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DESIGN AND SIMULATION OF A SCADA – CONTROLLED GREENHOUSE FOR OPTIMIZED ROSE CULTIVATION

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Abstract. This study presents the design and simulation of a SCADA system for monitoring and automated control of environmental and operational parameters in a rose greenhouse. The development of the SCADA system within this project was supported by the Ignition platform – a modern, modular and industrially oriented software solution from Inductive Automation, which enables the creation of SCADA, HMI and IoT applications. Careful design considerations were applied to ensure that the virtual model accurately reflects actual operational conditions. By modifying the parameters, the system can be easily adapted to manage different types of plants. The application of SCADA technology in horticulture enables advanced resource optimization strategies, resulting in enhanced greenhouse production outcomes, operational performance and efficiency. By combining design and simulation, this study highlights the potential of virtual SCADA systems as tools for planning, analysis, and development of efficient solutions for process management in contemporary horticulture. While the simulation confirms that the design meets all specified requirements, real greenhouse implementation would require modifications or adjustments to the control logic to adapt to actual operational conditions.

1. Introduction

Operating as a centralized control platform, SCADA systems integrate computing technologies, communication networks, data acquisition units and interactive graphical interfaces. Utilizing continuous observation, real-time analysis and automated control mechanisms, SCADA systems enhance operational efficiency and support prompt intervention during critical situations. The foundations of the first SCADA systems were introduced in the 1960s to address the rising demands for supervision and automation of complex processes within the industrial sector. Over the years, they have evolved into advanced technological platforms that support intelligent real-time process management. Improvements are reflected in their functionalities, including remote access, predictive diagnostics, data processing and enhanced security protocols. Driven by growing industrial requirements for efficiency, continuity, reduction of operating costs and production quality, modern horticulture is confronted with the demand to integrate advanced technological solutions that facilitate automated control. Greenhouse construction management is a multi-factor optimization problem that affects crop yield and resource utilization efficiency of land, water, and energy [7]. Within the scope of this project, a SCADA system was virtually developed to replicate the functional conditions and operational dynamics of a greenhouse specialized for rose cultivation. Greenhouse complex nonlinear coupled climate and biological models are discussed with high importance in greenhouse optimal control solutions [6].

Keywords. Tag, alarm, temperature, soil moist, air humidity, script

2. Background and Related work

Automated control systems have been widely implemented in modern horticulture, demonstrating their effectiveness in managing environmental conditions. Various studies have explored the application of SCADA systems in greenhouse management, indicating significant potential for process automation and real-time monitoring. Building on the general concept of SCADA-controlled greenhouses, we introduce our original simulation framework that models both climatic and irrigation parameters for optimized rose growth. Our approach uses control logic, sensor modeling and data visualization without relying on pre-existing template or code. It should be noted that the parameter values used in the simulation are based solely on scientifically established standards and recommendations from relevant professional literature and are not original findings of this research.

3. Optimal Cultivation Parameters

In greenhouse cultivation, optimal conditions are defined by a precise set of specified operational and environmental parameters that support a controlled and productive microclimatic setting for plant development. Determining what the basic measurands that have to be considered are is essential for the design of a monitoring and control system for the greenhouse environment [8]. Being both delicate and commercially valuable, roses require precise control over their growing conditions. Accordingly, the SCADA system provides continuous monitoring and regulation of the following parameters: temperature, relative air humidity and soil moist. Temperature regulation is performed based on the plant’s growth stage given in Table 1. The SCADA system provides dynamic regulation through manual phase selection, triggering relevant control mechanisms (heating or cooling) to keep the temperature within defined boundaries.

Table 1. *Optimal temperature regime*

Development phase	**Range**	**Phase description**
Vegetative growth	3°C – 9°C	Growth of roots, stems and leaves
Bud emergence	10°C – 15°C	Bud initiation stage
Bud enlargement	18°C – 22°C	Bud growth and formation
Flowering	16°C – 20°C	Flower opening stage
Second flowering cycle	14°C – 20°C	Secondary flowering

Relative air humidity indicates the proportion of water vapor in the air and its maximum capacity at a specified temperature. Maintaining levels between 70% and 80% supports effective water regulation and improves floral outcomes, while deviations may provoke dehydration and increase pathogenic infestations. Air humidity is regulated by coordinating automated sprinkler-based humidification and ventilation mechanisms. Although roses tolerate relatively dry soil, ideal soil moisture levels are maintained between 21% and 40%. The irrigation system is activated when soil moisture drops beneath the lower limit. The SCADA system provides real-time monitoring of the specified parameters through a distributed sensor network within the greenhouse environment.

4. Function and Relevance of SCADA

By monitoring and controlling optimal growing conditions, the system supports efficient greenhouse management and process optimization. The SCADA system performs a range of critical functions:

- temperature monitoring,
- air humidity monitoring,
- soil moisture monitoring,
- controlling ventilation and air conditioning system,
- operating the irrigation system,
- alerting when monitored parameters exceed or fall below the defined limits.

Additionally, the system allows real-time visualization of the current conditions through a graphical interface, presenting all monitored parameters continuously. Every modification in the monitored parameters is recorded and can be analyzed. Consequently, the SCADA system not only provides automation but also establishes the basis for smart and sustainable greenhouse management. The system's design supports expandability and modification, enabling its application with different plant varieties. Parameter settings and control logic can be modified without the need for a complete system redesign.

5. Layout and Architecture of the Sensor and Control System

Modern greenhouses are technologically advanced and controlled agricultural systems, designed to maintain optimal growing conditions for cultivated plants, regardless of external environmental variations. Today, with the application of technological means, the function of greenhouses is not only to provide physical protection from external influences, but also to enable dynamic adjustment of internal conditions, according to the precisely defined needs of the plants that grow in them. The model for which the simulation is intended is designed with the dimensions of a small greenhouse: length 4 m, width 3 m, and maximum height 3 m. This prototype was chosen to enable SCADA implementation, while retaining all fundamental features of a greenhouse. The greenhouse interior is structured into two cultivating areas, each 3 m by 0.6 m, separated by 0.6 m, establishing a well – defined zone for simulating agronomic activities.

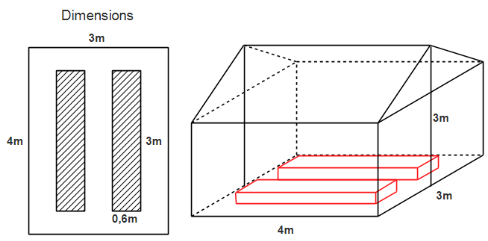

Figure 1. *Dimensions of a greenhouse*

Based on the information obtained from the sensors, the SCADA system applies algorithms to regulate the relevant operation of the associated control systems, minimizing the need for manual intervention and increasing operational efficiency.

The sensor system is carefully dimensioned and arranged to create realistic estimation of climatic and soil conditions. Soil moisture sensors are installed in each of the cultivating areas. Their function is directly linked to the activity of the irrigation system, which receives water from a reservoir and transfers it to the entire planting area. The temperature and air humidity sensors are positioned at a height of 1 m, in order to obtain reliable data of the microclimate in the area. The air conditioning system is placed at a height of 2 m. Its function is to maintain stable internal conditions, in accordance with the values registered by the sensors. This organization enables symmetrical distribution of equipment and efficient coverage of the entire space by sensor and control components.

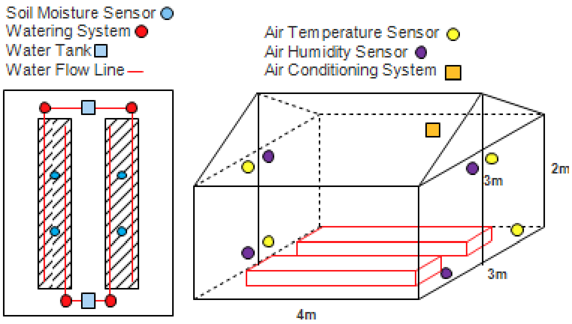

Figure 2. *Sensor system*

6. **Simulation Software Platform Selection**

Since this project is implemented exclusively as a simulation, without any physical components, the entire system was developed in a virtual environment. Therefore, the selected software must provide not only a visual representation of the process, but also the ability to program operating logic, interactive visualization, data processing, alarm generation, and analysis of system behavior under different operating conditions.

The Ignition platform supports integration with various types of industrial devices, such as PLCs, sensors, and databases, making it highly flexible and suitable for a wide range of automation applications. Through Ignition, the SCADA system can be accessed from any location over the Internet, which is particularly important for modern industrial processes requiring flexibility and immediate response to changes. Ignition comes with a built-in Ignition Designer, as a powerful integrated development environment (IDE). Within the Ignition software platform, the Perspective module offers a modern approach to developing web-based user interfaces. This module allows the development of visualizations accessible through standard Internet browsers. Perspective's key advantage is its ability to provide access and control through mobile devices, which is particularly valuable for remote supervision. Perspective is mobile-oriented, meaning it automatically adapts to changes in screen size and orientation, giving users a personalized view into their processes that are automatically optimized for whatever device they are on[1].

7. Process Variables and Tags Configuration

Process variables are a selection of specific parameters that directly reflect the physical state of the controlled process. The greenhouse SCADA design is built around agro-technically defined variables such as temperature, humidity and soil moisture. To simulate these parameters in Ignition, each process variable is represented with a corresponding tag. Tags in Ignition are digital representations of physical or logical parameters used to monitor, control, and analyze the process. The developed SCADA system relies on fundamental process tags for the simulation of environmental and soil variables:

- *Air Temperature* – This tag simulates the current air temperature value. The value changes dynamically depending on the status of the heating and cooling system.
- *Air Humidity* – This tag simulates the relative air humidity, whose value adjusts dynamically depending on the operation of ventilation and sprinkler systems.
- *Soil1* and *Soil2* – These tags represent soil moisture sensors assigned to the two planting areas. Their values are dynamically modified by the irrigation system.
- *Phase* – This tag is an integer memory variable with values ranging from 1 to 5, each representing a specific biological growth stage. Depending on the phase, the system sets the required temperature range.
- *C1–C5* or *H1–H5* – These tags are auxiliary expression tags for cooling and heating based on the biological phase. Each tag activates when the Air Temperature crosses the defined boundary (upper for cooling, lower for heating) of the respective phase and remains active until the temperature stabilizes within the designated setpoint.

The SCADA simulation operates through a set of defined algorithms that control the behavior of the process variables. As the simulation runs, all tags are updated in real time, reflecting changes in the process state. The algorithms also allow testing of control strategies under various hypothetical conditions.

Algorithm 1 Expression for C2

Input: Phase, Air Temperature, Cooling
Output: C2

if (Phase = 2 **and** Air Temperature > = 15) **then**
    C2 = 1;
else if (Phase = 2 **and** Air Temperature > = 12 **and** Cooling = 1) **then**
    C2 = 1;
else
    C2 = 0;
end

[1] https://www.docs.inductiveautomation.com/docs/8.1/ignition-modules/perspective

- *Cooling* or *Heating* – These tags are a Boolean expression variable, defined through the disjunction of C1-C5 for cooling and H1-H5 for heating, ensuring automatic activation whenever conditions demand it.

Algorithm 2 Expression for Heating

Input: H1, H2, H3, H4, H5
Output: Heating

if (H1 = 1 **or** H2 = 1 **or** H3 = 1 **or** H4 = 1 **or** H5 = 1) **then**
  Heating = 1;
else
  Heating = 0;
end

- *Ventilation* – This tag represents the activation of the ventilation system. It is activated when *Air Humidity* exceeds 80% and remains active until it decreases to 75%.

Algorithm 3 Expression for Ventilation

Input: Air Humidity, Ventilation
Output: Ventilation

if (Air Humidity > 80) **then**
  Ventilation = 1;
else if (Air Humidity > = 75 **and** Ventilation = 1) **then**
  Ventilation = 1;
else
  Ventilation = 0;
end

- *Sprinklers* – This tag functions as a Boolean expression variable, controlling the activation of the water sprinkler system. It is activated when *Air Humidity* falls below 70% and remains active until it reaches 75%.

Algorithm 4 Expression for Sprinklers

Input: Air Humidity, Sprinklers
Output: Sprinklers

if (Air Humidity < = 70) **then**
  Sprinklers = 1;
else if (Air Humidity < = 75 **and** Sprinklers = 1) **then**
  Sprinklers = 1;
else

```
        Sprinklers = 0;
    end
```

- *Tank_Level* – This tag indicates the current water level in the reservoir as an integer value from 0 to 100 (%). During irrigation, the *Tank_Level* decreases by 2% if only one cultivating area is irrigated and by 4% if both areas are irrigated simultaneously. When the tank is refilled, the value increases by 1%.
- *Refill* – This tag functions as a Boolean variable and it signals that the reservoir is filling with water. It activates when the *Tank_Level* falls below 20% and stays active until the tank reaches 90%.
- *Watering1* and *Watering2* – These tags are Boolean variables that represent the irrigation status for each cultivating area. They become active when *Soil1* or *Soil2* falls below 21% and stay active as long as the moisture remains under 40%.

Control logic is used to simulate real conditions for temperature, air humidity, soil moisture, the operation of heating, cooling, ventilation, sprinklers, irrigation systems, as well as the change in the water level based on the activity of irrigation and refill systems.

8. Control logic

The SCADA simulation includes two separate scripts that are designed to implement dynamic modeling of air temperature and humidity variations, and to control the irrigation system and soil moisture. These scripts are executed periodically, thereby continuously updating the tag values. The first script is developed to model the dynamic behavior of *Air Temperature* and *Air Humidity* in the greenhouse environment, based on the operational status of the respective climate control systems.

Algorithm 5 Script for air temperature and air humidity regulation

Input: Air Temperature, Cooling, Heating, Air Humidity, Sprinklers, Ventilation
Output: Air Temperature, Air Humidity

```
initialization;
  read all tags:
    Air Temperature, Cooling, Heating, Air Humidity, Sprinklers, Ventilation;
  set value  = Air Temperature;
  set value2 = Air Humidity;
end
  while not at end of this document do
    read current;
    if (Cooling = 1) then
      value = random (Air Temperature – 0.5, Air Temperature);
    else if (Heating = 1) then
      value = random (Air Temperature, Air Temperature + 0.5);
```

```
    else if (Cooling = 0 and Heating = 0) then
      value = random (Air Temperature, Air Temperature + 0.5);
    end       if (Sprinklers = 1) then
      value2 = random (Air Humidity, Air Humidity + 1);
    else if (Ventilation = 1) then
      value2 = random (Air Humidity – 1, Air Humidity);
    else if (Sprinklers = 0 and Ventilation = 0) then
      value2 = random (Air Humidity – 1, Air Humidity + 1);
    end

    write:
       Air Temperature = value,
       Air Humidity = value2;
  end
end
```

A separate script is dedicated to the control of soil moisture within the cultivation areas. Whenever the readings fall under the required range, irrigation is automatically triggered and maintained until stability is achieved. Water usage is modeled through corresponding decreases in the tank level value in proportion to irrigation intensity. Additionally, the script provides an automatic refill cycle, avoiding water shortages.

Algorithm 6 Script for irrigation control and tank level management

Input: Air Temperature, Cooling, Heating, Air Humidity, Sprinklers, Ventilation
Output: Air Temperature, Air Humidity

```
initialization;
  read all tags:
    Watering1, Watering2, Tank_Level, Refill, Soil1, Soil2;
  set new_w1 = 0;
  set new_w2 = 0;
  set new_refill = Refill;
  set new_tank = Tank_Level;
  set new_s1 = Soil1;
  set new_s2 = Soil2;
end

while not at end of this document do
  read current;

  if (Soil1 < 21) then
```

```
   new_w1 = 1;
else if (Soil1 < 40 and Watering1 = 1) then
   new_w1 = 1;
end

if (Soil2 < 21) then
   new_w2 = 1;
else if (Soil2 < 40 and Watering2 = 1) then
   new_w2 = 1;
end

if (Tank_Level > 20) then
   if (new_w1 = 1 and new_w2 = 1) then
      new_tank = Tank_Level - 4;
   else if (new_w1 = 1 or new_w2 = 1) then
      new_tank = Tank_Level - 2;
   end
end

if (new_tan <= 20) then
   new_refill = 1;
   new_tank = new_tank + 1;
else if (new_tank <= 90 and Refill = 1) then
   new_refill = 1;
   new_tank = new_tank + 1;
else
   new_refill = 0;
end

if (new_w1 = 1) then
   new_s1 = random (Soil1, Soil1 + 1);
end

if (new_w2 = 1) then
   new_s2 = random(Soil2, Soil2 + 1);
end
write:
   Watering1 = new_w1,
   Watering2 = new_w2,
   Tank_Level = new_tank,
   Refill = new_refill,
   Soil1 = new_s1,
```

```
        Soil2 = new_s2;
    end
end
```

---

9. Monitoring Display and Notifications

As part of the simulation, the setup includes two interfaces: one for displaying the main parameters and regulated systems and another for visualizing alarm situations. The main SCADA interface, illustrated in Figure 6, consists of two segments: climate and soil. Air temperature is controlled according to the growth phase using heating and cooling systems. Air humidity is controlled by ventilation and sprinklers. Soil moisture is monitored in both cultivation areas and adjusted through the irrigation system. Digital displays present current values and water tank level is visualized and updated according to the irrigation and refill operations. System activity is indicated through status switches, reflecting the implemented control logic.

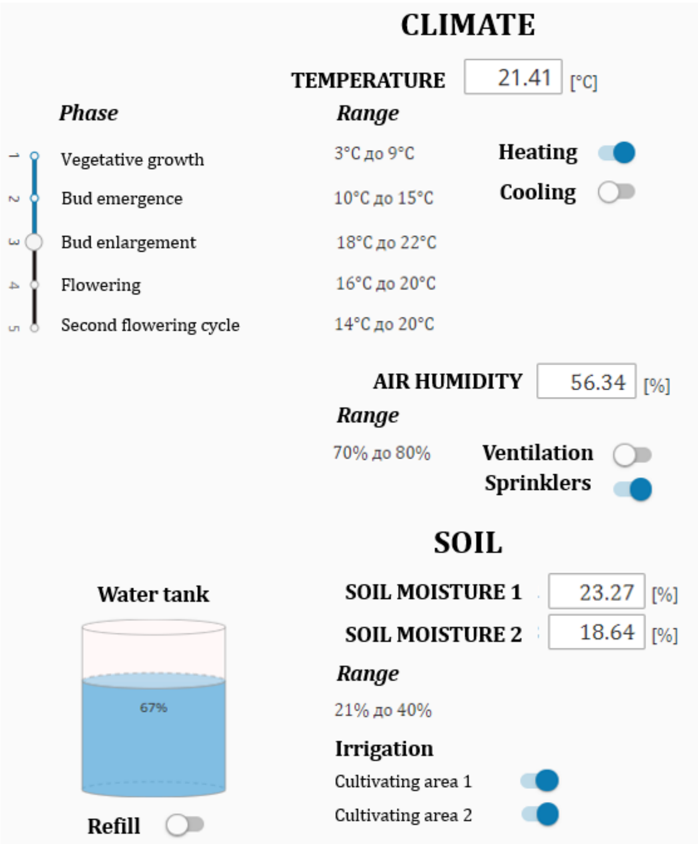

Figure 6. *Main screen for the greenhouse SCADA system*

The alarm interface supports interactive control through clearly structured alarm notifications, ensuring that corrective actions can be taken immediately. All active and historical alarms are displayed in real time, as shown in Figure 7, with defined priority levels that allow operators to identify critical issues and respond accordingly.

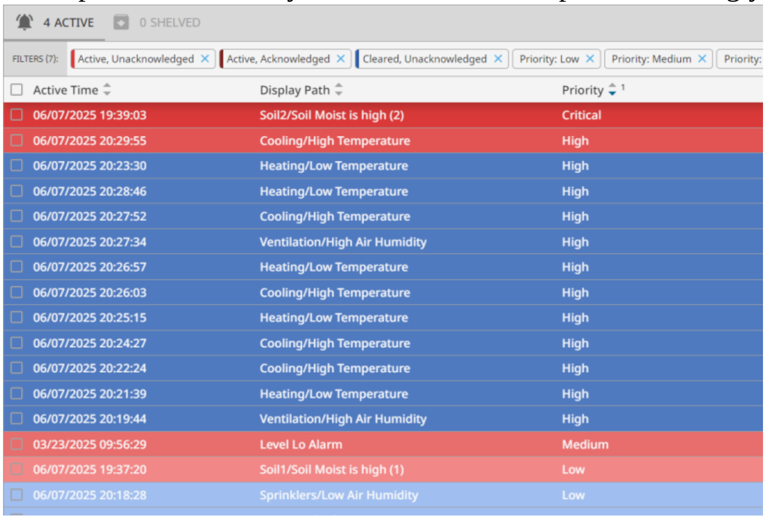

Figure 7. *Alarming system*

10. **Results and discussion**

This simulation is a useful tool for analysis, testing and optimization of control algorithms, without the need for real physical infrastructure. Acting as a centralized control framework, the system continuously monitors and automatically adjusts parameters to sustain the ideal conditions necessary for healthy plant growth and development, regardless of external environmental influences. The goal is to show through virtual modeling how this system can effectively contribute to the regulation of climate parameters and rational resource management. The system, with the implemented simulation code, is fully functional and capable of regulating the greenhouse parameters within the defined ranges. However, if it were a real system, the values simulated by the scripts would be real sensor readings. In order to implement this system in a real greenhouse, the simulation scripts that currently generate dynamic changes in temperature, air humidity, and soil moisture would need to be adapted to read actual sensor inputs instead of virtual values. This approach serves as both an educational framework and a foundation for future system implementation. Based on the simulation results and the monitoring of dynamic tag values, the following conclusions can be drawn:

- The greenhouse prototype successfully maintains the environmental conditions within the defined optimal ranges;
- Temperature, air humidity and soil moisture parameters respond as expected to the implemented control logic;

- Sensor modeling in the simulation accurately reflects changes in the system, although actual sensor readings would be required for real-world implementation;
- The irrigation system operates according to soil moisture optimal ranges, demonstrating proper activation and refill cycles;
- The system is fully functional in the simulated environment, but for practical application, the code needs to be adapted to read real-time data from physical sensors.

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