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Research article

CULTIVATIONS CONTROL SYSTEM IN A FOIL TUNNEL

Przemysław Filipek[1]✉

[1] Lublin University of Technology, Faculty of Mechanical Engineering, Nadbystrzycka 36, 20-618 Lublin, Poland
✉ corresponding author: p.filipek@pollub.pl

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ABSTRACT

The foil tunnel crop control system presented in this article operates an irrigation system and a system that regulates air temperature and humidity. The irrigation system consists of solenoid valves, supplying water to a tunnel area divided into four zones. This allows four different types of plants to be grown. The system uses rainwater, collected in a reservoir when it is available. The water is delivered to the plants via by means of rubber hoses with holes. Thanks to this solution, the water is fed directly under the plant. The executive elements of the control system temperature and humidity are a motor and a fan. The motor opens the window when the measured parameters exceed the set value. If the humidity of the air is too high the fan is switched on, accelerating the air exchange. The system has an anemometer, the purpose of which is to measure and report dangerously strong winds. When the wind speed exceeds a critical value, the microcontroller forces the windows to be closed to protect the tunnel. The system also has a display, showing values of measured parameters and setpoints, as well as buttons to view them and change the expected value. An alarm is attached to the system. It is activated when the microcontroller registers a parameter value that is impossible to achieve under the tunnel's operating conditions. This indicates a possible failure of the measuring system. The executed system correctly adjusts the indicated parameters within its tolerance. The system has confirmed its usefulness, effectively reducing the time and labour required for plant care.

KEYWORDS: foil tunnel, irrigation system, rainwater, temperature control, air exchange

1. Introduction

For more than a century, there has been rapid population growth as a result of technological development, and the process of urbanization has left less and less room for agriculture [1]. In order to meet the needs of the population, the search began for solutions to obtain the maximum possible yield from a given acreage. A milestone in this direction was the flourishing of electronics, especially programmable electronics, which made it possible to automate control processes.

Control systems, applied to crops, allow the measurement of plant growth parameters, such as soil moisture or temperature, and their regulation. As a result, optimal conditions for plant growth are provided, which significantly increase yields. Nowadays, such systems are widely used not only in industrial-scale productions, but also in amateur crops. The increasingly lowers the cost of electronic components and the intuitiveness of their operation make people more willing to use control automation even in small facilities such as plastic tunnels for growing plants.

2. Design assumptions

The basis of the designed control system will be the Arduino microcontroller Mega 2560.The task of the microcontroller will be to process signals from measurement sensors and to control the actuators accordingly. The system will be divided into two independently operating blocks – the irrigation system and the system that regulates air temperature and humidity. The tunnel area will be divided into four zones (Figure 1). A sensor, measuring soil moisture, will be placed in each of these sections. Combining the system with an appropriate number of actuators - electro-valves, will allow independent regulation of soil moisture for each zone. The system made this way will make it possible to grow four different types of crops. In addition, the irrigation system will have a tank for rainwater and a sensor, measuring its level. The microcontroller receiving the signal from the sensor will decide on the type of water supply for the system. By default, the irrigation system will use water from the reservoir, but in case of a shortage of water it will switch to the mains water supply.

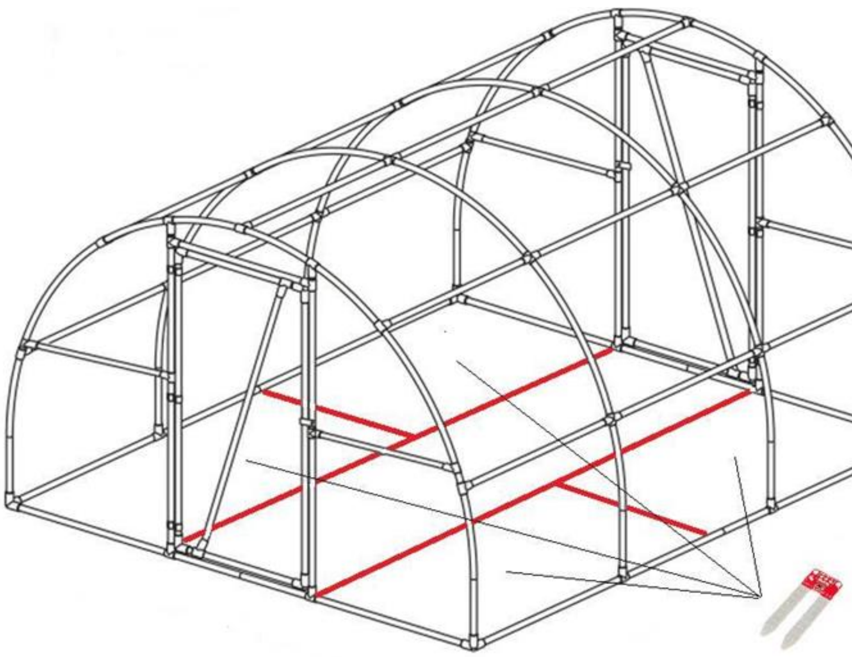

Figure 1. Tunnel design with zoning [2]

The second system will consist of, among other things, temperature and humidity sensors. These sensors will affect the opening and closing of the window. In addition, if necessary, a fan will be switched on to increase air circulation inside the tunnel. The element coupled to the system will be an anemometer. It will become a safety element. In the case of a strong wind, the microcontroller will force the window to close to avoid damage.

The control system will also be equipped with an LCD display and three buttons, which will allow the setpoints to be easily changed without interfering with the control program. The first button will allow viewing the setpoints and values measured by each sensor. Using the other two buttons it will be possible to change the setpoints.

2.1. 3D model

Below is a 3D model of the tunnel with the planned arrangement of the implementing elements. The model was made in the Solid Edge program. Figure 2 shows the overall design of the tunnel.

The next drawing (Figure 3) shows the connection of the motor to the window and the location of the fan.

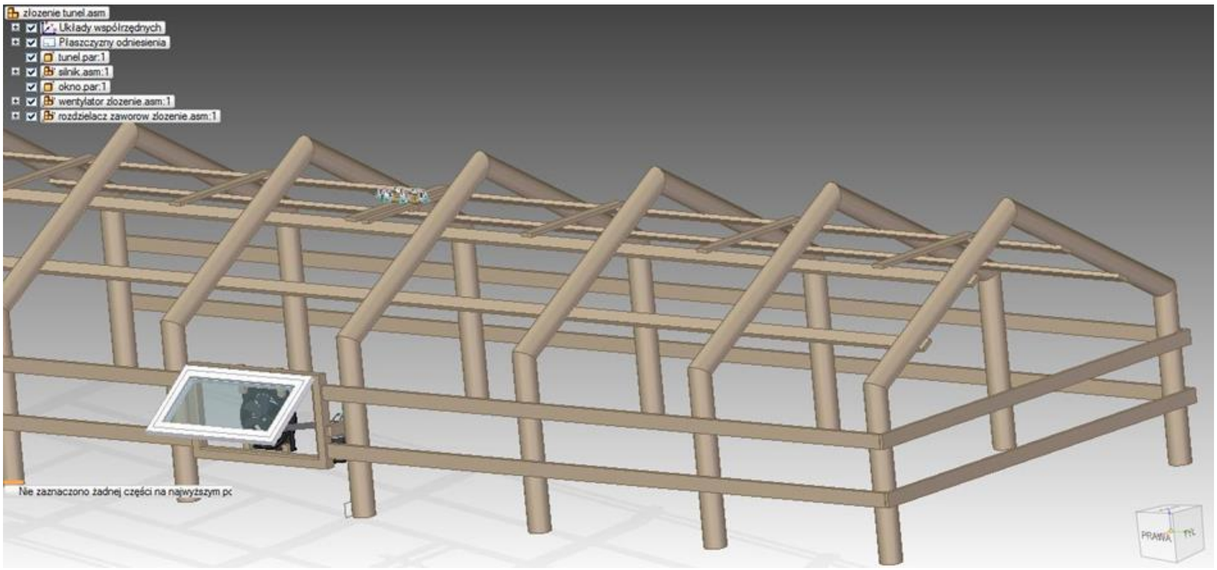

Figure 2. Tunnel construction model

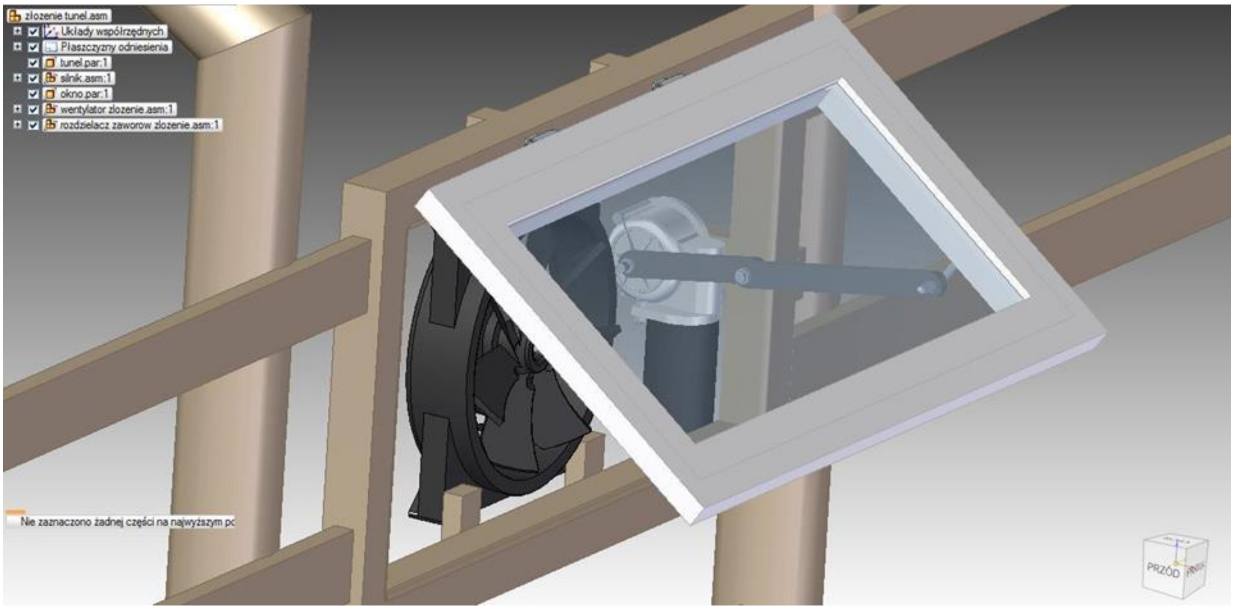

Figure 3. Window and motor connection

2.2. Electronics

The most important element of the designed control system is the microcontroller. The module used will be Arduino company's Arduino Mega 2560, based on the AVR ATmega2560 microcontroller. The processor is clocked at 16 MHz and has 256 kB of Flash program memory, 8 kB of SRAM and 4 kB of non-volatile EEPROM memory [3].

The described module will be used in the project due to the large number of required pins. In addition, the remaining free pins can be used to expand the system or to support an analogous system for the second tunnel.

A DS18B20 digital sensor will be used for temperature measurement. The range of the measured temperature is -55 ^{o}C ÷ 125 ^{o}C. The measurement accuracy for the range of 10 ^{o}C ÷ 85 ^{o}C is

± 0.5 °C. Another measuring element, included in the system regulating the temperature and humidity, is a digital sensor DHT11, allowing both relative humidity and temperature measurement. The measurement range of air humidity is 20 %RH ÷ 90 %RH, and the measurement accuracy is ±4 %RH.

The executive elements of the air temperature and humidity control system will be: a car wiper motor and a car radiator fan. The task of the motor will be to open or close the window. It will be powered by a power supply 12 V, with a capacity of 5 A.

The fan will be switched on when the set value of relative humidity has exceeded relative humidity of the air. Its task will be to increase air circulation inside the tunnel and accelerate its exchange with the outside air. Due to quite high current consumption, the fan will be powered by a rectifier. The role of the sensor measuring soil moisture will be performed by the probe module. The principle of its operation is to measure the voltage drop between two electrodes placed in the soil. The module sends a signal to the microcontroller that is inversely proportional to changes in soil moisture.

To measure the volume of water in the tank, an ultrasonic sensor HC-SR04 will be used, whose measuring range is: 2 cm ÷ 200 cm. The sensor measures the return time of a sound wave with a frequency of 40 kHz, then sends a signal whose duration is proportional to the measured distance [4]. The components responsible for controlling the flow of liquid will be valves electromagnetic valves [5]. The valves are powered by 12 V DC and are NC type. Reviewing the control parameters will be enabled by an LCD display [6] having two lines of 16 characters each. The display is operated by the built-in controller HD44780 [7].

2.3. Software

The code fragments of the control program show the code fragment responsible for opening the window.

```
void loop(){
...
if (anem.permission())
 {
 int suma = temp.windowCondition() + hum.windowCondition();
 if(suma > 0 && !windowPosition)
  changeWindowPosition(windowPosition);
 else if(suma <= 0 && windowPosition)
  changeWindowPosition(windowPosition);
 }
else if(!anem.permission() && windowPosition)
 changeWindowPosition(windowPosition);
}

int Temp::windowCondition()
{
 if(showReadValue() >= showSetpointValue() + 2*hysteresis
  && showReadValue() > outsideTemperature + 2*hysteresis)
   return 2;
 if(showReadValue() > showSetpointValue()
  && showReadValue() > outsideTemperature + 2*hysteresis)
   return 1;
 else if(showReadValue() < showSetpointValue() - hysteresis)
   return -1;
 return 0;
}

int Humidity::windowCondition()
{
 if(showReadValue() >= showSetpointValue() + 2*hysteresis)
 {
```

```
  digitalWrite(ventilator, LOW);
  return 2;
 }
 if(showReadValue() > showSetpointValue())
 {
  digitalWrite(ventilator, HIGH);
  return 1;
 }
 else if(showReadValue() < showSetpointValue() - hysteresis)
 {
  digitalWrite(ventilator, HIGH);
  return -1;
 }
 digitalWrite(ventilator, HIGH);
 return 0;
}

void changeWindowPosition (boolean & _windowPosition)
{
 digitalWrite(ventilator, HIGH);
 digitalWrite(motor, LOW);
 delay(500);
 do
 {
  digitalWrite(motor,LOW);
 }while(digitalRead(motorLimitSwitch) == HIGH);
 digitalWrite(motor, HIGH);
 !  windowPosition; }
```

The anem object is an object of the anem class, defining methods responsible for the operation of the anemometer. The permission() method returns a binary variable specifying permission to open a window. The value of this variable is determined by the wind speed and the set value of the allowed wind speed. The windowPosition variable is also a binary variable, specifying the position of the window - a value of True indicates an open window. The windowCondition() methods of the temp and hum objects determine the "willingness" to open a window, i.e. that a single method does not determine whether a window is open, only the sum of the values returned by the two methods. The windowCondition() method returns 2 when the measured value is greater than the sum of the setpoint and the doubled value of the hysteresis variable, 1 when the measured value exceeds the setpoint, -1 when the measured value is less than the difference of the setpoint and the hysteresis variable, and 0 otherwise. The hysteresis variable is an integer variable through which an artificial hysteresis loop is created. This avoids the continuous change of the window position. The returned value of 1 indicates the desire to open the window, -1 the desire to close the window, and 0 the transient state. When the returned value equals 2, it means that the measured parameter significantly exceeds the setpoint, and in order to protect the plants, the method forces the opening of the window. This is the only case where a comparison of the values of only one parameter.

3. Actual execution

The control system has been housed in an enclosure under a canopy. The enclosure is suspended from the wall tangent to the end of the tunnel.

Figure 4 shows a manifold with valves. The valves mounted on the left and right correspond to individual irrigation zones. The two outermost valves are used to select the water source. The output of the valves has been reduced to 1/2". This resulted in higher pressure in the rubber lines. Connections valves with the manifold and valves with reducers have been sealed on the inside with with tarpaulins and with silicone on the outside. The rubber lines are placed a few centimeters above the ground. They are supported by metal hooks. Thanks to this, water from the holes is directed downwards, under the plants.

Figure 4. Connection of valves to the manifold

Rainwater is collected in a Mauser-type tank. The ultrasonic sensor was attached to a suitably bent flat bar. The flat bar was restrained to the tank so that the sensor is as far as possible from the water inlet. The water inlet pipe to the tank is in contact with the bottom of the tank. At its end holes have been cut through which water enters the tank at the very its bottom. This allows to minimize the rippling of the water when the water surface rises of the water. This greatly improves the accuracy of the measured distance by the ultrasonic sensor. Water flows into the tank from the roofs of two buildings. At the inlet to the tank there is a filter designed to trap larger debris. It consists of two impaled discs, rotated relative to each other so that the holes do not overlap. At the outlet of the pipe, a filter is installed to retain finer particles. The use of two filters reduces the frequency of cleaning.

Figure 5 shows the attached motor, connected to the window. To open the window the first gear of the motor is used. This allows the window to open slowly without the risk of damage. Temperature and humidity sensors have been placed halfway between the window and the end of the tunnel. Placing the sensors too close to the window would result in rapid changes in the measured parameters, caused by sudden air changes. Placing them at the end of the tunnel would not would allow correct measurement, due to the long time required for air exchange in the extreme areas of the tunnel. The edge sensor, which determines the position of the window, was fixed on the motor, near the shaft. Two tabs were glued to the shaft to close the limit every half turn. In this way, the position of the window is determined. The window position is stored in the microcontroller's EEPROM. This way, even after power is lost, the microcontroller remembers the last window position.

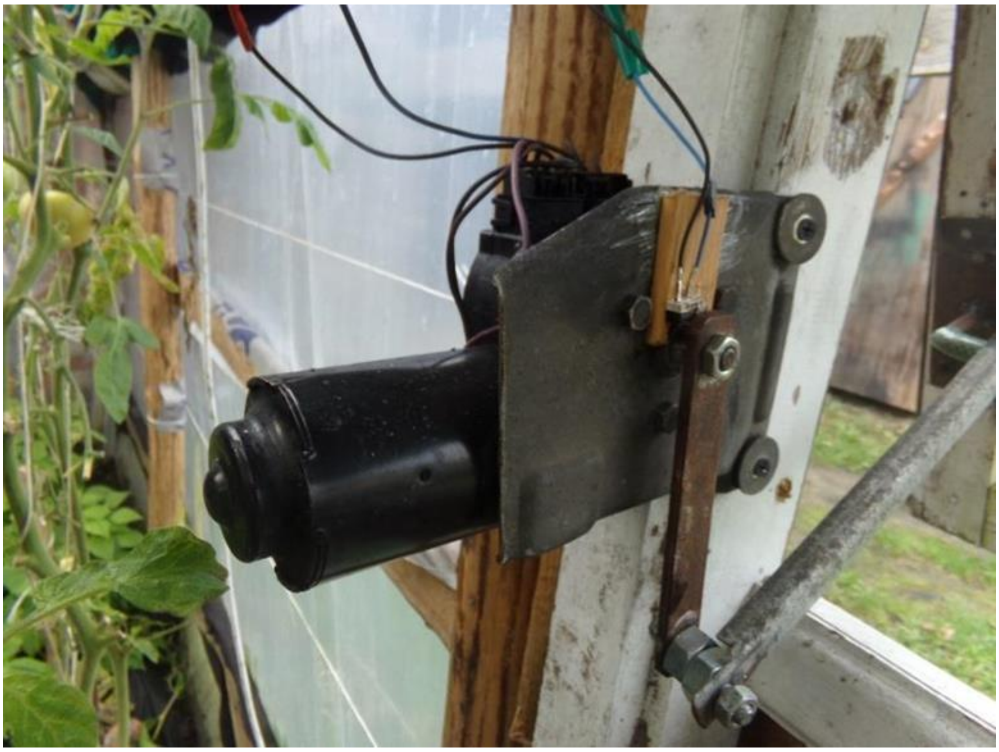

Figure 5. Window opening motor

The fan has been fixed to the window frame because of its role. It is turned on in case of extremely high humidity and is designed to accelerate air exchange and lower the humidity inside the tunnel.

The anemometer was placed above the top of the tunnel. With each rotation, the tie circuit is closed. It is connected to the pin of the microcontroller's interrupt. This ensures that no rotation of the anemometer is skipped. Wind speed is measured every 10 seconds.

4. Screening tests

As part of the system performance test, tests were carried out by measuring the adjustable parameters and the system's response to a change in the setpoints.

Parameter recording was done every three seconds. The tests were conducted in the second half of half of September, on a sunny day. To see the effects of the system's adjustment, the system was turned off and a certain time was waited until the microclimatic parameters were established microclimatic parameters. The initial values of air humidity, indoor temperature and outdoor temperature were recorded. Fluctuations in the parameters with the system turned off were detected, which are due to the accuracy of the measuring elements, but also to a lesser extent to air movements in the tunnel. With an accuracy of ±4 %RH of the air humidity sensor, it is necessary to establish quite a large tolerance of the control parameter. The outdoor temperature sensor is located in a shaded area. To decide whether to open or close the window, the system compares the setpoints with the measured values. If both parameters exceed the maximum setpoint, the window is opened. If at least one parameter is below the minimum value, the window is closed and the fan is turned off. When the value of at least one parameter is above the critical value, the window is forced open and the fan is turned on for humidity. This is done to protect the plants. The humidity values are characterized by a large scatter. This is due to the measurement accuracy of the sensor as well as sudden gusts of air when the window is opened. Nevertheless, after a period of fluctuation, the average value settles near the line of the expected value. A correlation between temperature and humidity was also observed during the measurements. Opening the window to lower the humidity causes the temperature to drop. Due to the interrelation of the parameters, this is usually a desirable situation. However, in certain situations, it leads to a significant reduction below the expected value. The aforementioned problem arose in the study due to the period of the research and the weather. On a sunny autumn day, after heating, the temperature in the tunnel is much higher than the outside temperature. Therefore, after opening the window, the temperature drops much faster than the humidity on a summer day.

During the tests, soil moisture was also recorded. When the soil moisture value is lower than the setpoint, the corresponding valves are activated. When the setpoint is reached, the valves are turned off. The position of the sensor has been selected so that there is no direct contact with water from the rubber hose and value spikes. Such a selected position results in a longer rise time. However, thanks to this, once the required value is reached, the fluctuation of the parameter is much smaller. The results of the adjustment depend, among other things, on the type of soil and its permeability.

5. Comments and conclusions

The irrigation system used in the article was chosen with the type of plant growth planned in mind. Initially, the plan was to seedlings and grow plants in beds or pots, for which such an irrigation system would be most suitable. However, since this was the first year of use of the tunnel, as a trial and gathering experience, it was decided to grow conventionally. In this case, it is not possible to take full advantage of the system's benefits. Dividing the tunnel into irrigation zones helps maintain uniform soil moisture throughout the tunnel.

For the safe operation of the tunnel and due to the role played by it, an anemometer was installed hence allowing to focus on measuring higher wind speeds with higher accuracy. Designed

anemometer is only intended to measure dangerously high speeds and was not designed to measure accurately over its entire measurement range.

An overhead pump was used in the irrigation system from the reservoir, which resulted in a significant reduction in the usable volume of water in the reservoir. This was necessary due to the use of two stages of solenoid valves (i.e., the water first flows through the water source valve, then through the zone valve) and their characteristics of the amount of fluid flow to the fluid pressure at the valve input.

The developed control system shows high usability. It correctly regulates the parameters included in the design and significantly reduces the time and labour required for plant care. The tolerance of the control parameters has been established on the basis of the accuracy of the measurement elements used, so that if a parameter is at the limit of the setpoint, there will be no sudden oscillatory activation of the actuators. The use of better-quality sensors will allow more accurate measurement, reduce the tolerance of the parameters, and consequently their more accurate regulation without the risk of the system falling into oscillations.

The foil tunnel in which the system was installed is a seasonal tunnel. There is possibility to make an automatic heating system and use the tunnel also in winter. Another element possible for the expansion of the system is a system of LED lamps, with adjustable length of emitted electromagnetic waves, switched on during cloudy days. It would also be helpful to make a buffer tank, where protective preparations, fertilizers would be mixed with water and further supplied to the plants by the irrigation system. Thanks to the use of a microcontroller with a large number of leads, it is achievable to build a second tunnel, controlled by the same control unit. In the second tunnel, it is possible to grow different types of plants and adjust the control systems and fertilizers, protective preparations, to their preferences. Another expansion, important for the microclimate of the tunnel, would be to build an additional window on the opposite wall. This would increase the tunnel's passive ventilation and minimize the need to run the fan.

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