# Step transient response of light-dependent resistor and temperature sensor

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**Abstract**

Step input is a common driver function in many control systems. The paper aims to find out the step output of light-dependent resistor and temperature sensor in response to flashlight activation and proximity to refrigerated drink can. The study successfully calculates a $t_{\text{fall}} = 350$-second falling time of the cooling transient response and a $t_{\text{rise}} = 605$-second falling time of the heating transient response. However, the study fails to calculate the relevant time constants for the transient response of the light-dependent resistor. For both light and temperature sensor, the plot shows first-order high-pass and low-pass filter-like behavior.

Keywords: transient response, LDR, temperature/humidity sensor

## 1 Step transient response

A step-driving function is a ubiquitous driver in many control systems. The response to a step function is called a *step response* showing how a specific system responds to a step input. More generally, a step input starts from any steady value jumping to another different steady-state value. A common example would be in designing a controller for a hovering drone. Sending a certain command to change the altitude of a drone from one height level to another requires sending a step-driving function. The step response corresponds to the continuous dynamics of how the drone reacts to that step command. These dynamics, for instance, encompass how the drone rises, how far it overshoots, how long until it settles to the final desired altitude, and how much steady-state error is present as it settles to the final desired altitude.

Analyzing the step response of a certain system is an integral part of any control system design serving as a system requirement. It is important to note that, without knowing the specific transfer function of a system, it is difficult to identify if a certain response is coming from a step input function. [1]

There are different ways to quantify the characteristics of a certain step response. One common way to characterize a certain control system is via its transfer function in the frequency domain. However, much description can still be extracted by analyzing the system in the time domain. Of course, there exists a way to correlate these time-domain characteristic values into their corresponding frequency-domain characteristic values. For instance, the percent overshoot of a second-order system can be mapped directly to the natural frequency and damping ratio which can be analytically extracted by knowing the transfer function. This way, as a system requirement, the percent overshoot, for example, can be fine-tuned by choosing appropriate transfer function parameters in the system design.

In this paper, we will explore the time-domain constants of the step responses for (i) light-dependent resistors and (ii) temperature sensors. Specifically, we shall quantify the (i) rising time, (ii) percent overshoot, (iii) settling time, and (iv) time constant for the respective step responses.

## 2 Light-dependent resistors

In order to measure changes in brightness, a light-dependent resistor (LDR) is often used as a variable resistor with a varying resistance as a function of brightness. This mechanism is achieved using a semiconductor material which have light-sensitive characteristics. Examples of such materials possessing this property are the following: CdSe, CdS, CdTe, InSb, InP, PbS, PbSe, Ge, Is, and GaAs. [2]

This variability of resistance is achieved using the material's property to "unlock" the free electrons from its crystal lattice. Conductivity highly depends on the number of free electrons that are capable of moving across the surface of a conductor. LDR materials intrinsically contain few free electrons at their natural state and, hence, possess a high amount of resistance at their unexcited state. However, photons striking the material provide sufficient energy to excite the electrons locked on the crystal lattice of the material.

In this paper, we shall analyze the step response of an LDR when inducing a discrete brightness change from one reference level to another.

## 3 Temperature/humidity sensors

Another component that is used in many control systems (such as heating, ventilation, and air conditioning or HVAC) is the temperature and humidity sensors. Currently, there exists different temperature and humidity sensors sold commercially. One common electronic sensor is DHT11 temperature and humidity sensor; these are commonly integrated and controlled via an Arduino microcontroller that is already pre-programmed with the use of their respective libraries to directly quantify temperature and humidity in the commonly-used units of measure (such as Celcius for temperature). [3]

The humidity sensor works using a moisture-holding substrate as a dielectric between the two electrodes of the capacitor. Changes in the moisture of said dielectric changes the capacitance which can be quantified appropriately to sense the changes in the humidity of the environment. Meanwhile, the temperature sensor uses a thermistor to measure temperature changes as a function of resistance changes across the component. Using appropriate electronic components such as the DHT11, together with its c++ library, temperature and humidity values can be conveniently measured and such sensor can be easily integrated within any control system.

In this paper, we shall analyze the step transient response of the DHT11 sensor by inducing a step change in temperature.

## 4 Sensor transient response

To analyze the step response of an LDR, we construct a circuit which reads analog voltage value controlled by the LDR variable resistance. The following circuit shows utilizing an Arduino UNO microcontroller to read analog value at the A0 pin.

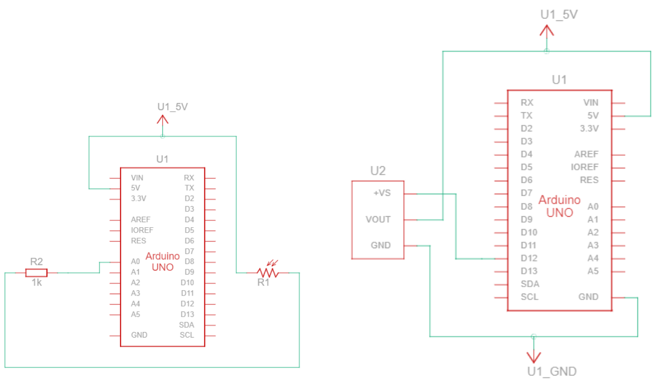


Figure 1: Left circuit shows R3 as LDR connected to 5V while right circuit shows U2 as 3-pin DHT11 temperature sensor.

To figure out the transient response of the incorporated LDR, we induce at brightness step function to the photoresistive component. In the study, the input step was done by placing the phone flashlight normal to the LDR direction, turning it on, waiting for one second, turning it off, and waiting for another second. The analog sensor value was left at the Arduino's native value range in the domain $[0, 1023]$. No further data processing and transformation was done to the sensor-gathered data set and was plotted in the said domain. The desired time constants was, then, extracted from the plot. The full code can be found at: https://github.com/schwarzschlyle/electronics-and-instrumentation/blob/master/transient-response/photoresistor-data/src/main.cpp. The full code referred to SparkFun Inventors Kit template for using photoresistors. The following is the Arduino code snippet used.

```
void loop()
{
  sensorValue = analogRead(sensorPin); // reads analog value at sensorPin = A0
  Serial.println(sensorValue); prints analog value and collected for plotting
}
```

Similarly, a step temperature change was induced to the temperature sensor. To do so, a simple circuit was constructed using a DHT11 sensor as the main temperature-reading device.

To induce a step temperature input, the DHT11 temperature sensor was first stabilized to read the room ambient temperature. The source of the step input was a cold, refrigerated, metallic can filled with liquid. The can was placed right next to the temperature sensor while the data is being gathered at a one-second granularity. Data gathering was halted some time after the temperature settled at some constant value. The full code referred to a manually-constructed code block without the use of the DHT library which can be found at https://github.com/schwarzschlyle/electronics-and-instrumentation/blob/master/transient-response/temp-humid-sensor/src/main.cpp. The following is the Arduino code snippet used

```
void loop()
{ ...
    Serial.print(" Temp = ");
    Serial.print(Temp); // Temp definition can be found at the main code repository
    Serial.print(",");
    Serial.print(TempComma);
    Serial.println("°C ");
...}
```

## 5 Transient response evaluation

### 5.1 Light impulse response

Data from the light impulse response shows a square-wave-like curve rising up when the flashlight turns on and falling down when flashlight turns off.

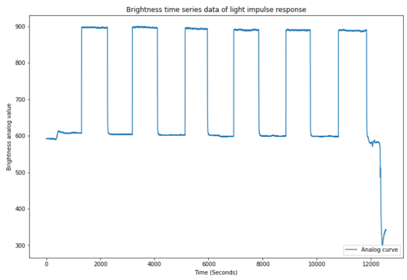


Figure 2

Upon close inspection, the rising and falling curves' transient behavior is not a perfect step function but qualitatively looks like a high-pass filter and a low-pass filter, respectively. This is more apparent in the falling section as the rising part possesses a low value of rising time which was not completely captured by the sampling time of the sensor.

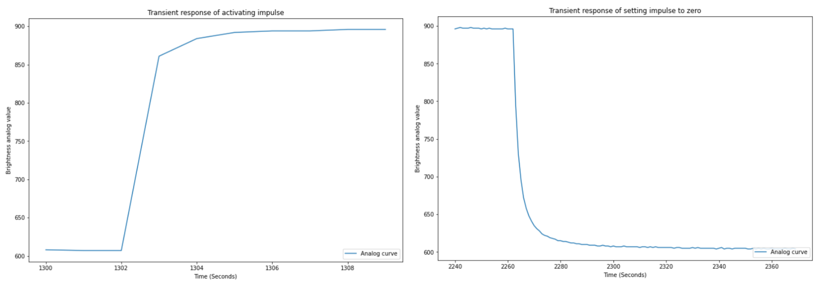


Figure 3: Left plot shows step response to flashlight activation while right plot shows step response to flashlight deactivation.

For the light activation step response, the starting analog value is 608 while the steady-state analog value is 896. The 10% level is 867.2 while the 90% level is 636.8 . At the 63% level, the analog value is 714.56 corresponding to the system's time constant. Without appropriate data points due to the limitation of the programmed sensor sampling rate, the relevant time constants could not be calculated

For the light activation step response, the starting analog value is 608 while the steady-state analog value is 896. The 10% level is 636.8 while the 90% level is 636.8 while the 90% level is 867.2. At the 63% level, the analog value is 789.44 corresponding to the system's time constant. Again, the limitation of sensor sampling is more apparent in the light activation step response which can be observed from the limited number of data points from the plot.

### 5.2 Temperature impulse response

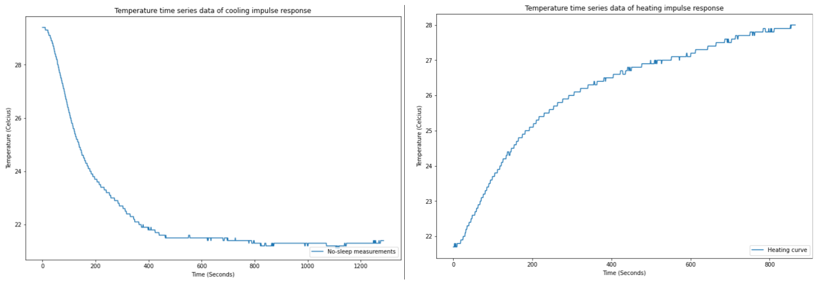


Figure 4: Left plot shows cooling response to a cold can input while right plot shows return to room temperature

Similarly, the temperature impulse response from the input step function follows a low-pass filter behavior for the cooling curve and a high-pass filter behavior for the heating curve. Throughout the discussion, all temperature units are in Celcius while all time units are in seconds.

For the cooling curve step response, the starting temperature is 29.4 while the steady-state temperature is 21.4. The 10% level is 28.2 corresponding to $t = 53$ while the 90% level is 21.8 corresponding to $t = 403$. Hence, the fall time (from 10% to 90%) is $t_{\text{fall}} = 350$ or 5.83 minutes. At the 63% level, the temperature is 23.96 corresponding to $t = 183$. Hence, the time constant of the cooling transient response is $\tau = 183$ or 3.05 minutes

For the heating curve step response, the starting temperature is 21.7 while the steady-state temperature is 28.0. The 10% level is 22.33 corresponding to $t = 39$ while the 90% level is 27.37 corresponding to $t = 644$. Hence, the rise time (from 10% to 90%) is $t_{\text{fall}} = 605$ or 10.08 minutes. At the 63% level, the temperature is 26.44 corresponding to $t = 379$. Hence, the time constant of the heating transient response is $\tau = 379$ or 6.31 minutes.

Observe that for all the discussed step responses, there exists no apparent settling time and percent overshoot. This may be an indicator that both LDR and temperature sensors are first-order systems.

## 6 Conclusion

Using Arduino UNO to gather data from the photosensitive and temperature sensor, the paper explores the step transient response to light and temperature step input, respectively. Both step responses resemble a first-order high-pass filter (for step input activation) and a low-pass filter (for step input deactivation). The study successfully calculates a $t_{\text{fall}} = 350$-second falling time of the temperature transient response as it progresses from 10% to 90% from the initial state to the steady state of the cooling transient response. For the return to the room temperature, the study successfully calculates a $t_{\text{rise}} = 605$-second falling time of the temperature transient response as it progresses from 10% to 90% from the initial state to the steady state of the heating transient response. Meanwhile, for the LDR transient response, limitations in the sampling rate fail to calculate the respective time constants.

## References

[1] MATLAB, The step response — control systems in practice (2020), https://www.youtube.com/watch?v=USH75nuHV6w&t=3s.

[2] E. Notes, Light dependent resistor ldr: Photoresistor, https://www.electronics-notes.com/articles/electronic_components/resistors/light-dependent-resistor-ldr.php.

[3] A. Lavaa, Temperature and humidity sensors: Ultimate guide (2021), https://www.linquip.com/blog/temperature-and-humidity-sensors-an-ultimate/.

## 7 Codes and Raw Data

All files regarding the experiment can be found here: https://github.com/schwarzschlyle/electronics-and-instrum

# 8 Reflections

## 8.1 Technical correctness

The objective of the paper is to explore transient responses of different sensor systems. Specifically, we explored the transient response of the light-dependent resistors and the DHT11 temperature sensor. The codes used are properly referenced on the main code file containing sufficient comments. Although there are several limitations on the numerical computations of the time constants, the paper managed to produce the required results and qualitatively displayed the low-pass and high-pass filter-like behavior when a step function is activated and deactivated. Overall, the objectives have been tackled appropriately.

Self-score: 35/35

## 8.2 Presentation quality

Circuit diagrams and codes were properly presented appropriately. Figure contains stand-along caption while plots have sufficient labels. Graphs are simple to comprehend and visually understandable. Hence, visual presentation of data is easy to digest.

Self-score: 35/35

## 8.3 Self reflection

From the previous sections, the self-score was justified concisely and properly. Sources were acknowledged both in-text and on the main.cpp code files. Citations were included as necessary to support literature for the study background. Moreover, the sampling rate limitations was tackled causing the inability to produce time constants limitations of the light-dependent resistor.

Self-score: 30/30

## 8.4 Initiative

Although I was originally planning to incorporate this transient response as a part of a larger project - as a part of the continuation of my SHS research (self-powered thermoregulation insoles), I failed to do so due to time constraints. I will, instead, try to integrate the motor and feedback control to the said research. Hence, I suppose no additional initiative is present on the current paper.

Self-score: 0/30

Overall self-score: 100/100