Blog

September 20$^{\text{th}}$ 2019

The eHives' sensors & errors of measurement

Bee hive

Temperature

Pt1000 measuring resistors of accuracy class AA are used for measuring temperatures inside the eHives. They are calibrated to an accuracy of $\pm$ (0.1 °C + 0.0017 $\times$ T) with T being the temperature in °C. Because the sensors are connected by a two wire circuit to the electronics for further signal evaluation, the line resistance also causes an error. Since the length of this circuit is small, the associated error should be comparatively small as well. On the circuit board, the sensors are connected in series with a 4.7 kΩ precision resistor each and a reference voltage of 10 V, c.f. Fig. 1. The precision resistors are exact with a tolerance of 0.1 %. The reference voltage is created by an ADR01ARZ with a tolerance of 0.14 %.

Now, the voltage difference between the temperature sensors and the reference voltage is digitised using an AD7789 analog-digital-converter (ADC). The ADC's $\pm$ 0,3 μV offset can be neglected because the change in voltage for a 1 °C temperature difference amounts to 5.7 mV. The ADC's resolution of 19 bit with a reference voltage of 2.5 V yields an effective resolution of 4.8 μV. In consequence, the ADC's contribution to the measurement error can be neglected as well. The 2.5 V reference voltage is created by an ADR03ARZ with a tolerance of 0.14 %, being equal to the tolerance of the ADR01ARZ mentioned earlier.

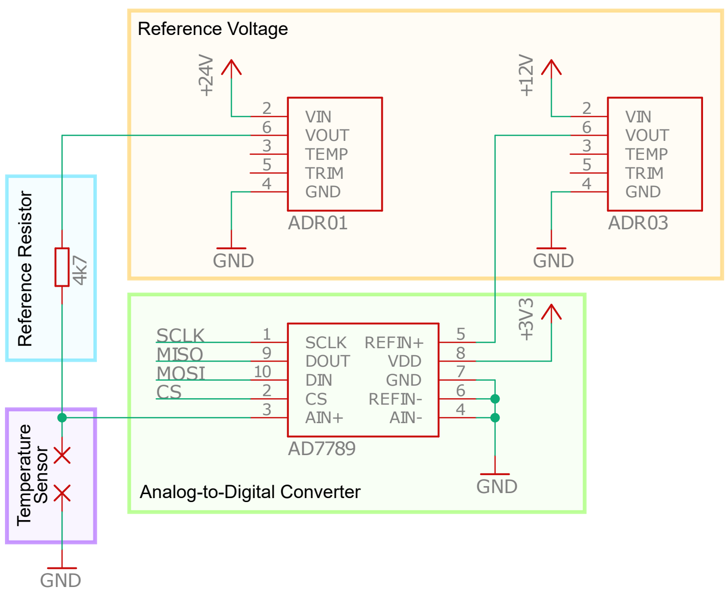

Fig. 1: Electrical circuit for evaluating the temperature sensors.

The sensors' measuring resistor itself is shielded by a shell made of stainless steel which reaches up to 20 cm inside the hive and is located at around two-thirds of the honeycombs' height. Usually, a sensor should be in between two honeycombs. However, sometimes the bee colony integrated one or more sensors in the combs. This is especially the case for top-bar-hives. Since different types of hives are used, the sensors' distribution differs and may not even be symmetric. Usually, a sensor is placed in every second comb alley. The exact arrangement is shown in the following table, where each column represents a comb alley according to its number in the first row of the table. The maximum number of comb alleys is 14, while most of the eHives have less. (Dark grey cells represent non-existing alleys.) The numbers 1-6 (respectively 1-5 for eHives with only 5 temperature sensors) in the remaining rows mark the position of the temperature sensors inside the hive according to their label in the database.

##	eHive ID	01	02	03	04	05	06	07	08	09	10	11	12	13	14
01	DEU-DHG-1		1	2		3	4		5	6					
02	DEU-FKG-1		1	2		3	4		5	6					
03	AUT-GSC-1														
04	AUT-WIS-1		1		2		3		4	5	6				
05	AUT-BIE-1		1		2		3		4		5		6		
06	ITA-FEM-1		1		2		3		4		5				
07	ITA-FEM-2		1		2		3		4		5				
10	POL-LOK-1					6	5	4	3	2	1				
12	DEU-BGT-1		1		2		3		4		5				
13	ITA-LFV-1														
14	DEU-MNG-1		1		2		3		4		5		6		
15	DEU-OEG-1		1		2		3		4		5		6		
16	DEU-FDG-1		1		2		3		4		5				
17	DEU-LPG-1		1		2		3		4		5				

Humidity

The air humidity inside the hive is measured using a SHT21 humidity sensor. This component is sold in a system that converts the digital signal into an analog signal using a PIC32MX micro controller. In consequence, the signal must be digitised again on the main circuit board. The tolerance of the sensor component is 2 % for humidity values between 20 % and 80 %. It increases linearly to 3 % for humidity values approaching 0 % or 100 % respectively. We guess the convertion to an analog signal increases the measurement error by approximantely 0.5 %.

Because the humidity sensor is located in the lower part of the hive below the combs, the measured value correlates heavily with the outside humidity. Since the sensor is relatively huge in dimensions, it was not possible to place it in a higher location of the hive where the colony's micro climate can be monitored better.

Scale

The eHive measures the hive's weight using load cells of type SEB46B, c.f. Fig. 2. On a spring torso made of stainless steel, attached distention straps change their electrical resistance depending on the load acted on the torso. Combining multiple distention straps to a Wheatstone bridge, the bridge's output voltage is amplified using an AD623 instumentation amplifier and then digitised using an AD7789 ADC (c.f. temperature section above). The voltage source for the Wheatstone bridge is identical to the one for the temperature sensors. The amplifier increases the signal strength by a factor of 99 with a deviation of 0.35 %. The amplification factor is regulated by a resistor and inherits its 0.1 % tolerance. The load cell's resolution amounts to 0.2 μV/g prior respectively 19.8 μV/g after amplification.

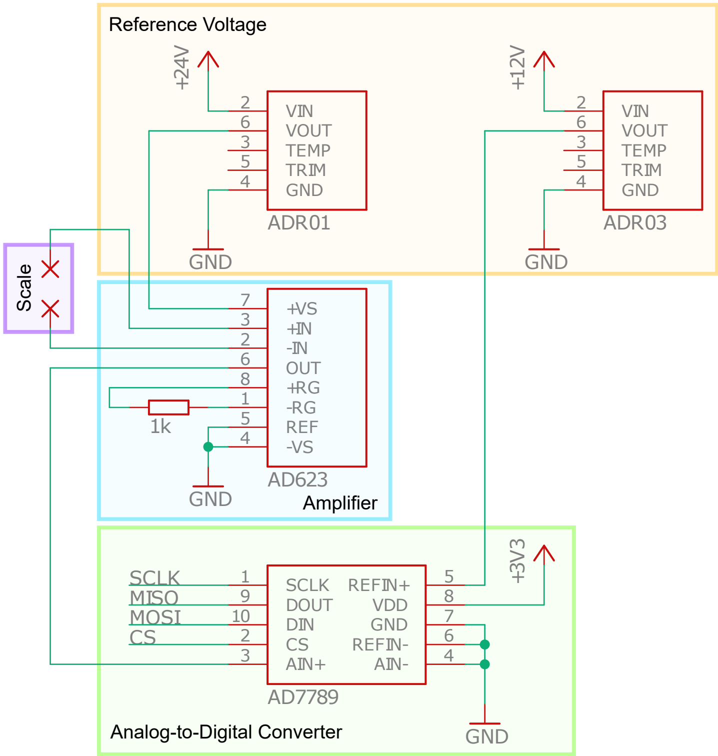

Fig. 2: Electrical circuit for evaluating the eHive's weight.

The load cell's smallest possible resolution is 6.6 g according to its spec sheet. At constant temperature this resolution can be reached by our weight measuring system. However, temperature changes can result in weight changes of some one hundred gram. Rainfall can lead to additional deviations because not all eHives are equipped with a roof (c.f. blog post The eHives' locations and surroundings). The sensors' drift over long periods of time is not known.

Weather station

All weather data, except air pressure, is measured by the weather station Vantage Pro 2 from supplier company Davis. Since the measured values are read out digitally all tolerances can be taken from the weather station's spec sheet. In the following paragraphs additional error sources and external influences are listed.

Outside temperature and humidity

For measuring air temperature and humidity in a comparable manner, the weather stations must be installed on a open area with defined surface and in equal height. However, reality is complicated and in consequence some weather stations are located on grassland, some on roofs, etc. which may influence the measured values. Nonetheless, it was tried to install the station around 2 m above the hive to monitor the relevant local micro climate at the hives' site.

Rainfall

Rainfall is measured with a seesaw below a funnel. As soon as a well-defined amount of water accumulated in one of the seesaw's two shovels, the seesaw dips over and activates a Reed relay using a magnet attached to the seesaw below its turning axis. One dip translates to 0.2 mm of rainfall. As a consequence of this technique, snow can only be measured in the process of melting, supposing it was not blown away from the funnel due to high wind speeds and/or the funnel's overflow prior to melting. Though electrical heating components are installed inside the rain meter at some of the eHives' locations, those heating components are not in use in most places due to low effectiveness. On top of that, the funnel sometimes gets blocked and may not be cleaned regularly, resulting in measuring zero rainfall over long periods of time.

Wind speed and direction

Equally to air temperature and humidity the weather stations installation site may influence the wind values. The height of the wind sensor is supposed to be around 5 m above ground but can deviate heavily at some locations. For measuring the wind direction, the sensor must be oriented exactly northwards. However, that is not always possible to a high precision, so the measured absolute values may deviate by some degree. The listed measurement error is a relative error.

Solar irradiation and UV index

At some locations the two irradiation sensors are shadow-casted by trees of buildings during parts of the day. Usually, once a day the shadow of the installation mast casts the sensors. This happens because the two sensors are attached to the weather station's base component and in consequence to the fact that in most cases both the base component and the wind sensors component of the weather station are installed to the same mast.

Air pressure

For measuring air pressure a BMP280 sensor is used which is located on the main circuit board. The sensor's output is digital and therefore the measurement error in the spec sheet can be adopted.

Internal sensors

Complete current and radiator current

For measuring currents ACS712 sensors are used which supply a voltage proportinal to the current. This voltage is digitised using the Arduino's internal 12 bit ADC that works with a maximum voltage of 3.3 V and therefore theoretically exhibits a resolution of 0.81 mV. Since the current sensor outputs 0.185 V/A, one step of 0.81 mV translates to a change in current of 4.4 mA. According to the sensor's spec sheet its resolution amounts to 75 mA, which was rounded to 0.1 A due to the small effective resolution of the Arduino.

The sensor for the radiator current can be allocated freely. For example, it would be possible to measure the charging current if an eHive is powered by battery.

Charging voltage

The charging voltage is the voltage at which the electrical system is operated. Since as of today this voltage is supplied by a power-supply unit at all eHives and therefore is almost constant, the name is a bit confusing. The voltage is measured using the Arduino's ADC after being reduced by a voltage divider using a 1 kΩ and a 4.7 kΩ precision resistor. The resisitors' contribution to the total measurement error can be neglected. The theoretical resolution therefore amounts to 4.4 mV, however it was rounded up due to the small effective resolution.

Microchip temperature

The Arduino's mirco controller features an internal temperature sensor which absolute value must be calibrated individually for every single sensor. Since this was not done, the absolute values of this sensor exhibit an offset of ± 45 °C. The relative error amounts to ± 3 °C according to the spec sheet.

Tabular overview of measurement errors

(for details and comments c.f. sections above)

Sensor	Error	Unit	Annotations
Inside temperature	0.2	°C	
Inside humidity	2.5	%	below 20 % and above 80 %: increase to 3.5 %
Weight	0.01	kg	higher deviations at changing temperatures
Outside temperature	0.5	°C	
Outside humidity	3	%	above 90 %: increase to 4 %
Rainfall	0.2	mm/h	above 4 mm/h: 5 % of the measured value
Wind speed	3	km/h	above 60 km/h: 5 % of the measured value
Wind direction	7.5	°	relative error
Solar irradiation	90	W/m^2	
Air pressure	1	mbar	
UV index	0.8	UVI	
Complete current	0.1	A	
Charging voltage	0.01	V	
Radiator current	0.1	A	
Microchip temperature	3	°C	relative error, offset ± 45 °C