Project µC – Part 1 – Temperature Sensor

1. Theme description

The aim of the project is to build an automated greenhouse system with various systems and sensors, in order to monitor the temperature, the air quality and humidity, the soil acidity and moisture and the CO_2 levels. As well as tend to the needs of the plants.

2. Generic list of components

Sensors:

- Temperature sensor
- Humidity sensor
- Light sensor
- Moisture sensor
- Air quality/CO_2
- Soil pH sensors

Processing:

- Microcontroller
- Amplifier
- ADC

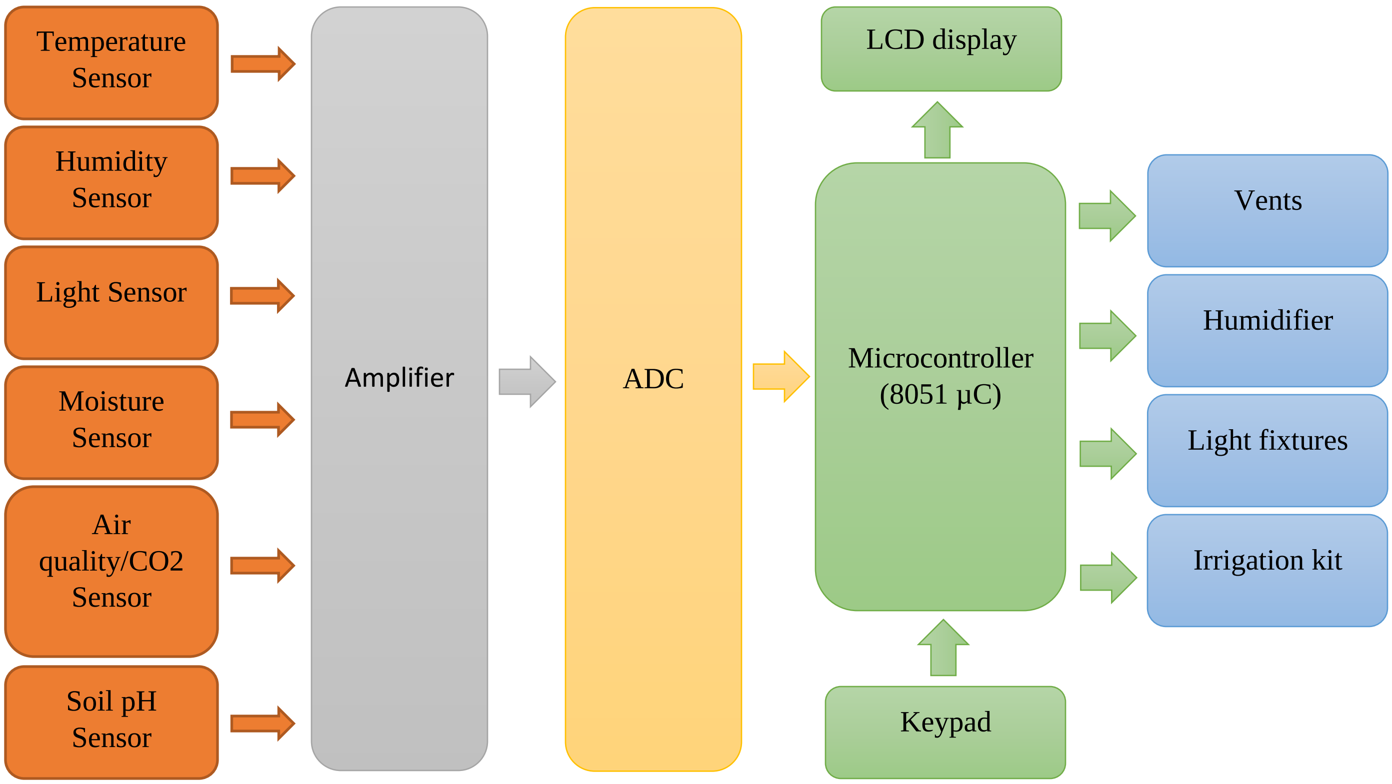
Input/output:

- Keypad
- LCD display

Other:

- Humidifier
- (Drip) irrigation kit
- Light fixtures
- Vents (cooling/heating/air circulation)

3. Block diagram



4. Measurement methods

Temperature measuring sensors come in a wide variety but have one thing in common: they measure temperature by sensing some change in a physical characteristic.

Thermocouples – voltage devices that indicate temperature measurement with a change in voltage. As temperature goes up, the output rises, not necessarily linearly.

Often, the thermocouple is located inside a metal or ceramic shield that protects it from exposure to a variety of environments.[1]

Resistance temperature sensor (RTD) – is a contact sensor. It uses the variation of the resistance of a metal according to the temperature. This type of sensor uses several metals that offer different measuring ranges.[2]

RTDs are in general, more linear than the thermocouples. They increase in a positive direction, with resistance going up as temperature rises.

Thermistor – another type of resistance sensor, that uses the variation of metal oxides according to the temperature.

There are two types of thermistor sensors: **NTC** (Negative Temperature Coefficient) which generally have a regular negative resistance and **PTC** (Positive Temperature Coefficient) which shows a sudden positive resistance variation for a narrow temperature range.

A thermistor has a fast response time and is inexpensive but, on the other hand they are quite fragile, have a much narrower temperature measurement range. It also is an extremely nonlinear semiconductive device that will decrease in resistance as temperature rises, due to its different type of construction.[1][2]

Infrared sensor – non-contacting sensors. It measures the radiation of a surface in the infrared range to derive the surface temperature. The main advantage of this type of a sensor is that it works remotely, without any physical contact with the targeted surface.

Very fast response time. They do not need to establish thermal equilibrium, as such these sensors can measure moving objects.

The downside to this sensor is that since they can only measure the surface temperature of the target, the measurement can be influenced by the condition of the targeted surface (dust, rust, etc.), by the cleanliness of the lenses (dust) and the optical path between the sensor and the target (dust, humidity, combustion, gas, etc.) [1][2]

Bimetallic sensors – take advantage of the expansion of metal when they are heated, two metals are bonded together and mechanically linked to a pointer. When heated, one side of the sensor strip will expand more than the other. When geared properly to a pointer, the temperature measurement is indicated.

The main advantages of such sensors are their portability and independence from a power supply. Unfortunately, they are not usually quite as accurate as are other sensors, and one cannot easily record the temperature value as with electrical devices, such as thermocouples or RTDs.[1]

Thermometers - well known liquid expansion devices also used for temperature measurement. They are organized in two main classifications: the mercury and organic types. The distinction between the two is notable, because mercury devices have certain limitations when it comes to how they can be safely transported or shipped.[1]

Change-of-state sensors – measure a change in the state of a material brought about by a change in temperature, as in a change from ice to water and then steam. Commercially available devices of this type are in the form of labels, pellets, crayons, or lacquers.

Limitations include a relatively slow response time, and the accuracy is not as high as with most of the other devices more commonly used. [1]

Silicone Diode – is a device developed specifically for the cryogenic temperature range. Essentially, they are linear devices where the conductivity of the diode increases linearly in the low cryogenic regions. [1]

5. Proposed method

Using all the information presented earlier, of all the mentioned types of temperature sensor, the silicone diode is the first one that must go, primarily because it was built for cryogenic temperatures.

Considering the temperature range, the thermocouple sensor offers the widest and highest range since those are best for working at higher temperatures [3] and so, probably, not the best for agricultural purposes. However, all the other sensors offer some quite satisfying parameters.

Taking into account that the sensor will be used in a greenhouse, an infrared sensor would make no sense in using because there will always be dust/humidity in the air and/or the lens.

Another sensor that would not be the most useful in a greenhouse is the bimetallic sensor, because we have no need of the advantages it offers and there are other sensors more accurate. The same could be said for the change of state sensor.

A thermometer is a poor choice as well, first, because mercury is considered an environmental contaminant, so breakage can be hazardous and second, because there are certain limitations when it comes to shipping.

We find ourselves with 2 choices left: RTD and thermistor. Which brings me to the following table:

Sensor type	Thermistor	RTD
Temperature range	-100 to 352℃	-200 to 650℃
Accuracy	0.05 to 1.5℃	0.1 to 1℃
Long-term stability@100℃	0.2℃/year	0.05℃/year
Linearity	Exponential	Fairly linear
Power required	Constant voltage/current	Constant voltage/current
Response time	Fast (0.12 to 10s)	Slow (1 to 50s)
Susceptibility to electrical noise	Rarely susceptible High resistance only	Rarely Susceptible
Cost	Low to moderate	High

Table 1. Thermistor vs RTD

Upon taking a closer look on Table 1, the RTD would make a perfect fit, considering the temperature range, the accuracy and the long-term stability. But considering the lower cost and the fast response time of a thermistor combined with the fact that there is not such a huge difference when it comes to accuracy between the two, the thermistor would be the natural choice. And since the NTC thermistor is mainly used for temperature control and measurements applications, I think it would make a perfect fit for our smart greenhouse.

6. Sensor comparison

Model	B57881S [7]	NTCLE100E3 [8]	NI24MA0502H [9]
Accuracy	High	Over a wide temperature range	High
Availability	Yes	Yes	Yes
Price	11.07 RON	1.71 RON	6.61 RON
Applications	Temperature measurement	Temperature measurement Compensation	Temperature measurement Air intake temperature Evaporator probe
Operating Temperature	-55℃ to 155℃	-40℃ to 125℃	-55℃ to 150℃
Resistance Tolerance	±1%	±5%	±3%

Table 2.

Interfacing – since microcontrollers read voltages and not resistances, the simplest circuit to convert the resistance change, generated by the thermistor, to voltage change is a voltage divider (Figure 1). So, the variation of the resistance can be measure in the middle of the two, when the resistance changes, so does the voltage. [10][11]

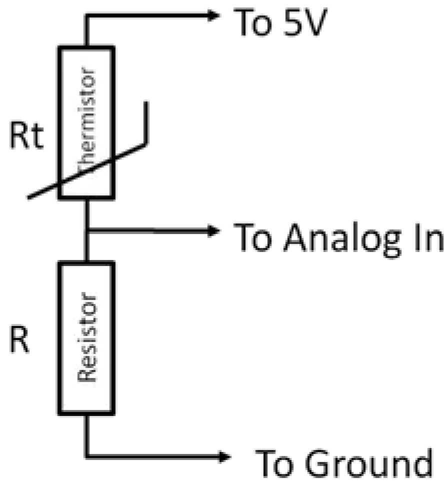


Figure 1. Voltage Divider [11]

The output voltage will be:

$$Vo = \frac{R}{R + R_{Thermistor}} * Vcc \qquad [11](1)$$

The ADC equation:

$$ADC = \frac{Vo}{VCC} * 2^N \qquad [11](2)$$

Where N is the resolution of the ADC

By combining (1) and (2) we get:

$$ADC = \frac{R}{R + R_{Thermistor}} * 2^N \qquad [11](3)$$

To find the temperature, the system uses the Steinhart-Hart equation:

$$\frac{1}{T} = a + b * lnR + c(lnR)^3 \qquad [11](4)$$

However, the Steinhart-Hart equation is rather complex and requires a lot of variables, which brings us to the simplified B/β equation:

$$\frac{1}{T} = \frac{1}{T_0} + \frac{1}{B} * \ln\left(\frac{R}{R_{Themistor}}\right) \quad [11](5)$$

Where, T_0 is the room temperature, B is the coefficient of the thermistor, $R_{Thermistor}$ the resistance at room temperature and T is the temperature in Kelvin.

7. Proposed sensor

Based on Table 2. we have 3 similar thermistors, with only major differences being the price and the applications.

If we are after an inexpensive sensor, the NTCLE100E3 would be the obvious choice, but it does not offer such a wide range of applications. Application wise, the same could be said about B57881S thermistor, may it have the widest temperature range of the three.

Here is where the NI24MA0502H sensor comes in. A relative cheap sensor, with a wide variety of applications that could prove useful in our greenhouse. That, combined with a temperature range that is just 5°C smaller than the one of the B57881S and a 2% larger resistance tolerance, would make it the perfect candidate for our smart greenhouse.

8. Bibliography

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