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Temperature and Humidity Sensors Utilization in Automobile

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The goal of the thesis work was to implement and utilize sensory elements to measure and send information about the environment inside a particular vehicle, thus letting the user know to prepare for the travel by defogging window and heating up the engine. The demonstration circuit will be able to measure a closed space temperature and humidity, then transferring the information to another platform via a Photon device so that it can be monitored from a distance.

The device includes one of each sensor type, which are a 1k-Ohm NTC thermistor used to react to difference in temperature and a Honeywell HIH-4000 series humidity sensor to measure the relative humidity of the environment. The outputs of these sensors will then be transferred to a Photon device capable of translating the value into approximate temperature and humidity values. In the end, these values are directed to a monitoring platform that can be viewed online.

The final test board achieves the goal of the project. Although the circuit is simple, the functionality can be increased by adding more elements to the circuit, as well as giving more options for environment settings and scheduling to the user.

Keywords	temperature, humidity, sensor, distance

Contents

List of Abbreviations

AC	Air conditioner
CLI	Command-line Interface
HVAC	Heating, ventilation, and air conditioning
IDE	Integrated development environment
IoT	Internet of Things
NTC	Negative temperature coefficient
RH	Relative humidity

1 Introduction

As weather and environment changes can be extreme and unexpected, many machineries are designed with precautionary measures against it. For automotive industry specifically, shifts in temperature and humidity of indoor and outside of a car can affect travel safety greatly. Condensed moisture on glass surface can greatly block the driver vision, making it dangerous to proceed without clearing the mist. It can also get into the engine oil, which can cause damage to the pistons, crankshaft, and camshaft, and lowering the engine lifespan. Knowing this, car manufacturers have been implementing ways to monitor and change the car environment with the air-conditioning system (HVAC), as well as utilizing circuitry to heat up the area, hence evaporating the condensed mist and making the area comfortable.

The purpose of this thesis was to create a small sensor circuit that can simulate and analyze the environment with temperature and humidity sensors. A microcontroller unit can then acquire the data and send it to a cloud service so that user can view remotely.

To acquire data, a combination of temperature and humidity sensors is required. The temperature sensor chosen is an NTC thermistor that changes its resistance according to the environment temperature. The humidity sensor is an HIH-4000 capacitive humidity sensor, that outputs a linear voltage that can be then collected by a Photon. This Photon controller will handle the input data and send to the Cloud to be viewed.

2 Thesis Research Overview

2.1 HVAC Utilization in Automobile

2.1.1 HVAC System Overview

Heating, ventilation and air conditioning (HVAC) system is designed so that human can monitor and adjust the environment as desired, be it a small room or a large building. It can be everyone's home air-conditioner, or a much larger system used in factory compounds or institutional complexes. The main goal of the system is to provide indoor thermal control and comfort, using thermodynamics, fluid mechanics and heat transfer.

HVAC system can be separated into two main categories: centralized or decentralized (local) [1, 4]. Centralized HVAC occupies a big amount of space such as a skyscraper to reduce the equipment capacity as long as the desired conditions of the whole targeted space are the same. In contrast, local HVAC variation is much smaller in size, and used to monitor a smaller area. This system is also more favorable when there are multiple different requirements in a single unit, such as personal apartment or storage space.

The HVAC system in general has four determined requirements to consider beforehand: primary equipment, space requirements, air distribution and piping [1, 5].

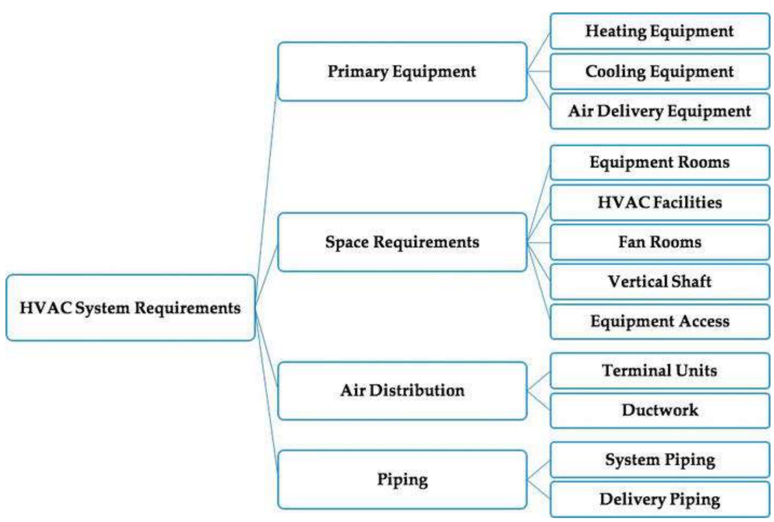

Figure 1. HVAC system requirements (reprinted from [1, 5])

As illustrated in figure 1, the equipment is a heating machine such as a water boiler to create heat to the space, an air delivery subsystem that will deliver the conditioned air using fans, and a cooling equipment to direct cooled air into the area. Space requirement is about determining the area for the installation of the equipment as well as the space for air distribution. For air distribution, it is utmost important to consider ductwork so that it is most efficient and quiet as possible. Piping system in the other hand is used to direct the flow of refrigerant, water, etc.

2.1.2 Car Heating System

Car heating system uses heat from the connected engine cooling system to warm up the cabin. A main heat exchanger is built inside the HVAC system, functioning as a small radiator. This is called a heater core and is connected to the cooling system. [14.]

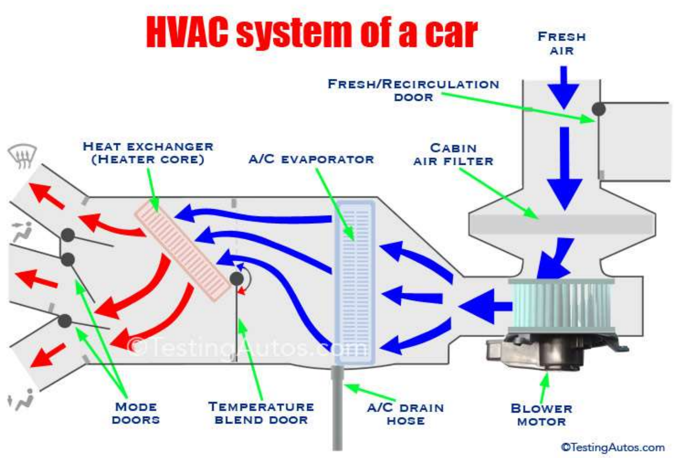

Figure 2. Simple model of an HVAC system in a car (reprinted from [14])

Figure 2 shows how HVAC system looks like in a car. In the engine cooling system, liquid coolant is circulated between the engine and the car radiator by a water pump. When the engine starts, hot coolant also starts circulating to the heater core area. A blower motor will create an air flow that goes through an A/C evaporator/condenser to remove any vapor in it. The removed water condense will drip out of a drain tube and go out under the car [15]. The dry air continues forward to the heater core, absorbing the heat and eventually through a network of air vents, warming up the car interior.

Additionally, a separate car heater can be installed to the engine compartment. It can either use fossil fuel or electrical energy.

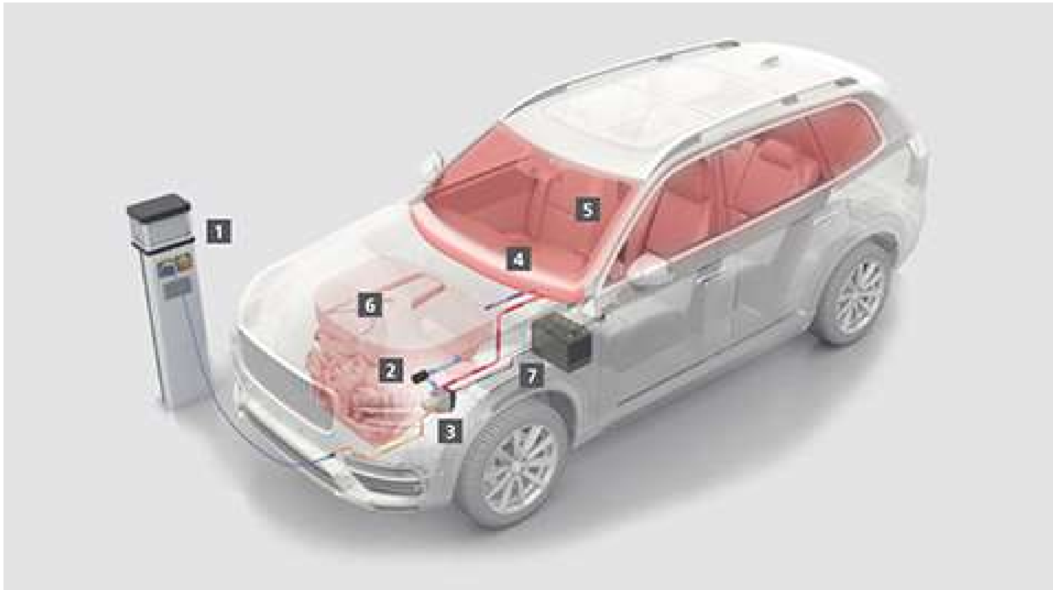

Figure 3. An example of a separate electric heater device. (reprinted from [16])

The heater (3 in figure 3) has a coolant circuit (2 in figure 3) that acts like a heat exchanger. The hot coolant that gives off heat to the air is also transported on to engine and heats it up as well. The result is a warm interior that dehumidify the surface as well as being comfortable for driver, and a warmup engine to make sure everything works well.

2.1.3 Car Defogger

As the name stated, car defogger function is to remove the condensed water droplets that stick to the front, rear and side windows of a car [3]. This leads to improvement in visibility and safety for travelling. The fogging phenomenon usually happens during rainy season when water droplets are most abundant. In cold region, water can even be frozen on the window surface and block the driver view. This can easily cause deadly accident if it happens while traveling on highway or dangerous mountain route.

There are two main types of car defogger: primary and secondary. The primary defogger is used for the front windscreen and side windows, while the secondary one works at the back of the car. The reason for the different types of defoggers is mainly the functional positions.

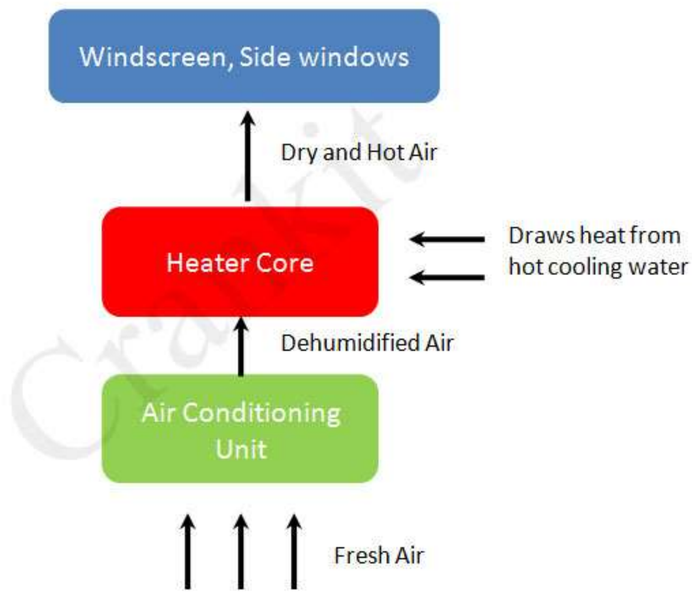

Figure 4. Primary defogger construction (reprinted from [3])

The primary defogger utilizes the HVAC system to provide dry hot air to the windscreen and side windows. According to figure 4, when the defogging happens, HVAC will draw in fresh air from outside into the air conditioning unit to be dehumidified. Then it will pass the heater core, where heat is absorbed from hot cooling water. The hot air will finally be distributed along the windscreen and side windows through a vent circuit connecting from the HVAC to the desired area. This dehumidified hot air is very effective to absorb the moisture and will remove the condensation in the process.

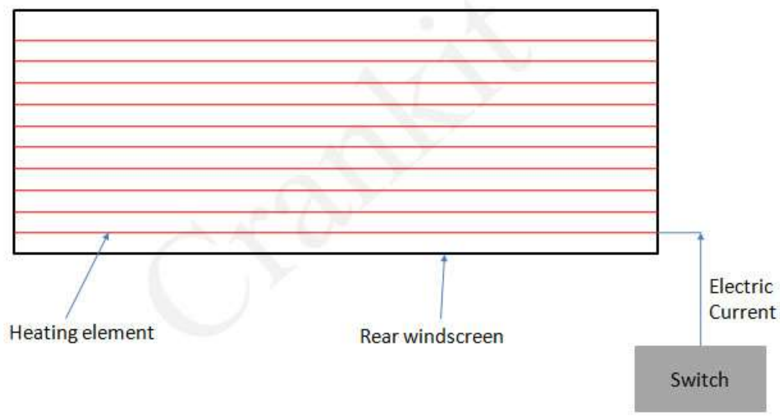

Figure 5. Secondary defogger system (reprinted from [3])

While the front and side defogger have the support from HVAC, the secondary defogger is a simple resistive electric heating system in form of a series of resistive electric lines like in figure 5. When turned on by the switch, electric current will run through the system and provide heat for the rear windows, thus vaporizing any frozen or condensed water on the surface of the windows.

2.2 Automatic Climate Control

Automatic climate control is the ability to monitor and control an environment in terms of temperature and humidity, that happens automatically without manual intervention. The system consists of one or multiple temperature and humidity sensors, depending on each of their purposes, to monitor the environment. The acquired information will then be sent to a climate control system, usually a microcontroller unit, to remotely review and maintain them at specific values. This removes the needs for human effort to regulate the area by switching the AC and/or sliding warmer/cooler control.

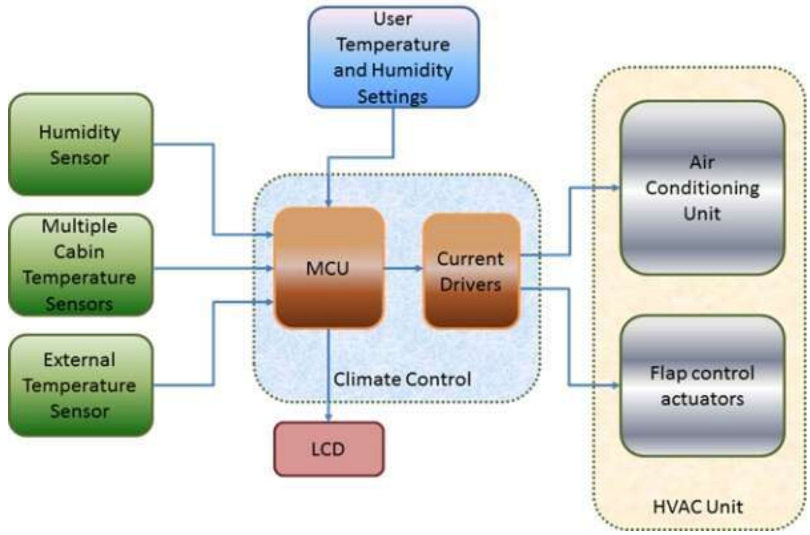

Figure 6. Demonstrating the process of an automatic climate control (reprinted from [13])

In figure 6, multiple sensors are placed in various locations in a cabin. Each sensor will give information for the area that it is setup. All data will go to the MCU, shown on to a viewing platform and then compared with the user settings to give out an action based on the data acquired. This action can range from adjusting fan speed, regulating air vent distribution, etc.

2.3 Dew point

Dew point is the temperature to which air must be cooled (at a constant pressure) for water vapor to condense into dew or frost. Any temperature condition has its own maximum amount of water vapor that it can hold, which is called the water vapor saturation pressure. Adding more water vapor than the saturation point will cause condensation. [10.]

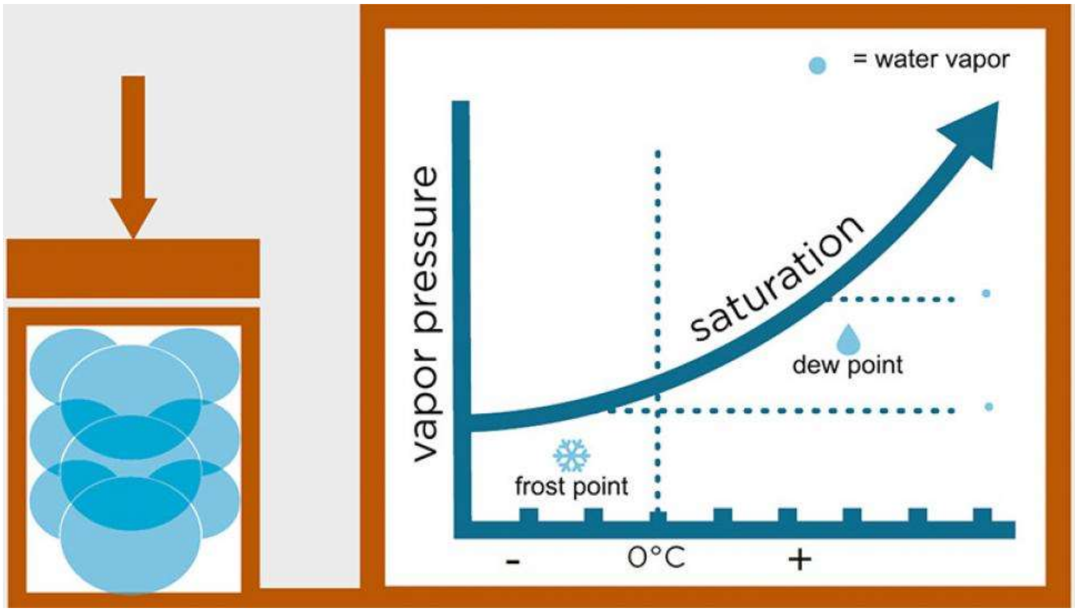

Figure 7. Chart showing the concept of dew point and frost point of water vapor (reprinted from [10])

According to figure 7, higher dew point means more moisture in the air so the higher dew point is considered humid and therefore not comfortable for general activities. A general comfort levels using dew point is comprised by [11]:

- Less than or equal to 55^{o}C: the environment is dry and comfortable.
- Between 55 and 65^{o}C: the environment becomes “sticky”.
- Greater than 65^{o}C: the environment is oppressive due to excessive moisture in the air.

In certain industries, dew point is also an important factor since water vapor and pressure can affect engine lifespan, cause blockage in pipeline and even freezing. Measuring dew point is therefore essential for said industries. A device called hygrometer is widely used to measure dew point, along with calibrating other types of humidity sensors.

For simple approximation of dew point, a formula was proposed by Mark G. Lawrence. The formula describes the relation between dew point, relative humidity, and the environment temperature:

$$T_d \approx T - \frac{100-R}{5} \quad (1)$$

Or

$$RH \approx 100 - 5(T - T_d) \quad (2)$$

Where T_d is dew point temperature, T is environment temperature and RH is relative humidity. This calculation has an accuracy of ±1°C, hence it should be considered that if a higher accuracy is required, a more complex formula is advised to avoid faulty components.

2.4 NTC Thermistor

Thermistor is a solid-state temperature sensing device acting like an electrical resistor but temperature dependent in nature. It is thermally sensitive transducer constructed using sensitive semiconductor-based metal oxides with metallized or sintered connecting leads formed into a ceramic head. [4.] This allows the thermistor the ability to change its resistive values according to ambient temperature. The output of the thermistor is an analogue voltage signal.

NTC or negative temperature coefficient thermistor is an electronic component that has its resistance reduced over time when the temperature increases and vice versa. These kinds of thermistor are usually made of sintered non-oxide ceramic made of manganese, nickel, cobalt, and other elements. An electrode is formed in the ceramic part, and the lead type and chip type are in common appearance shapes. [2.] NTCs are most used as temperature sensors and current-limiting devices.

NTC has a negative resistance versus temperature (R/T) connection. With large negative response, a small change in temperature can create significant effect in its resistance. This means that NTC is very accurate for temperature measurement. Usually to separate NTC, a based resistance at room temperature will be the main factor. Another important value is the B value, varying based on the ceramic material used to create it. This constant describes the R/T curve over a particular temperature range. Different materials give different B values. Figure 8 below gives an example of how a range of temperature affects a specific thermistor.

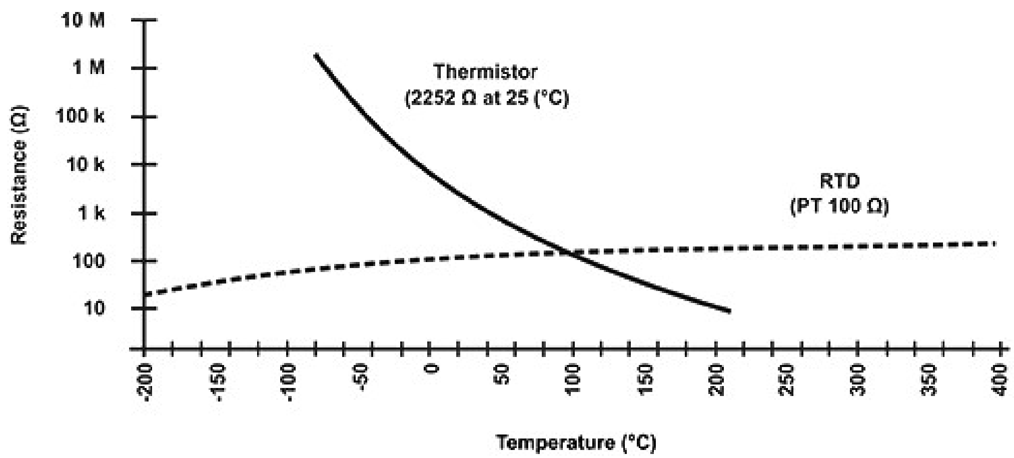

Figure 8. Thermistor characteristic curve example (reprinted from [4])

An equation from [4] that gives an accurate result is a formula revolving around material constant β which comes from measurement and usually provided by the thermistor vendor.

$$R(T) = R(T_0) * e^{\beta(\frac{1}{T}-\frac{1}{T_0})} \quad (3)$$

Another popular and accurate way to elaborate the connection between ambient temperature and resistance of a thermistor is by using Steinhart-Hart formula, published in 1968:

$$\frac{1}{T} = A + B(lnR) + C(lnR)^3 \quad (4)$$

In the formula (4), which is provided by [4], R is the resistance of the NTC thermistor at temperature T. A, B and C are coefficients derived from experimental measurements. These coefficients are usually stated by the manufacturers in the datasheet. However, if the accuracy of the formula, which is close to ± 0.15 degree Celsius, is still not enough for consideration, point-by-point calibration is required to visualize a large number of data and create a comparison table.

2.5 Humidity Sensor

Humidity or the amount of water present in the surrounding air [5] is a key environment factor in various industries as well as the wellness of human life. There are three main measurements for humidity: absolute, relative, and specific. Absolute humidity describes the amount of water in the air, usually in grams per cubic meter. Relative humidity expresses the value in a percentage ratio between absolute humidity in present state and maximum theoretical humidity given the same condition. Specific humidity is slightly different from absolute humidity, in that it shows the weight of water vapor in an amount of air (grams of water vapor per kilogram of air) [6].

Humidity sensor is created to monitor and adjust said values to a desired degree, to provide comfort for human activities, or to create an optimal environment state i.e., for electrical safety.

Based on the parameters used for the measurement of humidity, there are three types of humidity sensors that are widely used nowadays:

- Capacitive humidity sensor
- Resistive humidity sensor
- Thermal conductivity humidity sensor.

2.5.1 Capacitive Humidity Sensor

Capacitive humidity sensor is constructed by using two electrode layers between a dielectric material. Figure 9 is a simple structure of a capacitive humidity sensor.

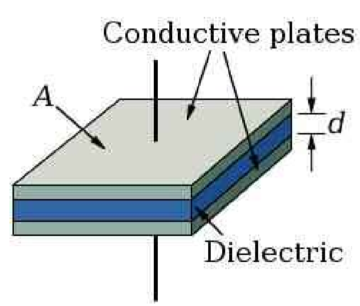

Figure 9. Basic structure of a capacitive humidity sensor (reprinted from [7])

The dielectric material for this type of sensor must be a hygroscopic one, usually a polymer film layer, meaning it can absorb water vapor from the environment. The dielectric constant for the material is often between 2 and 15, and the dielectric constant for water vapor is 80 at room temperature. The huge difference in this element makes it that when the material absorb water vapor from the surrounding, it can directly increase the capacitance of the sensor.[7.] This change will affect the output of the sensor and can be eventually calculated to relative humidity of the area.

2.5.2 Resistive Humidity Sensor

Resistive humidity sensor, sometimes called hygristor [8], is a type of humidity sensor utilizing the changes of resistivity of the conductive layer to determine the humidity value.

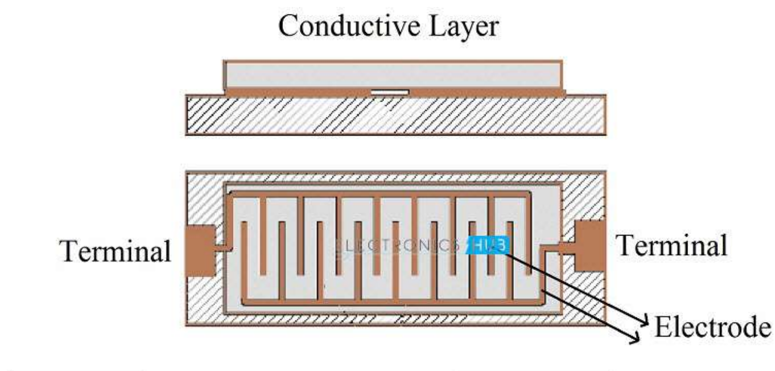

Figure 10. Construct of a resistive humidity sensor (reprinted from [5])

The conductive layer, similar to the dielectric layer in capacitive humidity sensor, is made of a hygroscopic material to absorb moisture. As in figure 10, inside the layer, there are a set of two electrodes, made in a comb-like shape, in an interdigitated pattern to increase the contact area. The electrode itself is made from a noble metal such as gold, silver, etc.

When the conductive layer absorbs water vapor, the hygroscopic element itself will increase in conductivity and thus decrease the resistivity of the sensor. Changes in resistivity can then be used to determine the relative humidity in the surrounding area.

2.5.3 Thermal Conductivity Humidity Sensor

Thermal conductivity humidity sensor is created to measure absolute humidity. The basic principle of this type of sensor is to calculate the humidity based on the difference of temperatures.

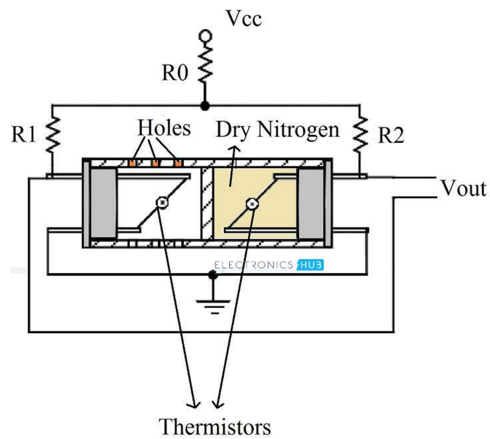

Figure 11. Design of a thermal conductivity humidity sensor (reprinted from [5])

As shown in figure 11, there are two NTC thermistors, one being sealed in dry nitrogen, and one being exposed to open environment through venting holes. An electrical current will run through the circuit and begin the self-heating process. While the thermistor sealed by Nitrogen will keep the same result relative to the temperature, the one exposed to the environment will have a different conductivity thus making a difference comparing to the sealed one. A simple resistance measurement between the two can directly lead to the calculation of absolute humidity eventually.

3 Circuit Implementation

This section is about constructing a small circuit including an NTC thermistor and a humidity sensor with outputs connected to a Photon device. The main goal of the implementation is to be able to monitor temperature and humidity in a closed environment (car indoor) from a distance via Particle Android app.

3.1 Circuit Elements

3.1.1 1k-Ohm NTC Thermistor

The NTC chosen is a 1k-ohm thermistor. Its characteristic values are provided by muRata [9], which includes a table of variances over a range of temperature. The one being used is the right-most column in figure 12.

Part Number	NCP□□XM221	NCP□□XM331	NCP□□XQ471	NCP□□XQ681	NCP□□XM102
Resistance	220Ω	330Ω	470Ω	680Ω	1.0kΩ
B-Constant	3500K	3500K	3650K	3650K	3500K
Temp. (°C)	Resistance (Ω)	Resistance (Ω)	Resistance (Ω)	Resistance (Ω)	Resistance (kΩ)
−40	4947.904	7421.856	11822.473	17104.854	21.266
−35	3703.755	5555.632	8767.745	12685.248	16.150
−30	2798.873	4198.309	6570.224	9505.855	12.347
−25	2135.887	3203.831	4971.784	7193.219	9.503
−20	1645.037	2467.555	3796.933	5493.436	7.365
−15	1278.034	1917.051	2923.400	4229.599	5.747
−10	1000.620	1500.930	2269.599	3283.675	4.516
−5	789.612	1184.418	1775.225	2568.411	3.572
0	627.752	941.628	1399.050	2024.158	2.844
5	502.474	753.711	1110.220	1606.275	2.280
10	405.010	607.514	887.257	1283.691	1.839
15	328.480	492.720	713.463	1032.245	1.492
20	268.044	402.066	577.375	835.351	1.218
25	220.000	330.000	470.000	680.000	1.000
30	181.576	272.365	384.800	556.733	0.825
35	150.668	226.002	316.757	458.287	0.685
40	125.681	188.521	262.177	379.320	0.571
45	105.336	158.004	218.069	315.504	0.479
50	88.717	133.076	182.297	263.749	0.403
55	75.059	112.588	153.150	221.579	0.341
60	63.777	95.666	129.249	186.998	0.290
65	54.415	81.622	109.551	158.499	0.247
70	46.631	69.946	93.281	134.960	0.212
75	40.115	60.172	79.750	115.383	0.182
80	34.637	51.955	68.446	99.029	0.157
85	30.013	45.019	58.996	85.356	0.136
90	26.110	39.165	51.036	73.839	0.119
95	22.790	34.186	44.332	64.140	0.104
100	19.957	29.935	38.640	55.905	0.091
105	17.541	26.312	33.790	48.888	0.080
110	15.453	23.180	29.664	42.918	0.070
115	13.663	20.494	26.123	37.795	0.062
120	12.114	18.171	23.091	33.409	0.055
125	10.778	16.168	20.472	29.618	0.049

Figure 12. Table of characteristics for several NTC series (reprinted from [9])

3.1.2 Honeywell HIH-4000 Humidity Sensor

The HIH-4000 series humidity sensor is a capacitive one, designed by Honeywell. Honeywell provided a clear specifications performance table for the series [17].

Parameter	Minimum	Typical	Maximum	Unit	Specific Note
Interchangeability (first order curve)	–	–	–	–	–
0% RH to 59% RH	-5	–	5	% RH	–
60% RH to 100% RH	-8	–	8	% RH	–
Accuracy (best fit straight line)	-3.5	–	+3.5	% RH	1
Hysterisis	–	3	–	% RH	–
Repeatability	–	±0.5	–	% RH	–
Settling time	–	–	70	ms	–
Response time (1/e in slow moving air)	–	5	–	s	–
Stability (at 50% RH)	–	1.2	–	% RH	–
Voltage supply	4	–	5.8	Vdc	2
Current supply	–	200	500	μA	–
Voltage output (1st order curve fit)	V_{OUT}=(V_{SUPPLY})(0.0062(sensor RH) + 0.16), typical at 25 ºC				
Temperature compensation	True RH = (Sensor RH)/(1.0546 – 0.00216T), T in ºC				
Output voltage temperature coefficient at 50% RH, 5V	–	-4	–	mV/ºC	–
Operating temperature	-40[-40]	See Figure 1.	85[185]	ºC[ºF]	–
Operating humidity	0	See Figure 1.	100	% RH	3
Storage temperature	-50[-58]	–	125[257]	ºC[ºF]	–
Storage humidity	See Figure 2.			% RH	3

Figure 13. Performance specifications at 5Vdc supply and 25ºC (77ºF) (reprinted from [17])

In figure 13, the information in the red rectangle is an output voltage formula that is utilized during the mathematics calculation in Photon code design.

3.1.3 Photon

3.1.3.1 Overview

Photon is a Particle's IoT hardware development kit that provides essential structures and resources to build a connected product. The device is built with a powerful ARM Cortex M3 microcontroller combined with a Broadcom Wi-Fi chip in a small thumbnail-sized PØ or P-zero module.

Photon has a 3.3VDC SMPS power supply, RF and user interface components (all built in PØ) that are mounted on a single-sided PCB board.

3.1.3.2 Power supply

There are two ways to power the Photon, via a Micro B USB connector or connection from a power source to VIN pin. The power connecting to VIN pin, if the USB connector is not used, must be regulated between 3.6 and 5.5VDC. Otherwise, if the USB port is used, VIN pin will output a 4.8VDC due to reverse polarity protection series schottky diode [12] between USB V+ and VIN. Max output load of VIN is 1A.

3.1.3.3 Pin and button definitions

Photon pins and buttons layout is shown in figure 14 below, provided by Particle [12].

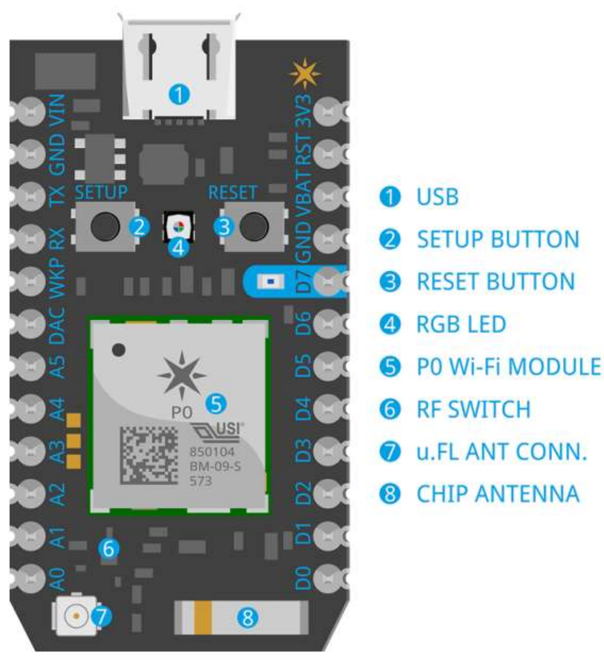

Figure 14. Photon pins and buttons layout, reprinted from [12]

There are two buttons on a Photon device, SETUP and RESET. These buttons are there to manipulate the device various modes with ease without having to control from another platform.

Pins definitions are well-described through Particle datasheet [12], shown in figure 15 below.

Pin	Description
VIN	This pin can be used as an input or output. As an input, supply 3.6 to 5.5VDC to power the Photon. When the Photon is powered via the USB port, this pin will output a voltage of approximately 4.8VDC due to a reverse polarity protection series Schottky diode between VUSB and VIN. When used as an output, the max load on VIN is 1A.
RST	Active-low reset input. On-board circuitry contains a 1k ohm pull-up resistor between RST and 3V3, and 0.1uF capacitor between RST and GND.
VBAT	Supply to the internal RTC, backup registers and SRAM when 3V3 is not present (1.65 to 3.6VDC).
3V3	This pin is the output of the on-board regulator and is internally connected to the VDD of the Wi-Fi module. When powering the Photon via VIN or the USB port, this pin will output a voltage of 3.3VDC. This pin can also be used to power the Photon directly (max input 3.3VDC). When used as an output, the max load on 3V3 is 100mA. NOTE: When powering the Photon via this pin, ensure power is disconnected from VIN and USB.
RX	Primarily used as UART RX, but can also be used as a digital GPIO or PWM[2].
TX	Primarily used as UART TX, but can also be used as a digital GPIO or PWM[2].
WKP	Active-high wakeup pin, wakes the module from sleep/standby modes. When not used as a WAKEUP, this pin can also be used as a digital GPIO, ADC input or PWM[2]. Can be referred to as `A7` when used as an ADC.
DAC	12-bit Digital-to-Analog (D/A) output (0-4095), referred to as `DAC` or `DAC1` in software. Can also be used as a digital GPIO or ADC. Can be referred to as `A6` when used as an ADC. A3 is a second DAC output used as `DAC2` in software.
A0~A7	12-bit Analog-to-Digital (A/D) inputs (0-4095), and also digital GPIOs. `A6` and `A7` are code convenience mappings, which means pins are not actually labeled as such but you may use code like `analogRead(A7)`. `A6` maps to the DAC pin and `A7` maps to the WKP pin. A4,A5,A7 may also be used as a PWM[2] output.
D0~D7	Digital only GPIO pins. D0~D3 may also be used as a PWM[2] output.

Figure 15. Pins definitions, reprinted from [12]

Pins definitions also contain various information about voltage and load limit for the Photon device.

3.1.3.4 Status LED and device modes

Shown in figure 14, an RGB LED is available, just like traffic light, to inform the user of the various modes the Photon is in. The LED can light up in different color combination, as well as various light patterns such as blinking and breathing.

Users can control the Photon modes via the RESET and SETUP buttons mounted on the board. Some useful button combinations are below:

- Holding SETUP button for three seconds to switch to listening mode. The LED will blink blue in this mode.

- Holding SETUP button for about ten or more seconds to erase stored Wi-Fi networks. The LED will blink blue rapidly during the process.

- Holding both buttons, then releasing the RESET until the LED start flashing yellow and eventually releasing the SETUP button to turn Photon into Device Firmware Upgrade (DFU) mode. From here users can either update the firmware to latest version or reset it by utilizing the Particle CLI to flash a reset command.

3.1.4 Resistors

A voltage divider is chosen to react to the changes on NTC. The resistor pairing with the NTC is a 1k Ohm resistor. Voltage source for the divider comes from the 3V3 pin of the Photon which has an output of 3.3Vdc (figure 15). Figure 16 is an illustration for part of the circuit concerning NTC.

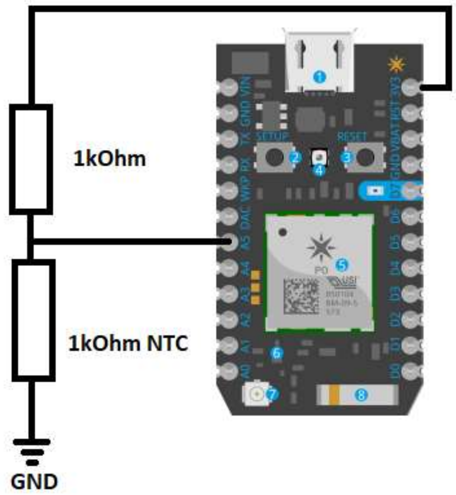

Figure 16. Simple circuit with voltage divider and NTC

The voltage input that goes into the Photon (for example pin A5) can be calculated as:

$$V_{A5} = \frac{R_{NTC}}{R_{NTC}+1k} * V_{CC} \tag{5}$$

For the humidity sensor, its output is in range for the voltage limit input for Photon so the output can be handled directly. The power supply for the humidity sensor can be taken from VIN pin as it provides 4.8Vdc (figure 15) while USB cable is used. The circuit involving the humidity sensor is drawn as figure 17.

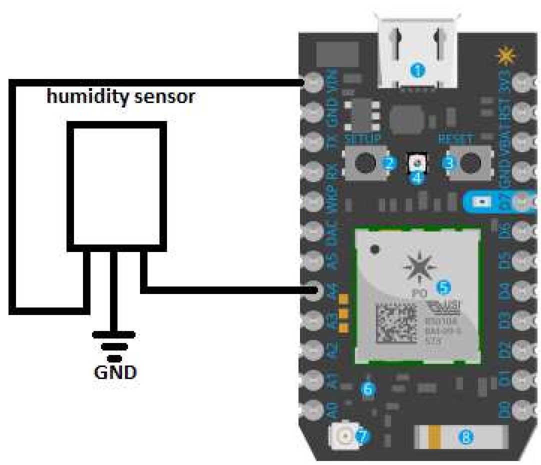

Figure 17. Simple circuit for humidity sensor

The end circuit should look similar as figure 18 below.

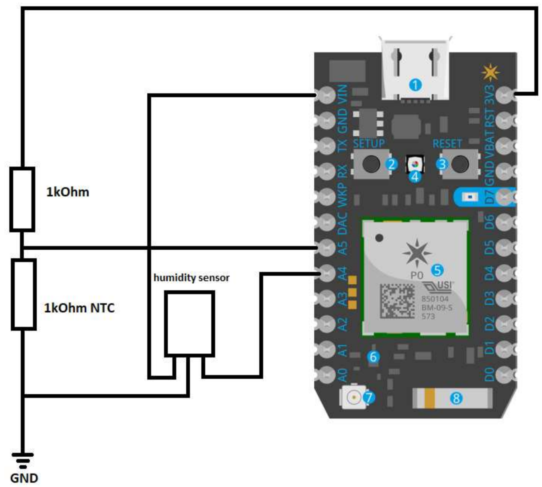

Figure 18. Full circuit with both sensors connecting to Photon

3.2 Implementation and Results

The full circuit on a breadboard is shown in figure 19 below.

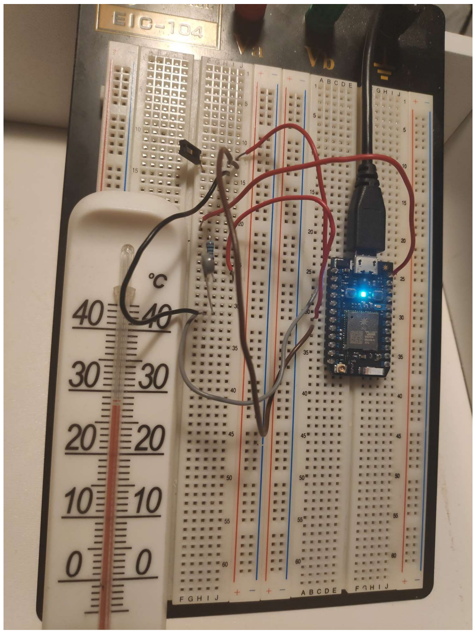

Figure 19. Breadboard circuit, with a small thermometer.

Below is a flowchart figure describing the process of the Photon code.

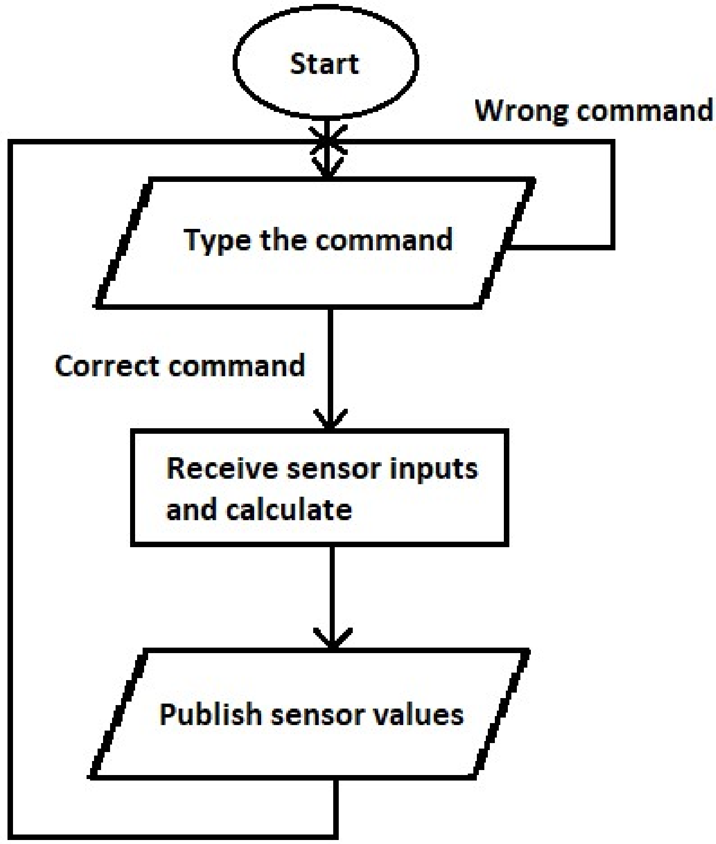

Figure 20. Flowchart for the Photon code.

In figure 20, when the device starts running, a command must be entered to start the measurement. After getting the inputs and calculating into actual values, the Photon will publish the results on to the Cloud service events. The process will keep looping and can be repeated by retyping the command.

Following figure 20 process, a Photon code is written as below in listing 1

```
#include "math.h"

int runMeasure(String command);

int humidPin = A4;
int tempPin = A5;
double temp;
double humidity;

void setup() {
    pinMode(humidPin, INPUT);
    pinMode(tempPin, INPUT);
    Particle.function("Run measurement", runMeasure);
}

void read_cycle() {
    int inputTemp = analogRead(tempPin);
    int inputHumidity = analogRead(humidPin);

    double Vtemp = (3.3 / 4095) * inputTemp;
    double Rntc = 1000 / ((3.3 / Vtemp) - 1);
    temp = 1 / (1 / 298.15 + (log(Rntc / 1000)) / 3500) - 273.15;

    double Vhumidity = (3.3 / 4095) * inputHumidity;
    humidity = ((Vhumidity - 0.826) / 0.0315) / (1.0546 - 0.00216 * temp);

    Particle.publish("Temperature", String(temp), PRIVATE);
    Particle.publish("Humidity", String(humidity), PRIVATE);
}

int runMeasure(String command) {
    if(command == "Yes") {
    read_cycle();
    return 1;
    }
    else return -1;
}

void loop() {
}
```

Listing 1. Photon code to demonstrate temperature and humidity values.

```
    Particle.function("Run measurement", runMeasure);
    Particle.publish("Temperature", String(temp), PRIVATE);
    Particle.publish("Humidity", String(humidity), PRIVATE);
```

Listing 2. Particle cloud functions used.

The first line from listing 2 is a cloud service that require the user input to return a value or perform an action. Here the function is to wait for input from user to start the measurement.

```
int runMeasure(String command) {
    if(command == "Yes") {
    read_cycle();
    return 1;
    }
    else return -1;
}
```

Listing 3. Function to run the measurement.

The second and third lines from listing 2 are cloud functions to publish the values to the Cloud as an event. In this case, temperature and humidity are the values to be registered so users can view remotely. When on the Particle Mobile app, if the command typed in the “runMeasure” function is correct (being “Yes”), the Photon will run the measure once and show the event results.

```
void read_cycle() {
    int inputTemp = analogRead(tempPin);
    int inputHumidity = analogRead(humidPin);

    double Vtemp = (3.3 / 4095) * inputTemp;
    double Rntc = 1000 / ((3.3 / Vtemp) - 1);
    temp = 1 / (1 / 298.15 + (log(Rntc / 1000)) / 3500) - 273.15;

    double Vhumidity = (3.3 / 4095) * inputHumidity;
    humidity = ((Vhumidity - 0.826) / 0.0315) / (1.0546 - 0.00216 * temp);
}
```

Listing 4. The measurement calculation.

Listing 4 shows the code function to receive the input from both sensors as Photon analog value. Since the input voltage is in range of 0V to 3.3V (pin min-max value according to Particle), and Photon analogRead function returns a value between 0-4095, there is a quick conversion formula to get the correct input voltage values (line 5 and 9 in listing 4).

For NTC temperature calculation, line 6 of listing 4 shows the calculation for the NTC resistance using formula (5). Then line 7 is the utilization of formula (3) with the help from the NTC datasheet for 1kOhm resistance at 25ºC being $R(T)_0$ and T_0. All the temperatures used in calculation must be converted into Kelvin degree for use and then reverted to Celsius degree for results.

For the humidity calculation, the formula is provided from figure 13 (in red rectangle). Line 10 in listing 4 combines the calculation of sensor RH value with the true RH value after temperature compensation formulas.

Particle Mobile app is used to ask user for command and show the results as event. After "flashing" the code to the Photon, it will automatically restart and reconnect to the Cloud, then wait for user input to start the measurement. As the correct command is received, the Photon will measure and send the data to the Cloud and publish as events shown in figure 21

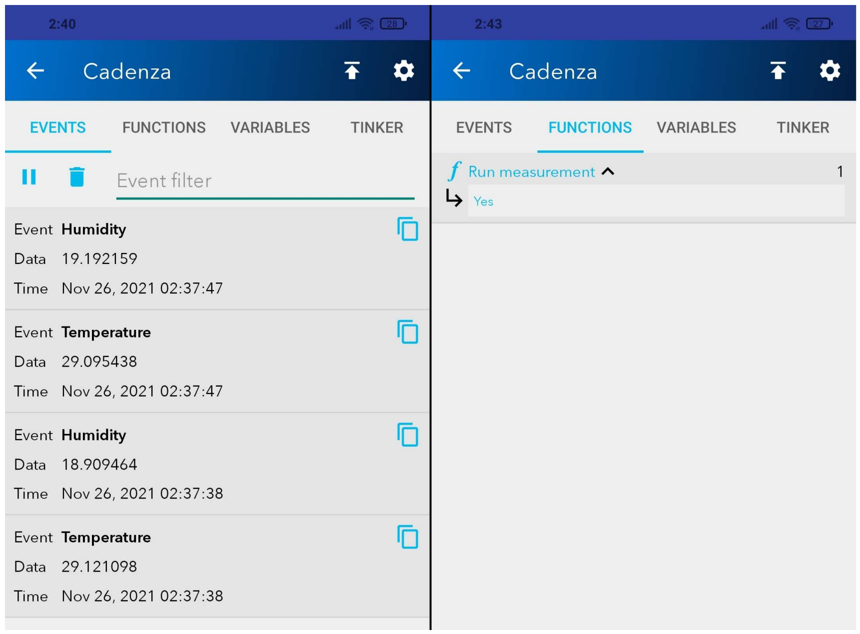

Figure 21. Particle Android app result view.

From figure 21, to get the sensor values, a "Yes" argument is typed in the "FUNCTION" tab of the app. It will show a number "1" on the function to signal that it is the correct prompt to run the calculation. Then user can switch to the "EVENTS" tab to view the sensor results. To run the measurement again, simply retype the command into the function.

4 Conclusion

The thesis work was to research and implement a simple system that can monitor the car indoor environment characteristics. The data acquired needs to be able to be viewed remotely for convenient purposes.

The system built from the project is a basic functional breadboard circuit utilizing NTC thermistor and a capacitive humidity sensor to react to the surrounding inside the car. The outputs of the sensors are both then acquired and converted into real values using Particle’s Photon microcontroller and Particle Web IDE. The result is sent to the Particle Cloud and can be viewed by the Particle Android app.

All the results from the final testing were positive. The circuit works properly, and the values acquired are all shown accurately and can be checked remotely through personal mobile phone app. Although the circuit and the code are simple, the possibility to upgrade the circuit and adding more functionality is very likely. The Photon code can additionally save user input as environment setting for personal preference or have a warm-up schedule based on personal needs.

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