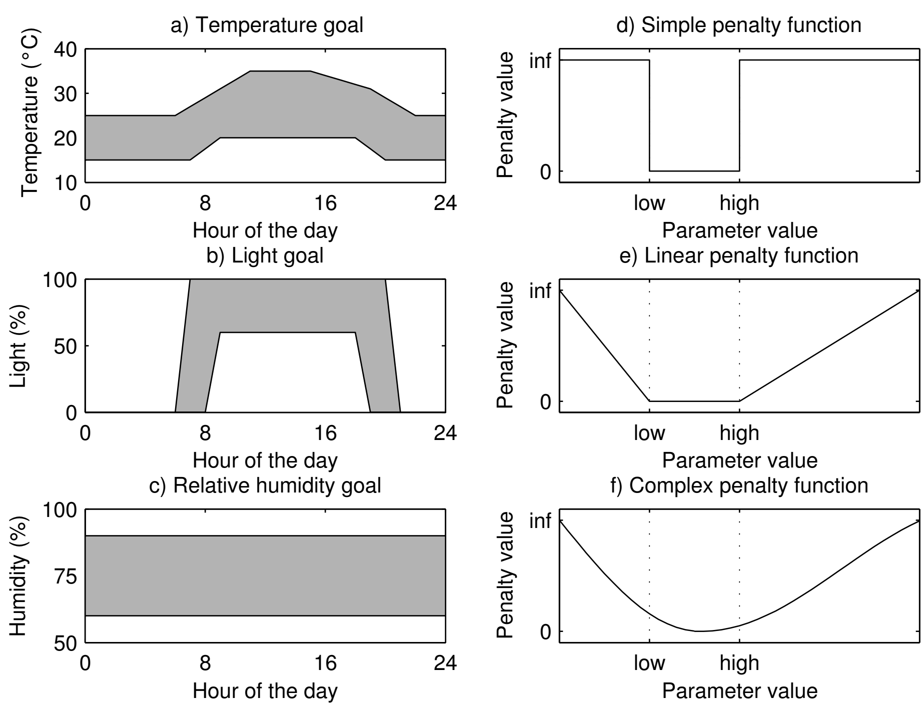

Figure 1: Goal specifications for (a) the temperature; (b) the amount of (natural or artificial) light; (c) the relative humidity; penalty functions having different levels of complexity (d)-(f).

The purpose of the control system is to choose the best accessible state of the greenhouse, therefore it is necessary to enumerate and to order the possible states based on the goals. Complex penalty functions (see e.g. Figure 1.(f)) are useful to ensure perspicuous ordering, or in case of simple functions prioritization of the goals is necessary.

At the first level of intelligent control mentioned earlier, the goals can be transformed into set-points for a traditional control system. The transformation can be realized by an expert system, calculating the best parameters from the goals and the actual measurements on the basis of the codified expert knowledge of the owner. Such control system is not intelligent in the manner of decision making, but it already provides a comfortable user interface. For higher level of intelligence, modeling of the greenhouse and its environment is necessary, as discussed in the next sections.

2.2 Models

Almost all control systems on the market have strong reactive characteristics: the necessary actions are taken only when the set-point limits are violated. A more sophisticated control solution should be able to predict the future state of the greenhouse and prevent suboptimal situations before they would occur.

The difficult task of modeling a complex physical system in and around the greenhouse can be decomposed into three closely coupled models: the external environment (the local weather), the heating system and the greenhouse itself. The external environment must be modeled, because it is affecting the internal state of the house depending on the current state of the actuators. In case of creating global control plans for hours ahead (four hours span seems to be adequate in practice), the change of local weather conditions cannot be neglected.

Modeling the greenhouse as a single entity has extensive literature, e.g. [6][7][8], but those solutions are not detailed enough for a sophisticated intelligent control system. In the greenhouses growing different types of plants together (a typical scenario e.g. for flower production) the owner may want to specify different goals for different compartments of the house. Using more measurements from the house, a more accurate model can be built, and its higher predicting power is essential for the control actions to be planned for hours ahead. Detaching the heating system from the house model is quite useful, because on the one hand when the heating is activated, the heating pipe temperature is practically independent from internal conditions of the greenhouse. On the other hand the inactive heating system can be neglected.

Some guidelines are given for the modeling in the next sections.

2.3 Time Series Mining for the External Environment Prediction

Modeling the external environment could be avoided by using online weather forecasts for the location of the greenhouse, if such forecasts would be available, accurate, and frequent enough for the current purpose. Even with the growing number of weather stations producing public data, we cannot assume a station at every greenhouse location, and the distance of even some kilometers makes quite a difference. Unfortunately the local conditions and the close surrounding of the greenhouse may noticeably alter the microclimate around the house, causing large deviations compared to the remotely measured data. Therefore local predictions have to be made based on the actual measurements around the greenhouse and the system can lean on the closest weather station data only in trends.

The most important, predictable external environmental factor is the outside temperature. So far only a few practical application needed outside temperature predictions limited for a few hours ahead, and in such cases the sample-and-hold prediction was acceptable [9]. In our case a more precise modeling is necessary, because the model predicting the internal state of the greenhouse strongly depends on the forecasts. Simple uninformed prediction methods (i.e. not using information about the physical processes), such as linear or higher order predictions, have still unacceptably large errors, calling for more sophisticated methods. Two new methods have been developed using knowledge of the problem domain, namely the cyclical changing of the temperature through the day and the similarity of the thermal profiles on the days preceding each other (see Figure 2) [10].

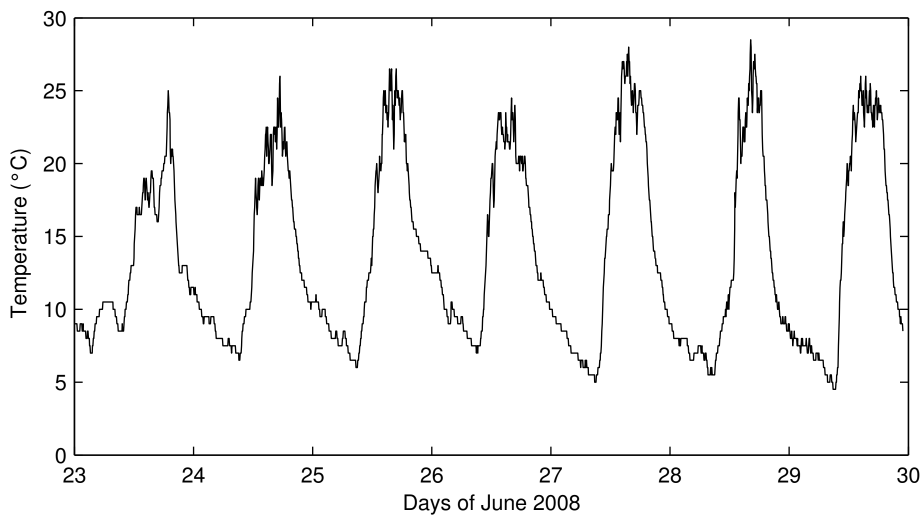

Figure 2: The external temperature data recorded by the experimental measurement system, from 23-06-2008 to 30-06-2008. Similarity of days close in time is noticeable.

The first approach, called Average Changes Method is based on the periodicity of the temperature data, which can be easily identified in Figure 2. The change of the external temperature in a given time of the day is alike the change on the previous day at the same time (if no dramatic developments in the local weather appear). This similarity can be used to create prediction based on the average change from an hour to an hour (see Figure 3 below).

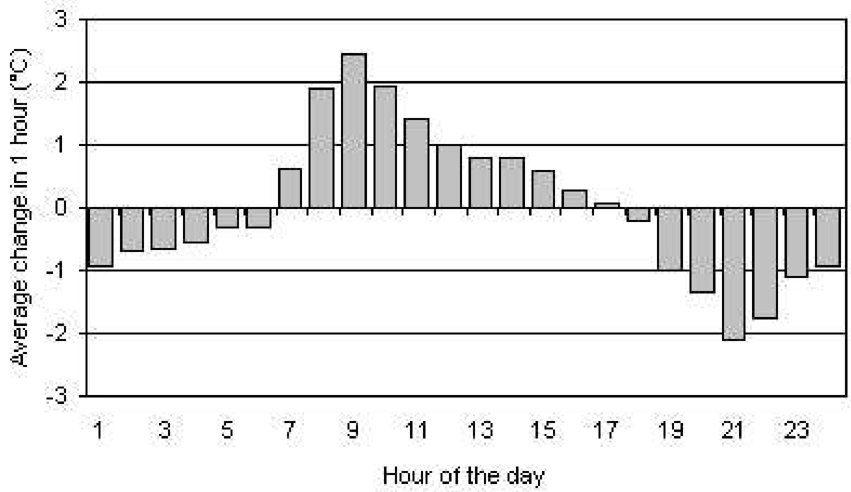

Figure 3: 7 days average change of the external temperature from an hour to the proceeding hour on summer days

After experimenting with several averaging periods, a 7 days interval proved best to describe the current weather situation, and can be used to make predictions with approximately 1.6 degree absolute error, for the 4 hours prediction horizon (see Figure 4).

This approach was generalized further by loosening the time constraints. The so called Precedent Based Prediction Method is looking for similar occurrences of the currently experienced thermal situation in the past, and uses them as candidates for prediction. The method is based on the fact that as the local conditions around the greenhouse do not change, and similar meteorological conditions reappear along the year. Records with the dynamics similar to the actual situation should exist, and their observable evolution could be used for short time prediction of the present. This method (see Figure 5) has approximately 1.4 degrees absolute error.

Models based on mining time series data measured immediately outside the greenhouse take implicitly into account all the local phenomena and process structures impossible to be tackled otherwise, due to the lack of models, or the uncertainty of the parametric information. As more data is available, the chance is higher that the actual conditions are reflected and can be recognized in the past behavior.

The amount of sunlight can be acceptably predicted based on the known position of the sun and on the online cloud coverage predictions available from the weather stations. Here the online forecasts give better results than the local modeling, due to the rapid changes in the cloud conditions and the usually homogeneous cloud

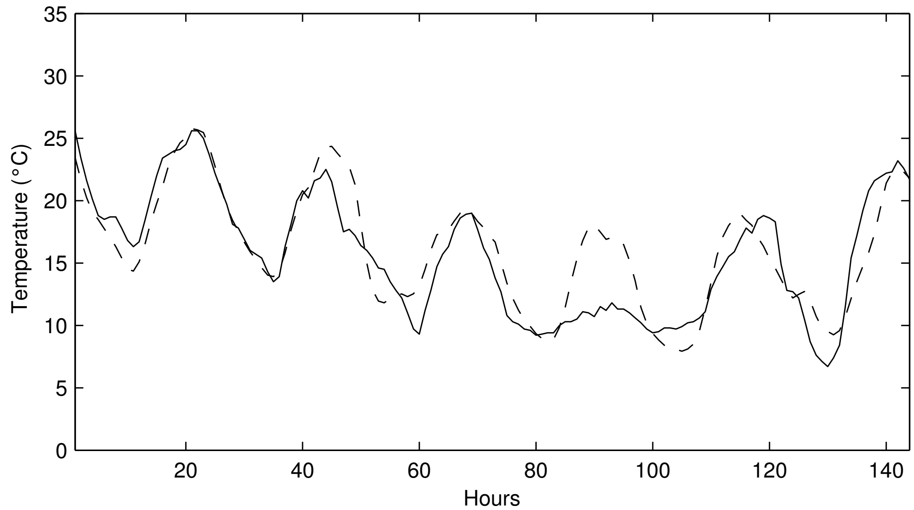

Figure 4: External temperature from April 2007: measured (solid) and 4 hours prediction with the Average Changes Method (dashed)

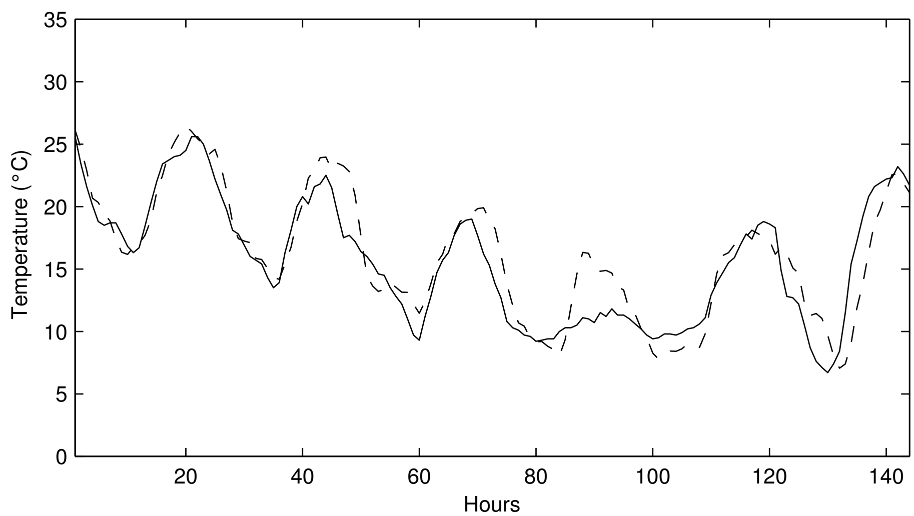

Figure 5: External temperature from April 2007: measured (solid) and 4 hours prediction with the Precedent Based Method (dashed)

coverage over larger geographical areas. The online forecasts can be also be used as a supplemental input for the modeling, but in this case, the control system has to be prepared to simulate this input in case of network problems, or service drop-outs.

The external weather forecasts introduced in this section can be used as an input for the greenhouse model responsible for predicting the internal state of the house, detailed in the next section.

2.4 Modeling the Greenhouse

In traditional control systems the greenhouse is considered usually as a single thermal entity, with the measuring of the internal conditions at a single reference point. In some cases it may be adequate, but most of the industrial greenhouses cannot be modeled as a single homogeneous thermal zone. On the contrary, based on the current state of the actuators, the house can be separated into a number of homogeneous thermal zones, with clear borders between them. Figure 6 shows the structure of the experimental greenhouse and the thermal zones identified.

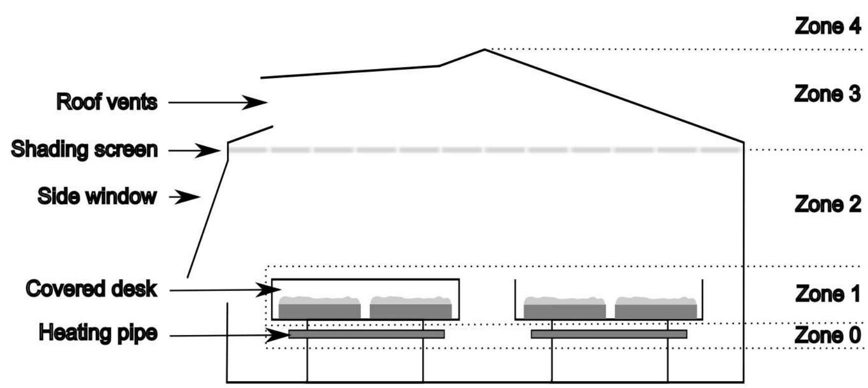

Figure 6: Structure and thermal zones of the experimental greenhouse

As mentioned, traditional control system would make measurements in only one of these zones. However for the accurate modeling of the greenhouse, the data should be measured in every indicated zone. Our current aim is to build the thermal model of the greenhouse, so we focus here on the temperature and on the closely related radiation measurements. Zone 4 (the external environment, i.e. the local weather) is special because the control system can not influence it. Zones 3 & 2 are only separated when the shading screen is activated. Zone 1 is the direct environment of the plants, in the current house it means usually being inside foil-veiled desks. Zone 0 (heating) is really not a true thermal zone, but it can be best modeled as such.

Temperature measurements are collected in the experimental greenhouse from Zone 0, 3 and 4 at a single point, from Zone 2 at two points, and in Zone 1 from all the desks holding the plants. Two point measurements in Zone 2 are necessary, because the house is split sometimes into two sections. For larger, industrial size greenhouses more sections can co-exist, making more measurement points necessary. In the current house thus 21 temperature and 2 radiation (from above and below the shading system) values are recorded.

The internal state of the greenhouse (Zones 1-3) is influenced by the two other zones. The outside temperature (Zone 4) affects constantly the internal zones through heat conduction of the walls and the roof, but this relationship can be boosted by opening the windows and deactivating the shading. The problem of the external temperature prediction was quite easy to separate, as already introduced in the previous section. The virtual zone of the heating pipe (Zone 0) can be neglected in cases when the heating is turned off and the pipe is already cooled down. When the heating pipe is hot, the temperature of the pipe is only loosely dependent on the internal state of the greenhouse; therefore it can be modeled separately, affected only by the state of the heating appliance.

The complex thermal modeling problem of the house can be thus split into separate problems based on the causal relationships between the compartments. Figure 7 displays the mentioned models and their relationship.

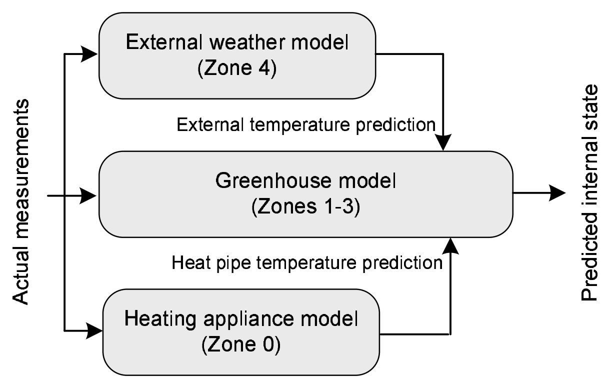

Figure 7: The decomposition of the modeling problem. The heating appliance model is only necessary in case of activated heating or hot heating pipes; otherwise it can be neglected.

The greenhouse model has to be available for all legitimate actuator setting combinations, because the actuators can change the structure of the greenhouse: e.g. the deactivation (retracting) of the shading unites Zone 2 and 3. Two possible solutions are to use the actuator states as the inputs of the model, or to create separate models for all possible situations. In the experimental greenhouse the number of legitimate actuator state combinations is limited about 20, because the activation of the heating is not allowed when any of the windows are open.

There are several methods to build the models predicting the state of the greenhouse. The next section focuses on the most important aspect of these models, namely the ability to follow model changes.

2.5 Adaptive Modeling

There are two possible ways to create the necessary models shown in Figure 7. The more accurate is the physical modeling of the house, but it is also time consuming and inflexible solution [6]. Using heat transfer equations and the known structure of the house, the model structure can be outlined, and the parameters can be identified. This method results in an accurate model at the time of the modeling (cf. the data used to identify the parameters), but without repeating the whole procedure it can not follow changes in the greenhouse (different type of plants or changes in the external conditions), furthermore every greenhouse has to be identified separately.

Other possibility is modeling the greenhouse with some kind of learning system. This solution also requires large number of measurement before the real operation could be commenced, but in this case the learning system can build the model from its own measurement, and can incrementally follow up the changes when the new data become available.

In both cases, the initialization of the model requires quite a large number of measurements; therefore the measurement system under the regime of intelligent control must be able to produce this data before the intelligent control can take over the house.

The second level of the intelligent greenhouse control incorporates the adaptive models, and makes the decisions based on the conformity of predicted state of the greenhouse with the goals set by the operator. This solution is similar to model predictive control methods. To build an even more effective system, activity planning has to be used, as detailed in the next section.

2.6 Planning

Predicting the future state of the greenhouse from the actual measurements and the choice of the best actuator setting yields great advantage over traditional control systems, but it still cannot ensure the optimal operation of the greenhouse. An even better solution is carefully planning the sequence of actuator settings. The control system is not limited to just evaluate the effects of changing the actuator settings in a given situation, but it can also predict the results of these changes, and plan the necessary operations to be implemented later in the future.

If the costs of single control commands could be calculated (this is simple for e.g. the gas consumption of the heating, but not so straightforward in case of calculating the amortization of the actuators or the cost of necessary repairs over time), then every plan could have a total cost value in the form of virtual or existing currency. The predicted states (at every sampling step) of the house can be checked for conformity with the selected goals: the sum of penalty function values can form a total penalty value. Figure 8 illustrates the evaluation of such plan on a short example.

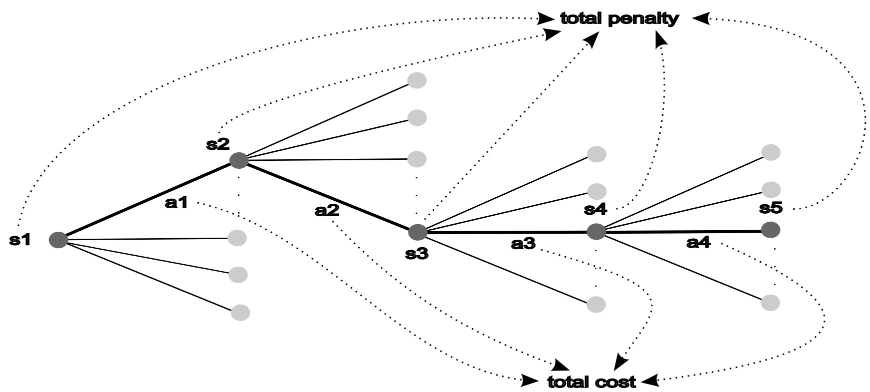

Figure 8: Evaluating a 4 step plan with states *s1-s5* generated by the actions *a1-a4*, from the starting state *s1*. The total penalty value is calculated from the predicted states of the system; the total cost is calculated from the actions of the control system (state transitions of the greenhouse).

The total penalty and the goal violation values can be used to select the best plan based on the preferences of the owner. The system can operate in the mode of maximum cost savings, or in the mode of optimal environment setting, or somewhere between these two extremities.

The planning makes it possible to take into account the regularly occurring natural effects, e.g. before the sunrise the heating can be turned off, if the inner temperature of the house is predicted to change properly only by the solar radiation. A similar situation occurs before the sunset, when the temperature of the house may be left higher, to conserve some extra energy, lessening the need of the costly heating at night.

Unfortunately the (configuration) space of plans, with e.g. a reasonable look-ahead 4 hours time span, and the measurements and control decisions made every 5 minutes, is too large to evaluate all possible plans in the run-time. The complexity of planning could be broken down by introducing constraints to the operation of the control system: e.g. the opening of the windows could be only allowed for a longer time span or moving the shading screen could be limited to once per hour. Such limitations would surely lower the complexity, but in return the optimality of the control would be lost, because in some rare situations the prohibited operations could still yield the optimal decisions. In the former example the opening of the windows even for a few minutes would be beneficial in spring late afternoon, when the overheating of the house could be avoided by letting in a small amount of the external cold air. Without such constraints on the possible operations in a plan the planning can not be performed in run-time because of the huge search space: the whole space of 4 hours plans with 5 minutes resolution and 20 legal actuator state has over 2^{200} different plans. Reduction of the search space is possible by planning on a higher abstraction level; therefore multilevel planning or other optimization methods are needed.

After finding the best plan, the control system has to activate the first step of the plan. Five minutes later, when the new measurement data become available, the planning process resumes from the beginning, however it seems a good heuristics to keep the best plan from the previous session and evaluate its possible extensions as the default options. This evaluation strategy can greatly cut down the planning time, because the earlier chosen plan is likely to be still the best, if no drastic changes in the conditions occurred within the measurement time span.

Planning is also useful while interacting with the greenhouse operators. The control system can explain the rationale of the control decisions, and with a suitable interface, the operators can also introduce special requirements for the planner, based on their needs or on occasionally available external information (e.g. weather forecasts, known actuator malfunctions, or economical needs).

The highest level of intelligent control incorporates all the methods outlined in the previous sections, namely goal formulation, predictive modeling and planning. Unfortunately the widely used low level control systems alone are not appropriate to run such control schemes, because of the high resolution and large volume of the data needed for accurate modeling, and the requirement of direct control of the actuators. It must be noted, that workarounds exist to current systems to eliminate these limitations (e.g. additional sensors can be connected, and appropriate setting of set-points can enforce direct actuator state changes), but a new measurement and underlying control system design seems to be more reasonable. Such system is introduced in the next section.

3 The Necessary Infrastructure for the Intelligent Control

3.1 Measurement System

The correctness of the planning relies greatly on the precision of the predictions, i.e. the accurate modeling. Traditional control solutions use only one measurement from the greenhouse to build the models, but due to the previously introduced zonal partition of the house, the accurate modeling here requires measurements from every zone. In a traditional system the set-points apply only to the single measurement point of the house. The goals of the intelligent system, on the contrary, should be allowed to be formulated with respect to any measurement location in the house. The most important part of the house is the direct surrounding of the plants; hence measurements from all desks (holding the potentially different types of plants with various demands) are needed. This scenario calls for a distributed measurement system in the greenhouse, to collect all the necessary measurements from every zone and from all desks. Figure 9 shows the topology of the measurement system developed for the experimental greenhouse.

Measurements collected by the system serve as the basis of the initial model building and the continuous model updating. Models are used to predict the future state of the greenhouse, which allows the selection of the best control plan as a function of costs and goal conformity. Every step of a control plan is a combination of actuator states; therefore the control system has to send out direct control commands to the actuators. This requires that the control system should be able to process direct control commands, instead of set-points. Such functionality does not exist in current industrial control systems because of a limited need for such a feature in the past. Although there are third-party interface applications aiming to present a standard interface to the greenhouse environment control computers, their functionality is also limited to measurement data extraction and set-point adjustment [11].

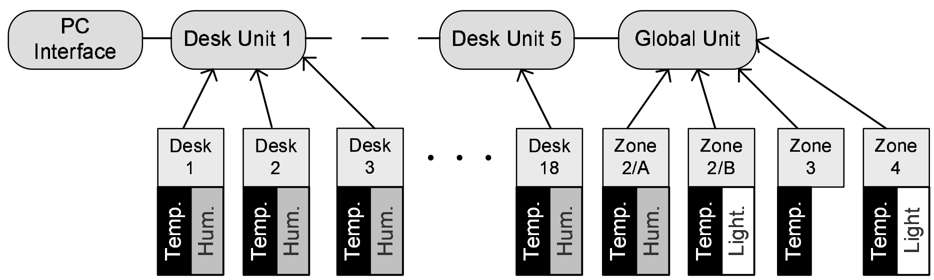

Figure 9: The layout of the measurement system: rounded rectangles (top) represent microcontroller units communicating on a bus, and collecting measurements from the different locations of the house (middle) with different type of connected sensors (bottom). (Temp. = temperature; Hum. = relative humidity)

Under such conditions it seems reasonable to develop a separate control system along with the measurement system described in this section. The control system must fulfill the needs of the intelligent control, and in the experimental greenhouse it must also support the development of the whole, integrated intelligent control solution. The next section deals with the control system in detail.

3.2 The Development Support Control System

The control system presented here has two major goals: to support the development of the intelligent system, and to provide the reference implementation of the underlying system.

To minimize the effort of intelligent control development in the future, the system demands flexible and remotely available interface to serve measurement data and to accept commands. The current system has a standard SQL interface and is able to export measurement data directly to the Matlab environment. Secure remote access is essential to make it possible to experiment with data in various environments (because of high computational complexity of e.g. evaluating large number of different models, the data archiving computer cannot be used as a development platform). Remote access capabilities ensure, that modeling, or even running the test implementation, can be done under appropriate conditions.

With respect to the reference implementation of the control system problems arise with the selected adaptive modeling approach. The initial model building requires numerous measurements, thus prior to the operation of the intelligent control, measurements must be collected. For the accurate modeling, the measurements should cover practically all possible states (actuator state combinations) of the greenhouse. Besides the recording of the measurement data, the state of the actuators must be monitored and recorded as well, which is beyond the capabilities of the measurement system designed only to sense physical parameters. This necessary information could be collected by monitoring the state of different actuators with dedicated sensors, or by developing a simple control system for the house to cooperate with the measurement system. The second solution was chosen, because this simple control system could be implemented at the reliable level of microcontrollers, yielding the following advantages: (1) it can control the house before the intelligent control is ready to be tested in the experimental greenhouse, and later on (2) it serves as a backup system, in case of software or hardware failure of the intelligent control running on an unreliable (possibly remote) computer.

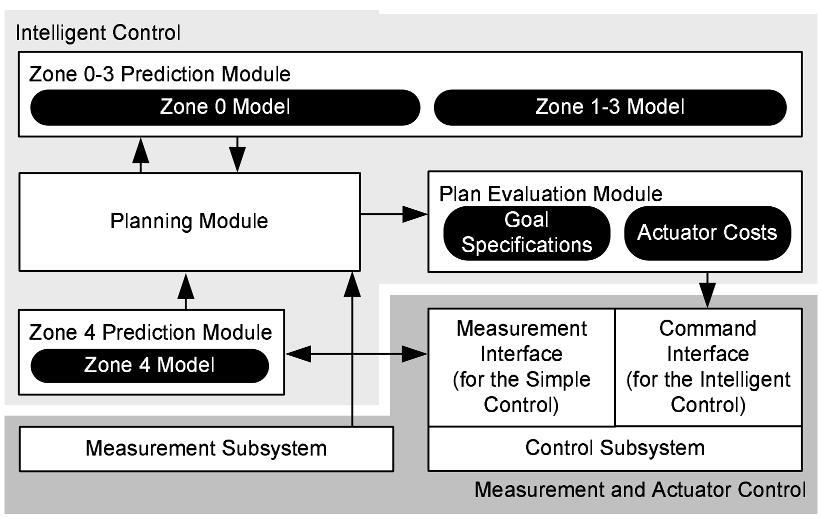

Figure 10: The scheme of the complete intelligent control

The structure of the measurement and control system and the intelligent control solution is illustrated in Figure 10. The data supplied by the Measurement Subsystem is used for the Simple Control (if necessary), and as inputs for the Planning Module and the Zone 4 Prediction Module. Prediction for Zone 4 (namely the external temperature) is created only once before planning (considering that the actuator commands in the potential plans cannot change Zone 4), while the

Zone 0-3 Prediction Module is used for every step of the potential plans. After the planning process the potential plans are evaluated by the Plan Evaluation module using the Goal Specifications and the known Actuator Costs. The result of the evaluation is the best plan, and that plan has to be executed using the Command Interface of the Control Subsystem.

4 Results

The main limitations of the traditional control solutions for greenhouses are their reactive nature, the missing synchronization of the actuators and the set-point based configuration. These drawbacks can be eliminated by the intelligent control system described in this paper.

The difficulties of finding out manually the optimal set-point configuration (without exact knowledge of the coupling between the different actuators) can be overcome by specifying goals for the control system. Goal specification belongs to the competence of the greenhouse operator and is based on the needs of the cultivated plants, unlike the set-point tuning, which requires knowledge and overview of the control logic. This approach ensures a comfortable interface and communication with the operator, and leaves it free to the control system to do almost anything to best fulfill the goals. This freedom is of course limited by financial constraints, but such limitations can be also specified as goals, and their priority (set by the operator) determines the balance between cost saving or optimal environment conditioning.

The reactive nature of the traditional control systems - namely reacting only after the set-point limitations are violated - can be avoided by the predictive control. To create accurate predictions a detailed modeling of the greenhouse is necessary. Because of the close relationship between the greenhouse and its environment, modeling of the external weather cannot be neglected either. In the external weather (in this case temperature) modeling simple methods are favored, because the computing power of the control system should be preserved to maintain the complex adaptive models of the greenhouse and planning. Therefore two time-series mining solutions were introduced to solve the external temperature prediction problem. Modeling the greenhouse itself can be also decomposed into the modeling of the heating appliance (behaving almost independently when activated, and having no effect after total cool down) and the other zones of the house. Modeling and predictions make it possible to take the necessary actions before harmful situations occur in reality.

Once the goals are specified and the models built, the central component of the intelligent control system is the planning module. This module evaluates control plans by their operational costs (e.g. price of gas or electricity used) and their conformity with the given goals (how optimal is the environment for the plants). After finding the best plan, its first step is executed, and in the next control cycles the planning starts over again. Planning ensures the ability of the system to select the best control option at any given time for the whole oncoming planning time span, making it possible to take into account natural phenomena such as sunrise or sunset. The accurate modelling and the need to execute direct actuator commands based on the best plan call for a novel measurement and control system design underlying the intelligent control. This system has to provide the required number of measurements from all important locations of the house and must be able to handle direct commands of the actuators.

The intelligent control concept described in this paper represents the methods and the modules necessary for such a control in a medium sized greenhouse with several (but not plenty) actuators. This solution can be also generalized to other greenhouses, as the potentially larger number of zones, or the smaller number of actuators does not affect the scheme itself. The control concept can also be applied to other buildings with similar controlled thermal environment, although the positive effects of forward planning greatly relies on the close thermal coupling of the greenhouse and its environment. The selection of appropriate models for the greenhouse and solving the complexity problem of planning requires future work.

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