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Investigations on IR Sensors For Detecting People In a Car

BSc Thesis

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Content

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Budapest, 14 February 2020

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Ricardo de Jorge Melgar

SUMMARY

This project is based on the need for passenger detection in cars because of the new legislation of the European Union. In my case I will study the use of infrared technology thermal sensors.

Therefore, to begin I will make an analysis of the most similar possibilities that are on the market or that it would be feasible to develop them since they are similar in terms of goal to the project that I have developed.

After analyzing the literature and the market, I will explain the infrared thermal sensors in order to understand better how they work and follow easier the rest of the project.

After finish explaining the environment of the project I will move on to the most practical part analyzing the tools that I am using in the project, as well as the necessary connections to get everything up and running. The main devices I will use are Arduino UNO, the AMG8833 IR sensor and the display attached to the Arduino board to display the thermal signals.

The whole project is based on the programming of the Arduino board, so I will also analyze above the programming necessary for the project and the changes that have been necessary for its realization.

Finally, the exposure of all experiments conducted with their respective results and explanations thereof to study whether it is feasible or not and under what conditions and positions should or should not be used.

SUMARIO

Este proyecto parte de la necesidad de detectar pasajeros en coches por la nueva legislación de la unión europea.

En mi caso voy a estudiar el uso de sensores térmicos de tecnología infrarroja.

Por tanto, para comenzar haré un análisis de las posibilidades más similares que hay en el mercado o que fuera viable desarrollarlas ya que son la competencia más cercana al proyecto que he desarrollado.

Tras analizar la competencia haré una explicación de los sensores térmicos de infrarrojos para entender mejor cómo funcionan y así entender mejor el resto del proyecto.

Al acabar de explicar el entorno pasaré a la parte más práctica analizando las herramientas que voy a utilizar en el proyecto, así como las conexiones necesarias para ponerlo todo en funcionamiento. Los aparatos principales que usaré son Arduino UNO, el sensor IR AMG8833 y la pantalla acoplada a la placa de Arduino para visualizar las señales térmicas.

Todo el proyecto se basa en la programación de dicha placa Arduino, por tanto, también analizaré por encima la programación necesaria para el proyecto y los cambios que han sido necesarios para su realización.

Por último, la exposición de todos los experimentos realizados con sus respectivos resultados y explicaciones de los mismos para estudiar si es viable o no y en qué condiciones y posiciones debería o no usarse.

1. INTRODUCTION

Nowdays cars are getting more and more intelligent; to enable such advancement, they need a huge amount of information, which they get from all the electronic devices, sensors and modules that all the modern cars have. In fact, electronics are one of the most important parts without which they could not work. To collect all the information to be processed sensors are needed, which we can find scattered throughout the car. We can find different kind of sensors, for example pressure sensors, distance sensors or temperature sensors.

The passengers detection inside the car, specifically the number of the passengers is getting important in order to improve the eCall systems acting as a provider of supplementary data. The target of eCall is giving the emergency services all the possible information about the passengers in the car, and this information has to be precise.

Having this in mind, the European Parliament voted in favour of a new regulation of the eCall. That new regulation oblige brands to equip eCall technology in all of their new cars from April 2018 [1]. Passenger detection is not a requirement, but a smart addition to such emergency services.

For this project I'm analysing the use of the temperature sensors in the cars, specifically in the interior in order to detect the number of passengers seated in.

The temperature sensor I am using is the AMG8833, connected to an Arduino UNO board and a screen to validate live information that the sensor obtains.

2. PASSENGER DETECTION METHODS, LITERATURE RESEARCH

Due to the new regulation of the eCall that I have commented previously, we can observe a growing interest among technology companies and automobile brands in passenger detection technologies inside cars. Currently there are already some of these technologies working in cars. Then I will comment on some technologies currently used and others that could be used apart from passenger detection with the thermal camera.

2.1 SEATBELT BASED SOLUTIONS

The EU has updated the seatbelts regulation, in a way that from September 2019, all of the new cars require a seatbelt reminder in all of the seats, front seats and back seats.[2]

Before that it was only necessary to have seatbelt reminder in the driver seat. The regulation about driver seat was agreed by EU in 2009. That regulation includes the need to be able for the system to detect the passenger and make an audible warning when the passenger seats in the car if the belt is no attached.[3]

That makes seatbelt solutions the most used to detect passengers nowadays as every new car has to equip it because of the regulation I have mentioned.

This system is not reliable 100% because the passengers sometimes don’t use it. There is a study done in Europe that reveals the use of the seatbelt in the cars, and the numbers are 88% for the front seats and as low as 74% for the back seats even with the regulations and the seatbelt reminders.[4]

Then I am explaining how seat belt solutions work. First, we have a sensor which is placed at the bottom of the seat to detect the passenger on it. One variable reluctance sensor is placed near the roller of the seat belt webbing. At the buckle of the seatbelt we have a touch sensor to know when the belt is attached.

When all doors are closed, the sensors start to send information to the microcontroller which is connected to the wheel speed sensor, and depending on the speed of the car, the seat belt reminder starts making his characteristic noise. Here, in Figure 1 we have a scheme of seat belt reminder system.

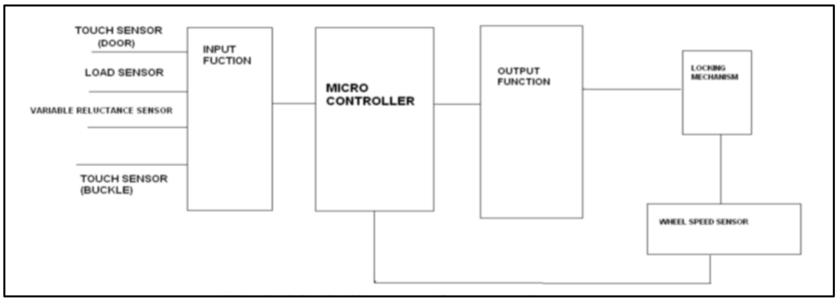


Figure 1: block diagram of proposed seatbelt system.[5]

In the end, the seat belt system is the main way nowadays to detect passengers in cars because it combines the security for the passengers and in addition it can detect passengers with the same system; to sum up, is a very important device in cars, because of it every modern car needs that system.

The problem with this system is that is not 100% reliable because the passengers don't use always the seatbelt and the pressure detector of the seats can detect something heavy which might not be a person.

2.2 TOF CAMERA

Time of flight cameras, known as TOF cameras, are sensors that have a technique used to estimate body distances by calculating the time elapsed between the emission and reception of an infrared beam of light. This means that they do the measurement of the time elapsed between the emission of a wave pulse, its reflection off of an object, and its return to the ToF sensor.

TOF cameras have different applications nowadays like autonomous driving, object detection for different applications and many more.

These devices have a built-in electronic shutter that operates in synchronism with the infrared light pulses.

The portion of the pulse blocked by the shutter depends on the arrival time of the pulse and the light integrated into the sensor depends directly on the distance travelled by the pulse.

The ability to detect distances is very useful in the automotive field. There are sensors to detect nearby objects when parking; detection for the protection of pedestrians and detection of nearby objects to avoid collisions.

By detecting the environment, the car has a lot of information to work with like for example do a trajectory change to avoid a person. Figure 2 shows how a 3D camera using TOF technology works:

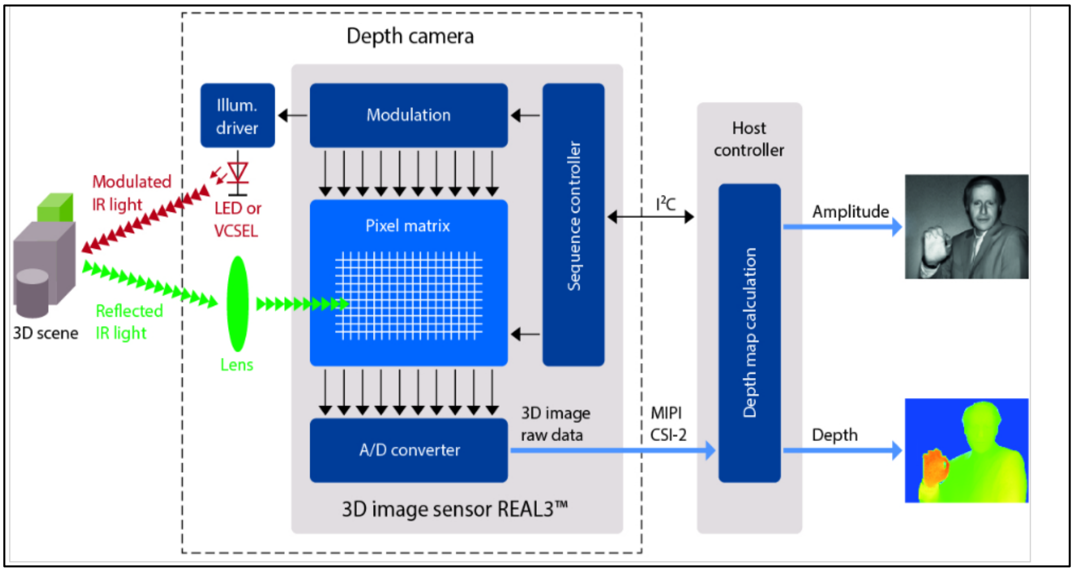


Figure 2: 3D camera development kit "pico flexx" from pmdtechnologies [6]

As we can see, TOF cameras are very useful and currently they are starting to being much more used than years ago as we can consider them a new technology with a lot of different uses.

The main problem with the TOF camera is the price. The sensor is quite cheap but the evaluation kit is so much expensive than other options, that makes it harder to use it in some applications in which a cheap price for the system is important.

2.3 GAS SENSORS

Another possible way to detect people in a car is by using gas sensors. This systems works with the concentration of CO_2 gas since humans exhale this gas when breathing.

In a closed room or in a car, the amount of CO_2 gas increases with the time that the people stays in the room and depending on the number of people breathing in the close space, it is possible to measure how fast the amount of CO_2 increases and by that way counting people.

This type of people detection in a car can also be useful to prevent excessive quantities of CO_2 which can be dangerous. With this information, the car can start an automatic ventilation.[7]

In Figure 3 we can see the variations of the concentration of CO_2 depending on the number of passengers and the time.

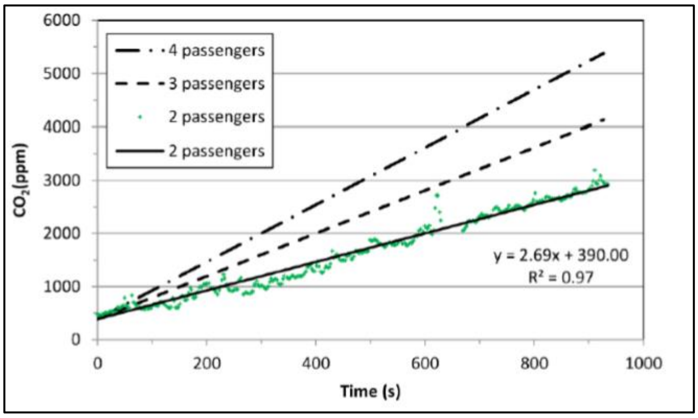


Figure 3: CO2 concentration inside a car with different number of occupants. The car is not moving and the air ventillation is swithed off [8]

As we can see, is possible to count people in close spaces with gas sensors, but the problem with gas detection is that it is not precise because any change on the ventilation of the room or the car would change the gas concentration. So it is useful only if we have a controlled area in which we could know the possible changes in the air concentration.

2.4 ULTRASONIC SENSOR

Ultrasonic sensors or ultrasonic sensors are proximity detectors that work free of mechanical friction and that detect objects at distances ranging from a few centimeters to several meters. The sensor emits a sound and measures the time it takes for the signal to return. These reflect on an object, the sensor receives the echo produced and converts it into electrical signals, which are produced in the valuation apparatus.

This sensor offers the possibility of detecting fragile objects, such as fresh paint, also detects any material, regardless of color, at the same scope, without adjustment or correction factor. Ultrasonic sensors have a learning function to define the detection field, with a minimum and maximum accuracy range of 6 mm. The problem presented by these devices are blind zones (blanking) and the problem of false alarms. The blind zone is the zone between the sensitive side of the detector and the minimum range in which no object can be detected reliably.

Some of the ultrasonic sensor’s applications are: flow measurement, waste management, maintenance and detection, but they have many more applications and seem to keep improving to starting being used in other areas. [9]

Here in figure 4 we have a picture about how they work:

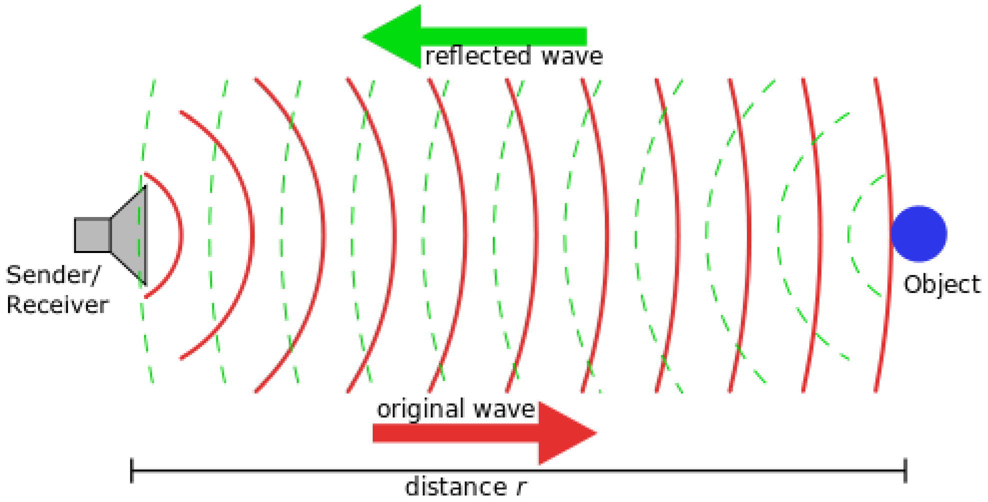


Figure 4: Ultrasonic sensor measuring distance [10]

Ultrasonic sensors are one of the better ways to detect people, as they are very reliable and can be used in different environments.

For passenger detection in a car is also one of the better ways to do it. The main problem of it is the price as a true/false ultrasonic detector cost around 100$. (MB7363 HRXL-MaxSonar-WRLS from Maxbotix, which we can see in Figure 5.)

Figure 5:MB7363 HRXL-MaxSonar-WRLS [11]

So it is a matter of price but anyways is much cheaper than a TOF camera but so much expensive than the IR sensors.

3. EXPERIMENTAL

3.1 Arduino UNO

Arduino is a project that born in 2003 in Interaction Design Institute Ivrea (IDII) in Ivrea, Italy. It was though as a way to bring the programming and circuit creation closer to the students and the population since it was much cheaper than the boards that were used at that time.[12]

The Arduino Uno is an open source microcontroller board developed by Arduino.cc and based on de ATmega328P microchip. In the Arduino we have analog and digital pins that can be connected to other circuits or expansion boards. The Arduino has 6 analog pins and 14 digital pins, all of them programmable with the Arduino software (Arduino IDE). For the programming, the Arduino uses USB type B cable. It can be powered by the same USB cable or it can use an external 9 volt battery as well.

In the Arduino website there are a lot of different projects that you can download and test for free. In Figure 6 we can see a standard Arduino:

Figure 6: Arduino UNO

Arduino is a very useful platform for tests and tests since it is very economical and flexible.,which makes it the best option for the development of this project. It is bought fully assembled with SMD miniature components (except the microcontroller, which make it easier to change). Currently you can buy the latest Arduino version for less than 30€ (Near 9000 HUF)

Technical specifications[13]

- Microcontroller: Microchip ATmega328P
- Operating Voltage: 5 Volts
- Input Voltage: 7 to 20 Volts
- Digital I/O Pins: 14 (of which 6 can provide PWM output)
- Analog Input Pins: 6
- DC Current per I/O Pin: 20 mA
- DC Current for 3.3V Pin: 50 mA
- Flash Memory: 32 KB of which 0.5 KB used by bootloader
- SRAM: 2 KB
- EEPROM: 1 KB
- Clock Speed: 16 MHz
- Length: 68.6 mm
- Width: 53.4 mm
- Weight: 25 g

3.2 INFRARED TEMPERATURE SENSORS

Infrared temperature sensors can be used to detect electromagnetic waves from 700 nm to 14.000 nm. The infrared temperature sensors have one or two photodetectors in which they focus the infrared energy emitted.

The infrared energy emitted is proportional to the temperature so when the photodetectors convert the infrared energy into an electrical signal, we can get accurate information about de temperature of the object.

Infrared temperature sensor are based in some formulas, which are old and well proven:

- Kirchoff’s law: Thermal equilibrium. “Kirchhoff’s law of thermal radiation, postulated by a German physicist Gustav Robert Kirchhoff, states that the emissivity and the absorptivity of a surface at a given temperature and wavelength are equal.[14] In Figure 7 there is a picture that represents it.

$$\text{emissivity } \varepsilon = \text{absorptivity } \alpha \qquad (1)$$

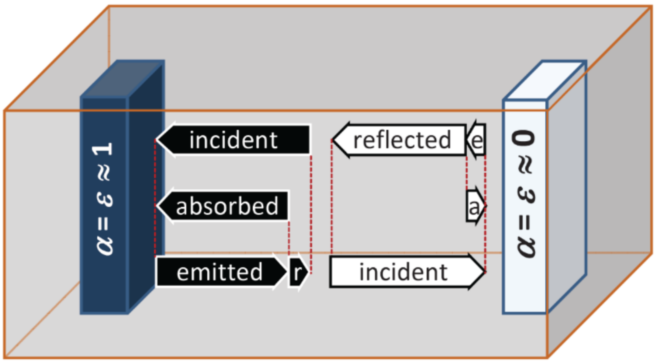


Figure 7: two bodies in thermal equilibrium [15]

- Stephan Boltzmann Law: The Stefan–Boltzmann law states that "the total energy radiated per unit surface area of a black body across all wavelengths per unit time j (also known as the black-body radiant emittance) is directly proportional to the fourth power of the black body's thermodynamic temperature T"[16]:

$$j^* = \sigma T^4 \tag{2}$$

-T: Black body's thermodynamic temperature

-j: Black body radiant emittance

- σ: Stefan-Boltzmann constant

Figure 8 represents the plot of emitted energy of a black body.

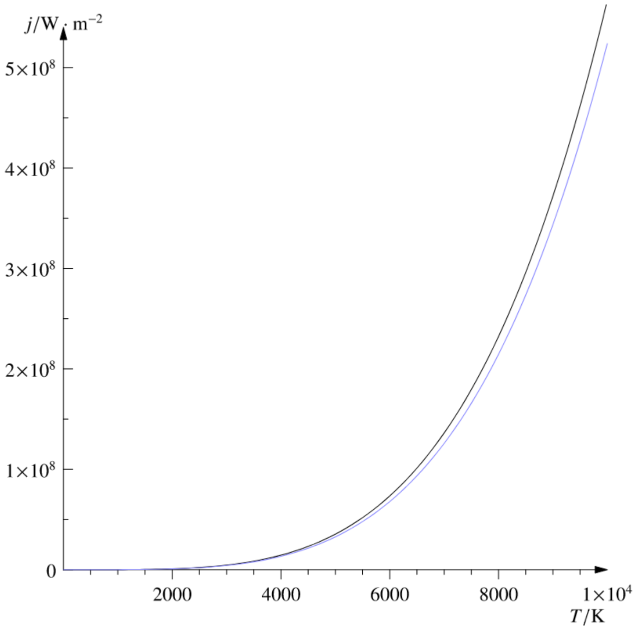


Figure 8: Function of total emitted energy of a black body proportional to its thermodynamic temperature.[17]

- Wien’s Displacement Law: “The Wien Displacement Law (in honor of Wilhelm Wien) is a law of physics that states that there is an inverse relationship between the wavelength at which the temperature peak of a black body occurs and Mathematically, the law is” [18]:

$$\lambda_{max} = \frac{0{,}0028976\ m \cdot K}{T} \qquad (3)$$

-T: Absolute temperature in kelvins

-λ_{max}: Wavelength for max spectral radiance of black-body radiation per unit wavelength

-$0{,}0028976\ m \cdot K$: Wien's displacement constant

Figure 9 represents the Wien’s Displacement Law:

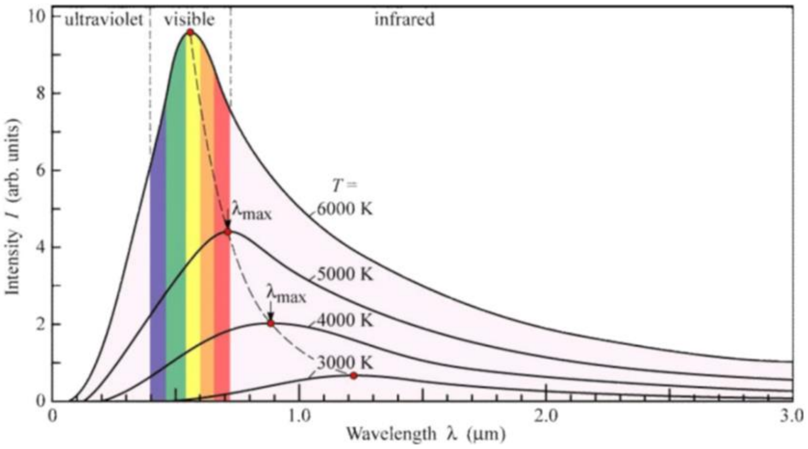


Figure 9: Wien's displacement law graphic [19]

- Plank’s ecuation: “Describes the relationship between spectral emissivity, temperature and radiant energy.” [20]

Infrared Temperature sensors are very useful because they have some advantages[21] if we compare them with contact-based temperature sensors:

- They are able to read moving objects. Contact-based temperature sensors do not work well on moving objects. So for example they can be used for reading the temperature of the tires in a moving car.

- IR sensors don’t make contact which means longer operating lives
- IR sensors can get more information as you can move them to a different spot to get other view.
- IR sensors can be used to detect motion by watching the fluctuations and the movement in the screen.

3.3 AMG8833 – GRID-EYE

The AMG8833 is an IR sensor in 14 pin. SMD module shown in Figure 10. It is from the second generation models of the Grid-EYE family which have improve the detection distance and the accuracy from it's predecessor the AMG8831 thanks to a better NETD (Noise Equivalent Temperature Difference).The high precision infrared array sensor is based on Panasonic’s MEMS (Micro Electro Mechanical Systems) technology. This new generation of Grid-EYE infrared array sensors combine a digital ASIC (I2C interface), a silicon lens in the same small package and an even more sensitive MEMS sensor chip.[22]

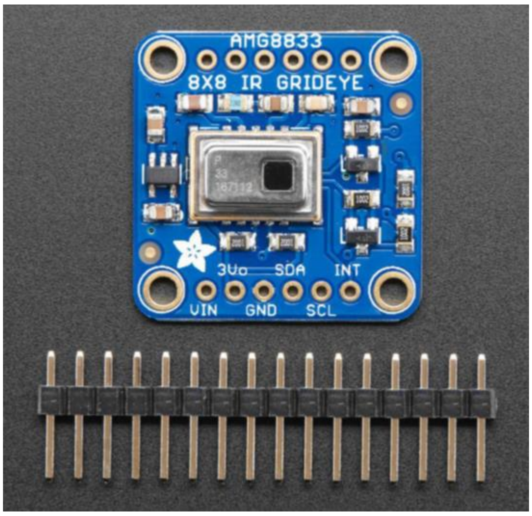


Figure 10: AMG8833 Grideye [23]

The AMG8833 is able to measure temperatures ranging from 0°C to 80°C having an accuracy of ± 2.5°C (4.5°F). With the improves in the new generation, now it can detect a human from a distance of up to 7 meters. It’s maximum frame rate is 10Hz, so it can be used to create a mini thermal camera with 10 frames per second.

When connected to a microcontroller it returns an array of 64 thermopile elements in an 8x8 grid format that detect absolute surface temperature without any contact.

Unlike conventional sensors, Grid-EYE uses a patented 60° silicon lens etched out of a silicon wafer, (less than 0.3mm height) which in the current market is the smallest lens. With all of these technologies, the sensor has an impressive size of only 11.6mm x 8mm x 4.3mm, which is smaller by far than competitors’ products.

To make it easier, the user can have it in a breakout board with a 3.3V regulator and level shifting. So it can be used with any 3V or 5V.

It’s current consumption is 4.5mA in normal mode, 0.2mA in sleeping mode and 0.8mA in stand-by mode.

It takes to enable communication after setup 50ms and 15ms to stabilize output after setup.

In Figure 11 we have a scheme that shows how the grid-EYE works:

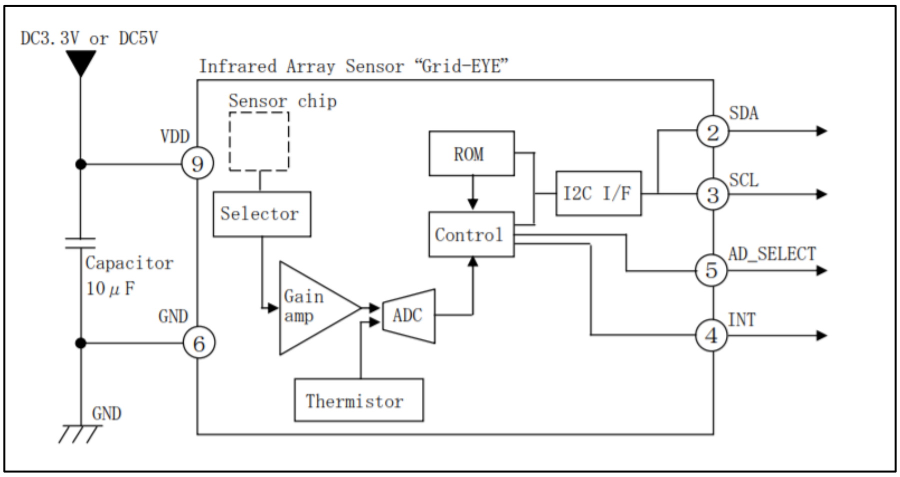


Figure 11: AMG8833 scheme. [24]

3.4 WIRING

To do the wiring of the thermal cam we will need: the Arduino UNO, the AMG8833 Grid-EYE, a screen to see what the thermal cam is seeing, a board to work with to connect everything and a few wires.

Once the project has every item in the inventory, the first thing we should do is to solder the pins. To perform the soldering, I went to the BME-ETT electronics laboratory and used the tool Weller Hot Iron EC 2002 in the Figure 12:

Figure 12: Weller EC2002 hand soldering device

After connecting the parts to the board now we have to connect them with the Arduino, The scheme to do the connections is given by Adafruit and we can see it in Figure 13:

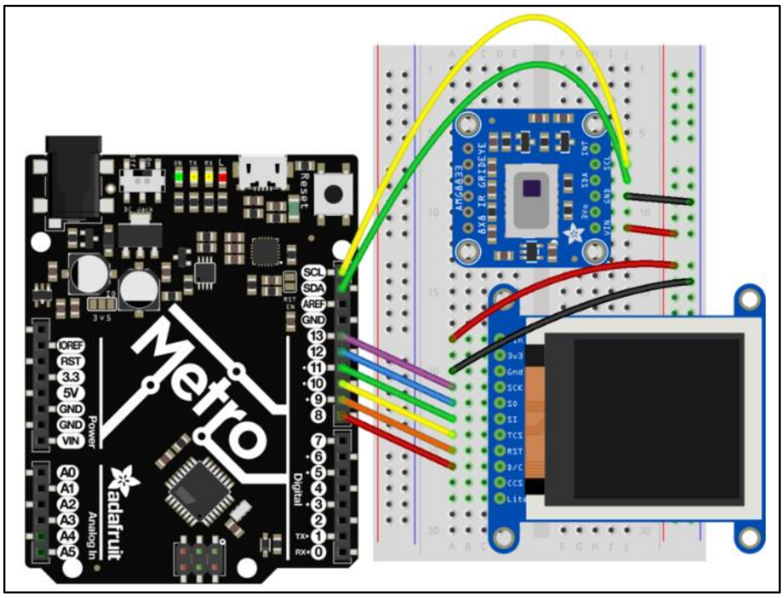


Figure 13: Thermal cam wiring [25]

The connections are realtively simple. The first thing to do is feed the board with the ground and the source from the Arduino, then we connect the screen and the Grid-eye to the ground and the source.

The Grid-eye only has two more connections, the first one is the SDA and we should connect it with the SDA pin in the Arduino. The second one is the SCL connection, and as in the first one it is connected with the SCL pin in the Arduino. (I^2C communication).

The screen has 6 more connections. And they are the six pins below the ground as we can see in the Figure 13 and the have to be connected to 6 digital pins to get the information from the Arduino.

Now everything is connected and working, but to do the tests, is not stable then to make it solid we used a bracket in which we have the thermal cam sticked with double sided sticky tape to it as we can see in Figure 14:

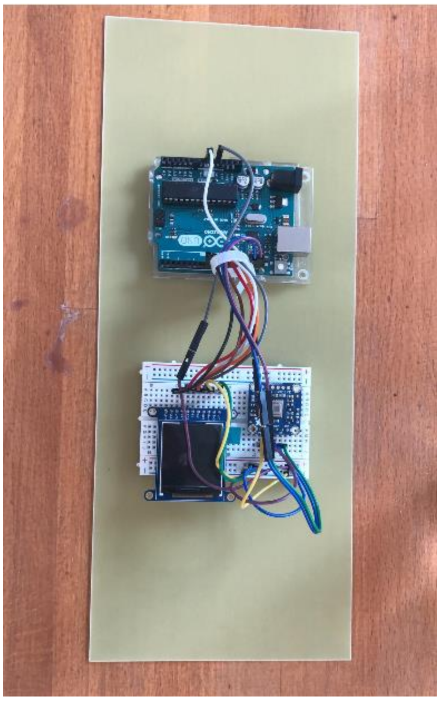


Figure 14: Thermal cam in the bracket

With this bracket is much easier to do the tests in the car because we can place it in the sunscreen and behind the onboard screen of the car as we will see in the tests. The bracket was cut from FR4 material, which is the basic substrate of the PCB production.

3.5 Programming

I was working with Arduino board, therefore the code is done with the app of Arduino. The app is called Arduino IDE, it is developed in java. The code of Arduino is very similar to C and C++. The main code for the thermal cam is uploaded and free in Adafruit[26] so I downloaded it and found all the necessary libraries to make it work.

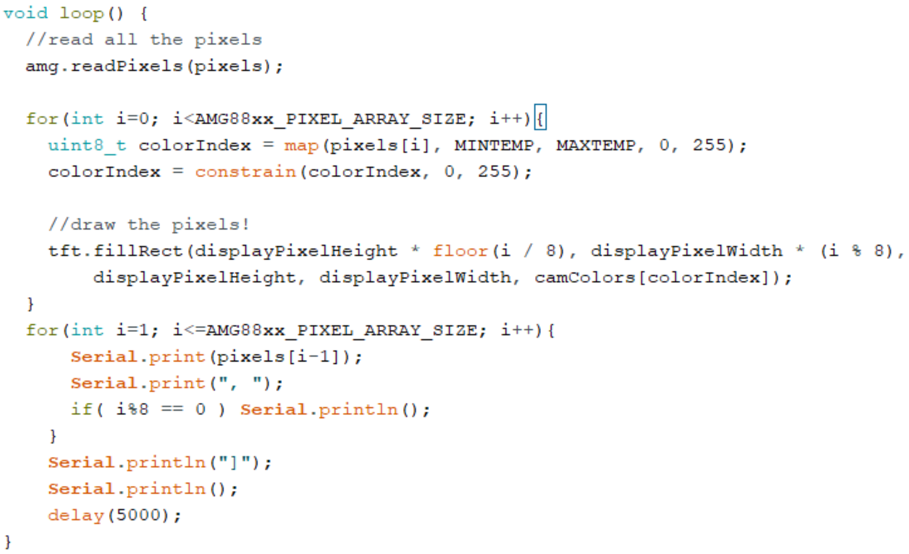
The original code of Adafruit is very useful to see how it works and check everything but, to do the tests and extract the information from it I needed to do some changes in the code.

One of the most important things at the beginning to see how it works is the variation of the temperature ranges as the minimum temperature is the blue colour and the maximum temperature is red so, to see the changes and the differences it is necessary set it up to the maximum and minimum temperatures that we are seeing. If I don’t change the ranges I might not see some differences in the screen or see unexpected colours and values.

The code is done to keep constantly drawing the Grid-eye data on the screen, but to do the test the user needs specific information and doesn’t need constant information. Having this in mind, I added to the code a function to send the matrix 8x8 of the sensor to the serial monitor of Arduino IDE. The information sends the information every 3 seconds. This timelapse is very easy to change therefore, depending on the test we are doing we use the time span that best matches the situation.

Now I’m explaining a little bit of the main function of the code (Figure 15):

The first loop for, as I said is the one to draw the pixels in the screen and before that we can see the function to read the pixels.



```
void loop() {
  //read all the pixels
  amg.readPixels(pixels);

  for(int i=0; i<AMG88xx_PIXEL_ARRAY_SIZE; i++){
    uint8_t colorIndex = map(pixels[i], MINTEMP, MAXTEMP, 0, 255);
    colorIndex = constrain(colorIndex, 0, 255);

    //draw the pixels!
    tft.fillRect(displayPixelHeight * floor(i / 8), displayPixelWidth * (i % 8),
        displayPixelHeight, displayPixelWidth, camColors[colorIndex]);
  }
  for(int i=1; i<=AMG88xx_PIXEL_ARRAY_SIZE; i++){
      Serial.print(pixels[i-1]);
      Serial.print(", ");
      if( i%8 == 0 ) Serial.println();
    }
    Serial.println("]");
    Serial.println();
    delay(5000);
}
```

Figure 15: test code

The second loop is the added one to send all the information to the serial monitor and in the last line of the code, there is the delay, where I can change the number to change the time lapse.

After the code, I need something to read the matrix given by the serial. In this project, I'm using an application called CoolTermWin[27] which change the serial matrix into a .txt document to save it and then work with it.

Now, with the code set up and all the wiring done, I can start testing.

3.6 Interpolated versions

In this project I've been working with the normal version of the AMG8833, which uses the 8x8 matrix but, there are interpolated versions which, with a bit of image processing are able to get a 64x64 matrix instead of the normal 8x8 matrix. That makes the definition 8 times higher than the original one.

Even though, interpolated versions can be very useful in some cases since the quality of the images is much better, is not useful for this project since these types of versions do not add more information but generate interpolations based on the information they receive from thermal sensor. Also, it would be more complicated to extract and analyse the information from this type of programming, therefore, I tried the method, but for the tests finally I have not used the interpolated versions.

3.7 Initial hardware validation tests

In order to test the capabilities of the sensor and how can the user work with it, I have done some tests. As we can see in the datasheet of the AMG8833, it can detect thermal human presence at 7 meters as a maximum range, obviously it is referred to optimal conditions. The tests have been done in different conditions and different distance to see the differences and the weak points of the sensor.

As I have explained, for the tests I have done some changes to the code of the thermal cam to see the pictures in the screen we are using with Arduino and, also see the information in the computer and save it.

3.7.1 Test 1: Indoors

In the first test I have check the sensor at different distance, from 1 meter to 4 meters. The clothes are quite important so the test is done for each distance with a T-shirt and without this T-shirt in order to see how the clothes work with the sensor and the differences between with and without the upper clothing.

We must have in mind as well the temperature of the room. The test was done inside a house so the temperature of the house is 20-21°C. (This is classical ambient room temperature.)

Is important also analysing the data that we have taken, so we should know the vertical and horizontal range of the sensor to have an idea about what is the sensor detecting and understand the values taken.

To calculate the range of the sensor we need trigonometry. We know that the angle of the sensor is 60° for both vertical and horizontal axes, so the vertical and horizontal ranges will be the same. I am using the Pythagoras theorem (Figure 16):

Range = R

Distance = D

$\alpha = ß = ɣ = 60°$

$$tan\left(\frac{\alpha}{2}\right) = \frac{R/2}{D} \qquad (4)$$

$$R = 2 \cdot \tan(30) \cdot D \qquad (5)$$

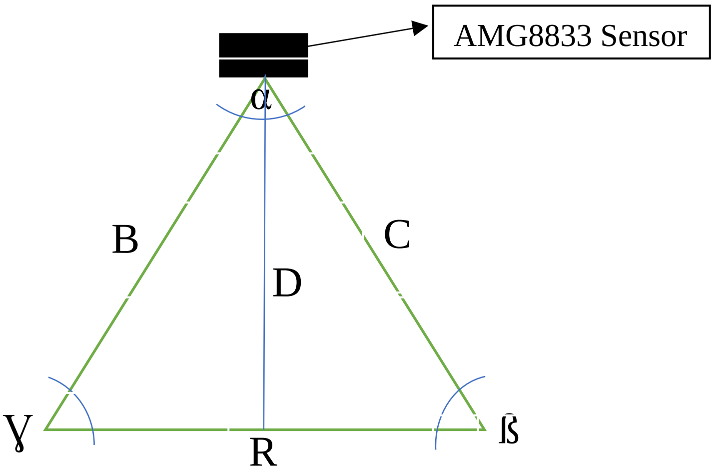


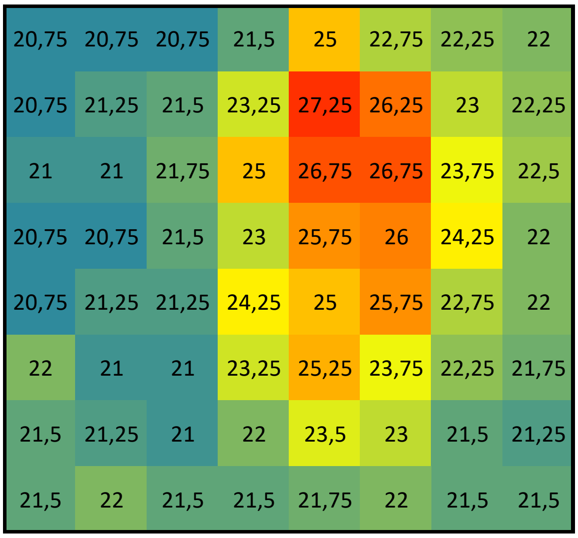
Figure 16: AMG8833 range scheme

3.7.1.1 1 meter

The first distance is 1 meter. The sensor range (width of sensed space, perpendicular to the vector of distance) at this distance is given by the equation we have seen before and it is: $R = 2 \cdot \tan(30) \cdot 1 = 1.1547$ m

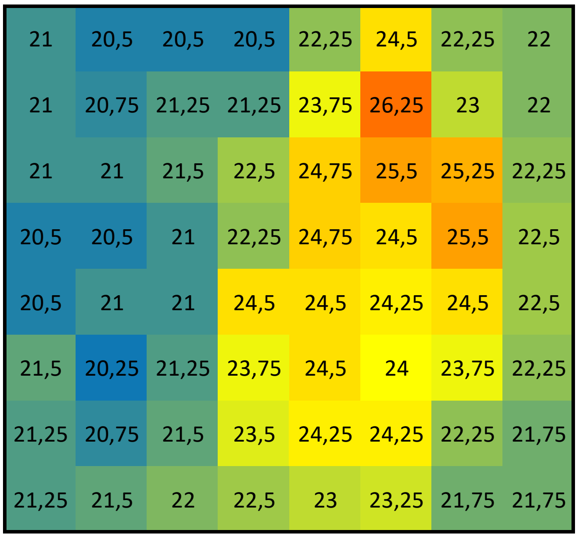
As the range is 1.15 at 1 meter, in the pictures we are seeing the upper part of the body, that is from the head to the hips.

Then here we can see the pictures for 1 meter. In Figure 18 we have the picture without T-shirt and in Figure 17, the one with T-shirt.



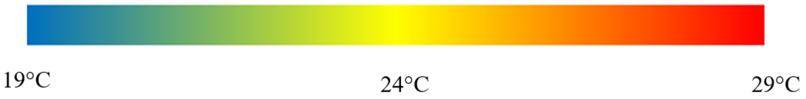
20,75	20,75	20,75	21,5	25	22,75	22,25	22
20,75	21,25	21,5	23,25	27,25	26,25	23	22,25
21	21	21,75	25	26,75	26,75	23,75	22,5
20,75	20,75	21,5	23	25,75	26	24,25	22
20,75	21,25	21,25	24,25	25	25,75	22,75	22
22	21	21	23,25	25,25	23,75	22,25	21,75
21,5	21,25	21	22	23,5	23	21,5	21,25
21,5	22	21,5	21,5	21,75	22	21,5	21,5

Figure 18: 1 meter without T-shirt



21	20,5	20,5	20,5	22,25	24,5	22,25	22
21	20,75	21,25	21,25	23,75	26,25	23	22
21	21	21,5	22,5	24,75	25,5	25,25	22,25
20,5	20,5	21	22,25	24,75	24,5	25,5	22,5
20,5	21	21	24,5	24,5	24,25	24,5	22,5
21,5	20,25	21,25	23,75	24,5	24	23,75	22,25
21,25	20,75	21,5	23,5	24,25	24,25	22,25	21,75
21,25	21,5	22	22,5	23	23,25	21,75	21,75

Figure 17: 1 meter with T-shirt



As we can see, the temperatures are clearly not the same but even with a T-shirt is very easy to distinguish human forms with the sensor.

The highest temperatures of the pictures are in the head and around the head although without T-shirt we can see high temperatures also in the chest, which is not happening with the T-shirt.

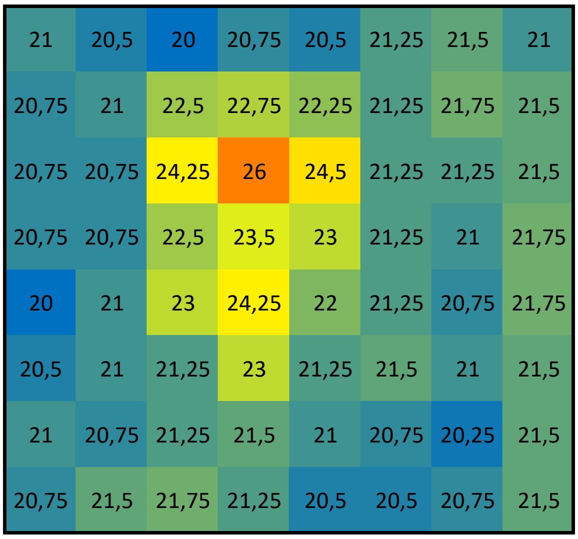
The parts without human presence are at 20-21°C as it is the temperature of the room. The maximum difference between background and the hottest part of the body (without T shirt) is 6.5 °C, and in the other case (with T shirt) 5.75 °C. It is clear to see, that it is easier to differentiate without the shirt, but the results are close to each other.

3.7.1.2 2 meters

The second distance is 2 meters. The sensor range at this distance is given by the equation we have seen before and it is: $R = 2 \cdot \tan(30) \cdot 2 = 2.31$ m

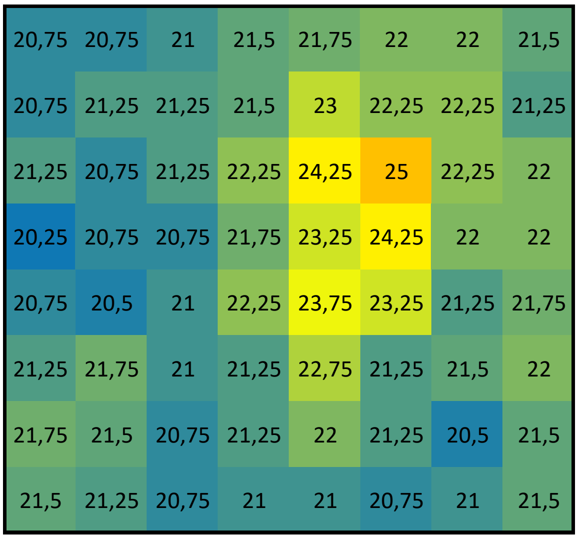
As the range is 2.31 at 2 meters, now in the pictures we are seeing the entire body as the person of the pictures is 1.80m tall.

Then here we can see the pictures for 2 meters. In Figure 20 we have the picture without T-shirt and in Figure 19, the one with T-shirt.



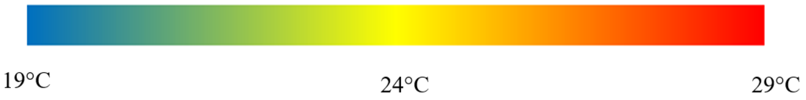
21	20,5	20	20,75	20,5	21,25	21,5	21
20,75	21	22,5	22,75	22,25	21,25	21,75	21,5
20,75	20,75	24,25	26	24,5	21,25	21,25	21,5
20,75	20,75	22,5	23,5	23	21,25	21	21,75
20	21	23	24,25	22	21,25	20,75	21,75
20,5	21	21,25	23	21,25	21,5	21	21,5
21	20,75	21,25	21,5	21	20,75	20,25	21,5
20,75	21,5	21,75	21,25	20,5	20,5	20,75	21,5

Figure 20: 2 meters without T-shirt



20,75	20,75	21	21,5	21,75	22	22	21,5
20,75	21,25	21,25	21,5	23	22,25	22,25	21,25
21,25	20,75	21,25	22,25	24,25	25	22,25	22
20,25	20,75	20,75	21,75	23,25	24,25	22	22
20,75	20,5	21	22,25	23,75	23,25	21,25	21,75
21,25	21,75	21	21,25	22,75	21,25	21,5	22
21,75	21,5	20,75	21,25	22	21,25	20,5	21,5
21,5	21,25	20,75	21	21	20,75	21	21,5

Figure 19: 2 meters with T-shirt



At 2 meters is still easy to distinguish a person in the pictures with T-shirt and without it and as in 1 meter pictures, we can see higher temperatures near the body in the picture without T-shirt. The maximum difference between background and the hottest part of the body (without T shirt) is 6 °C, and in the other case (with T shirt) 4.75 °C.

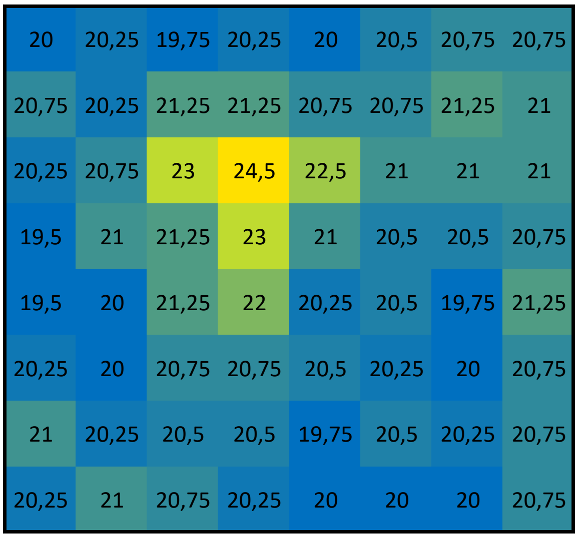
The highest temperatures are not as high as at 1 meter, that is because the human radiation gets lower as the person gets away. Also the differences are becoming smaller.

3.7.1.3 3 meters

The third distance is 3 meters. The sensor range at this distance is given by the equation we have seen before and it is: $R = 2 \cdot \tan(30) \cdot 3 = 3.464$ m

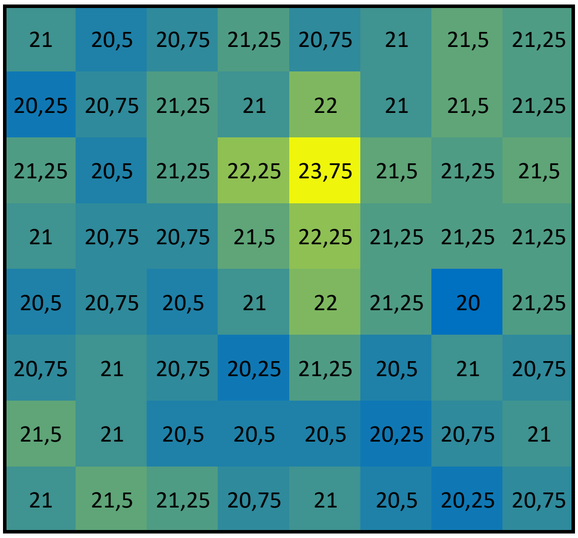
As the range is 3.464 at 3 meters the person in the picture occupies at least half of the picture.

Then here we can see the pictures for 3 meters. In Figure 22 we have the picture without T-shirt and in Figure 21, the one with T-shirt.



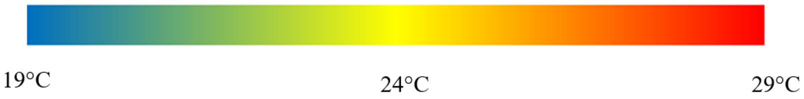
20	20,25	19,75	20,25	20	20,5	20,75	20,75
20,75	20,25	21,25	21,25	20,75	20,75	21,25	21
20,25	20,75	23	24,5	22,5	21	21	21
19,5	21	21,25	23	21	20,5	20,5	20,75
19,5	20	21,25	22	20,25	20,5	19,75	21,25
20,25	20	20,75	20,75	20,5	20,25	20	20,75
21	20,25	20,5	20,5	19,75	20,5	20,25	20,75
20,25	21	20,75	20,25	20	20	20	20,75

Figure 22: 3 meters without T-shirt



21	20,5	20,75	21,25	20,75	21	21,5	21,25
20,25	20,75	21,25	21	22	21	21,5	21,25
21,25	20,5	21,25	22,25	23,75	21,5	21,25	21,5
21	20,75	20,75	21,5	22,25	21,25	21,25	21,25
20,5	20,75	20,5	21	22	21,25	20	21,25
20,75	21	20,75	20,25	21,25	20,5	21	20,75
21,5	21	20,5	20,5	20,5	20,25	20,75	21
21	21,5	21,25	20,75	21	20,5	20,25	20,75

Figure 21: 3 meters with T-shirt



At this distance we can see some high temperature signals which let us guess it is a human body but is not clear as the difference with the rest of the room is around 3-4°C. The maximum difference between background and the hottest part of the body (without T shirt) is 5 °C, and in the other case (with T shirt) 3.75 °C.

The difference between the pictures is still there but as the person gets away, these differences decrease.

3.7.1.4 4 meters

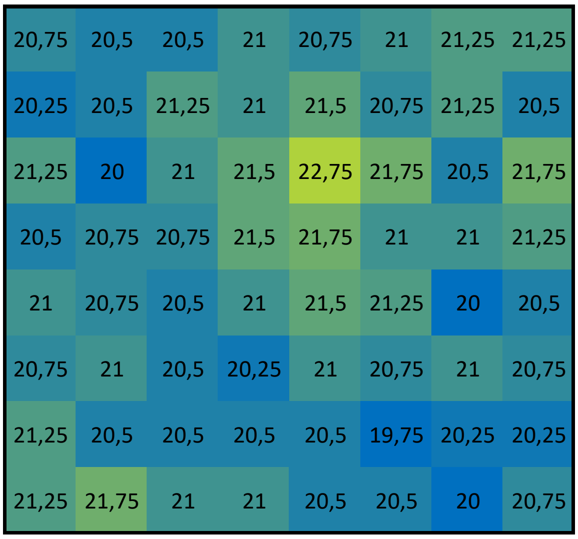
The fourth distance is 4 meters. The sensor range at this distance is given by the equation we have seen before and it is: $R = 2 \cdot \tan(30) \cdot 4 = 4.62$ m

As the range is 4.62 at 4 meters, now the body occupies more or less $^{1}/_{3}$ of the picture.

Then here we can see the pictures for 4 meters. In the Figure 24 we have the picture without T-shirt and in the Figure 23, the one with T-shirt.

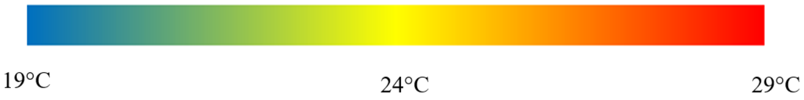
20,5	21	19,75	20,5	19,75	20,25	20,5	20,75
20,25	19,75	21,25	21	20,5	20,5	20,5	20,75
20	20,25	21,75	23,25	21,75	20,75	21	21
19,75	20,5	21,25	22	21	20,5	20,5	20,75
19,5	19,75	21	21,25	20	20,25	19,75	21,25
20,25	20,5	20,5	20,75	20,5	20,25	20,25	20,75
20,75	19,5	20,75	20	20,25	20,5	20,25	20,5
20,25	20,5	20,5	20,25	20,75	20,25	20,75	20,25

Figure 24: 4 meters without T-shirt



20,75	20,5	20,5	21	20,75	21	21,25	21,25
20,25	20,5	21,25	21	21,5	20,75	21,25	20,5
21,25	20	21	21,5	22,75	21,75	20,5	21,75
20,5	20,75	20,75	21,5	21,75	21	21	21,25
21	20,75	20,5	21	21,5	21,25	20	20,5
20,75	21	20,5	20,25	21	20,75	21	20,75
21,25	20,5	20,5	20,5	20,5	19,75	20,25	20,25
21,25	21,75	21	21	20,5	20,5	20	20,75

Figure 23: 4 meters with T-shirt



Now the results do not show much difference between the two pictures as both look more or less the same. The maximum difference between background and the hottest part of the body (without T shirt) is 3,75 °C, and in the other case (with T shirt) 3. °C.

At this distance we still have some high temperature signals but it is not enough to say that it is a human body because the minimum difference between the temperature of the room and the temperature of the human body is so low, 2 °C in the picture without T-shirt and 1°C with T-shirt. So I can say this distance is the useful limit for the sensor in normal conditions.

Figure 25 presents the trends of the measurements pointing to an approximately linear trend. When the differences between background and measured object reach ΔTs below 2-3 °C, the values arrive in the range of the background noise recorded by the camera, and they reach the precision of the sensor. Thus, application becomes limited.

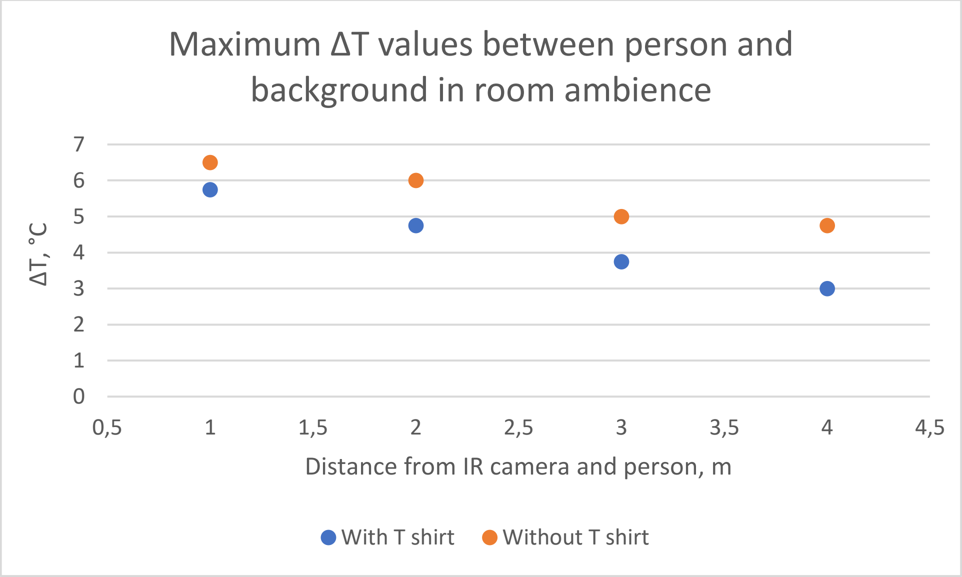


Figure 25: ΔT between person and backround in room ambience

3.7.2 Test 2: Inside the car

For the second test we have tested the performance of the sensor inside a car, placing the sensor in different positions with different angles to see which one would be the best option to detect people and check how many people can we manage with this sensor.

As in the test 1 we saw how the pictures changed between a person with T-shirt and a person without t-shirt, in this second test, for each position we are changing persons from no one seated to only one person and two people and in the last tests, to check the backseats, up to 5 people – from front sensor positions.

The outside temperature is -5°C and the initial temperature of the car is the same as the car was parked outside.

We should have in mind that the temperatures for this test are not as easy to understand as in the first test because when a person is seated for a while, then, when he leaves the car, the seat keeps some of the heat from it and the rest of the car gets heated as well. That makes the temperatures of the car increase throughout the tests. The faces don’t have the same temperature as in the test one because outside is so much colder.

In this test, all the people that we have used wear coats, so it will be difficult to detect the body if a person has just in the car, so we will focus the test in detecting heads.

3.7.2.1 Sensor in front of the driver

For the first location of the sensor, I placed the sensor just in front of the driver, in the sunshield as we can see in Figure 26:

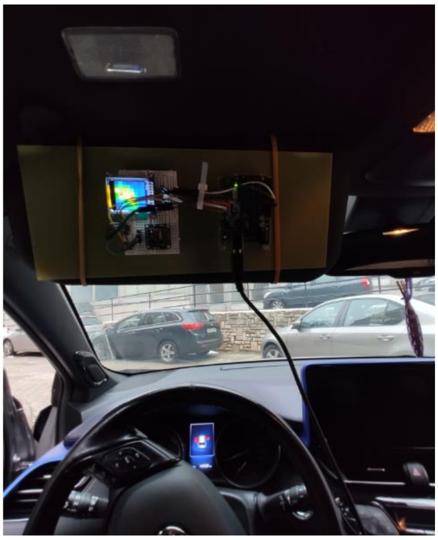
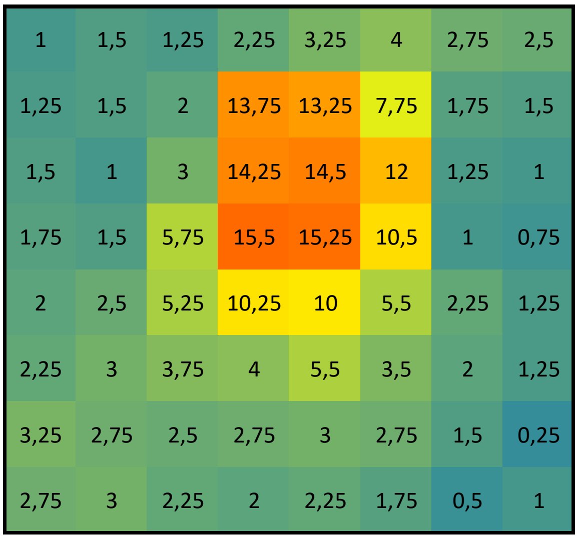


Figure 26: Sensor in front of the driver

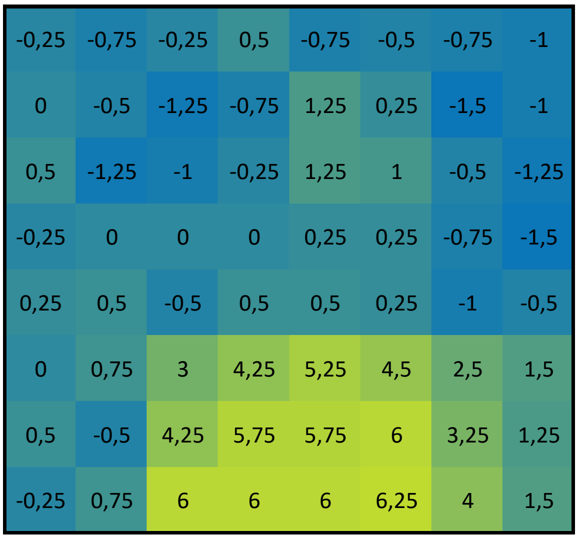
Having in mind that the angle of the sensor is 60°, it means that in this position the sensor can only detect the driver because it is so close to him and is completely in front of the driver.

In Figure 27 we can see when the driver is seated and in Figure 26, when the driver just left and the seat is empty.



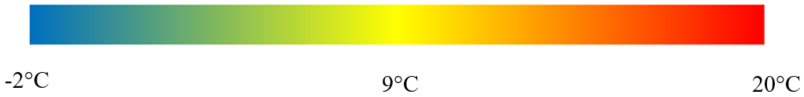
1	1,5	1,25	2,25	3,25	4	2,75	2,5
1,25	1,5	2	13,75	13,25	7,75	1,75	1,5
1,5	1	3	14,25	14,5	12	1,25	1
1,75	1,5	5,75	15,5	15,25	10,5	1	0,75
2	2,5	5,25	10,25	10	5,5	2,25	1,25
2,25	3	3,75	4	5,5	3,5	2	1,25
3,25	2,75	2,5	2,75	3	2,75	1,5	0,25
2,75	3	2,25	2	2,25	1,75	0,5	1

Figure 28: Sensor in front of the driver, seated



-0,25	-0,75	-0,25	0,5	-0,75	-0,5	-0,75	-1
0	-0,5	-1,25	-0,75	1,25	0,25	-1,5	-1
0,5	-1,25	-1	-0,25	1,25	1	-0,5	-1,25
-0,25	0	0	0	0,25	0,25	-0,75	-1,5
0,25	0,5	-0,5	0,5	0,5	0,25	-1	-0,5
0	0,75	3	4,25	5,25	4,5	2,5	1,5
0,5	-0,5	4,25	5,75	5,75	6	3,25	1,25
-0,25	0,75	6	6	6	6,25	4	1,5

Figure 27: Sensor in front of the driver, empty



As we can see in the left picture, when the driver is seated the sensor clearly detects his head. Is important to say that it only detects his head because the coat is so cold to be detected as it was outside and it is not touching directly the body.

In the right picture the sensor detects some thermal signals and that is because when the driver was seated there he was heating the seat and when he leaves the car, the seat remains a little bit hotter than the rest of the car.

The maximum difference when driver is in the car is 15°C. When the driver leaves, the difference becomes 6°C.

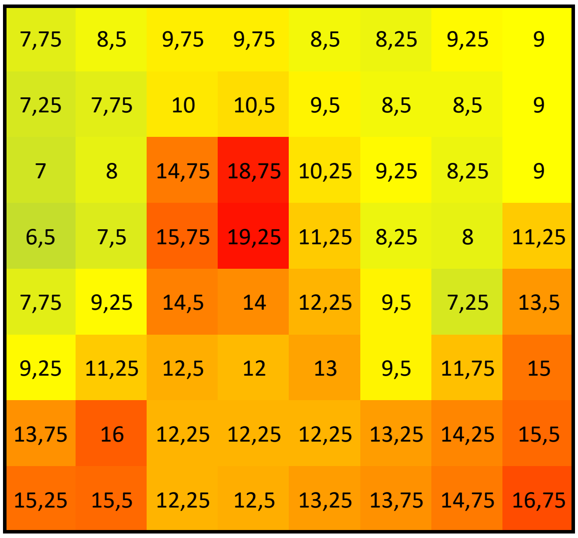
3.7.2.2 Sensor in the side (45°)

The second location of the sensor is the sunshield (Figure 29) in the side with an angle of 45°, the main target of this position is seeing if it can detect the driver and the passenger at the same time.

Figure 29: sensor at 45°

For this placement we are testing the sensor with the car empty, with passenger and driver seated and only with the passenger to see if we can difference between 1 and 2 people seated.

In Figure 31 we have both seated, in Figure 30 only the passenger is seated and in Figure 32, the car is empty.

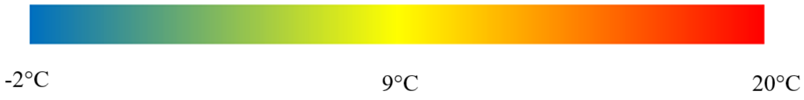


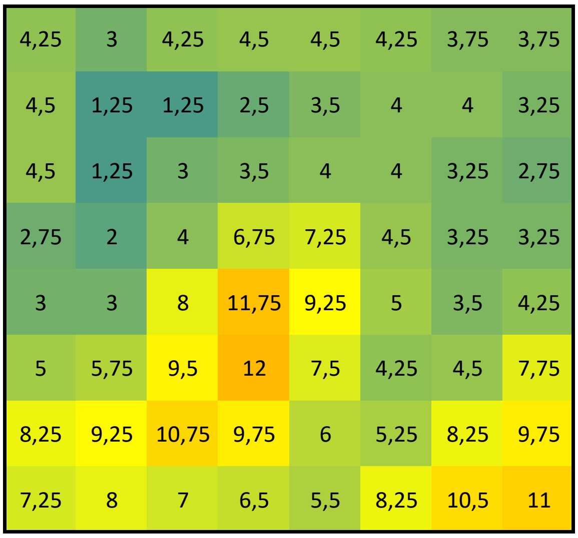
7,75	8,5	9,75	9,75	8,5	8,25	9,25	9
7,25	7,75	10	10,5	9,5	8,5	8,5	9
7	8	14,75	18,75	10,25	9,25	8,25	9
6,5	7,5	15,75	19,25	11,25	8,25	8	11,25
7,75	9,25	14,5	14	12,25	9,5	7,25	13,5
9,25	11,25	12,5	12	13	9,5	11,75	15
13,75	16	12,25	12,25	12,25	13,25	14,25	15,5
15,25	15,5	12,25	12,5	13,25	13,75	14,75	16,75

Figure 31: Sensor at 45°, driver and passenger seated

7,5	7,25	8,75	8,5	8,25	7,75	8	7,75
6,75	7,25	8,75	10	8,5	7,5	7,5	6,75
6,25	6,25	13,75	17,75	9,75	7,5	6,25	6,75
6	7,25	13,5	19	10,25	7,25	6,25	6
6,5	8,5	13,25	13,25	10,75	8,25	6	6,75
8,25	10,25	11,25	10,75	11,5	7,5	6,25	7
13,25	15,5	11	11,25	10,75	7,75	7,75	9,5
14	14,5	11	10,25	10	9	9,5	10,25

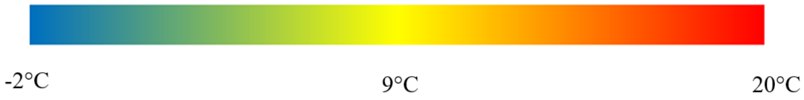
Figure 30: Sensor at 45°, passenger seated





4,25	3	4,25	4,5	4,5	4,25	3,75	3,75
4,5	1,25	1,25	2,5	3,5	4	4	3,25
4,5	1,25	3	3,5	4	4	3,25	2,75
2,75	2	4	6,75	7,25	4,5	3,25	3,25
3	3	8	11,75	9,25	5	3,5	4,25
5	5,75	9,5	12	7,5	4,25	4,5	7,75
8,25	9,25	10,75	9,75	6	5,25	8,25	9,75
7,25	8	7	6,5	5,5	8,25	10,5	11

Figure 32: Sensor at 45°, empty



As the sensor is in the side of the driver, the heat signal we can see on the left with both seated is the passenger and the heat signal on the right is the driver. As we can see, the passenger signal is hotter than the driver signal even being further. That’s because is so close to the driver and the sensor doesn’t detect de entire face of the driver. The maximum difference is ~12 °C.

With only the passenger seated, now we don’t see the heat signals on the right of the image, that means we can distinguish two people inside the car with this placement even without detecting the entire face of the driver. The maximum signal difference is ~11 °C.

In the last picture, with the car empty we only have the signals of the residual heat of the passenger and the driver in the seats. (The maximum difference increased to ~10°C)

3.7.2.3 Sensor in the side (90°)

This time we are keeping the sensor in the same position but changing the angle of the sensor from 45° to 90° (figure 33) to see which angle is better in this placement.

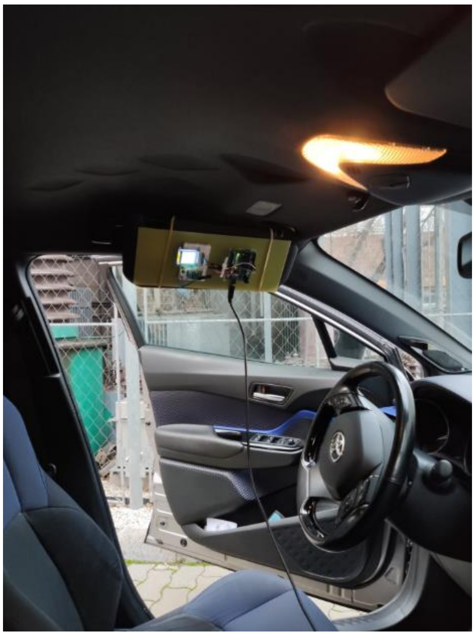
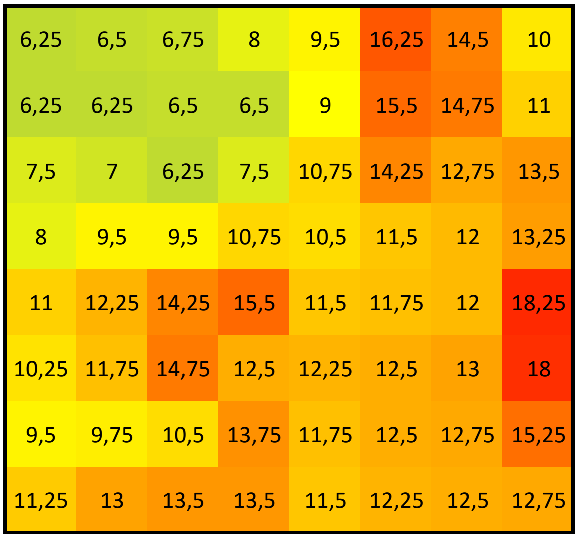


Figure 33: Sensor at 90°

As in the last test, we are testing in 3 different situations, with the car empty, with passenger and driver seated and only with the passenger to see if we can difference between 1 and 2 people seated.

In Figure 36 we have both seated, in Figure 35 only the passenger is seated and Figure 34, the car is empty.

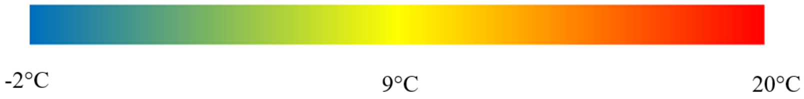


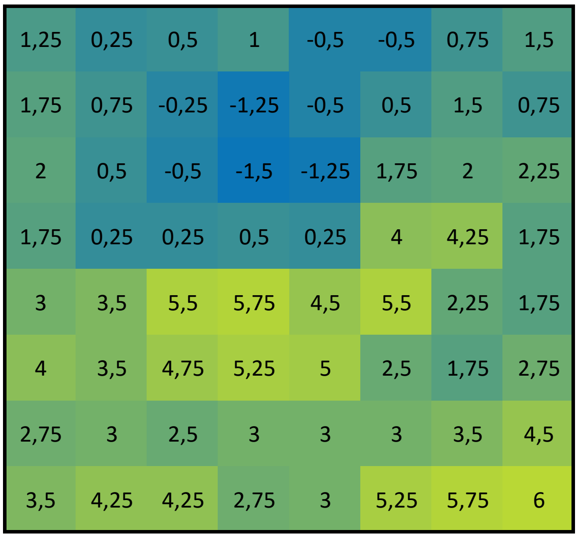
6,25	6,5	6,75	8	9,5	16,25	14,5	10
6,25	6,25	6,5	6,5	9	15,5	14,75	11
7,5	7	6,25	7,5	10,75	14,25	12,75	13,5
8	9,5	9,5	10,75	10,5	11,5	12	13,25
11	12,25	14,25	15,5	11,5	11,75	12	18,25
10,25	11,75	14,75	12,5	12,25	12,5	13	18
9,5	9,75	10,5	13,75	11,75	12,5	12,75	15,25
11,25	13	13,5	13,5	11,5	12,25	12,5	12,75

Figure 36: Driver and passenger seated, sensor at 90°

6	5,75	6,75	7,25	11,25	16	14,25	8
5,25	5	5,5	6	12,75	15,75	14	7
6,5	5,75	5,25	6	10,5	14	13,75	8
7,25	7,75	8	9,25	9,5	10,5	10	7,75
9,75	11,25	13,25	14,5	10,25	10,5	9,25	7,5
10,25	10,75	14,75	11	10	10,75	8,5	7,5
8	7,5	7,75	8,25	9,5	9,75	9,75	11,5
8	9,75	9,5	8	8,25	10	10,5	11

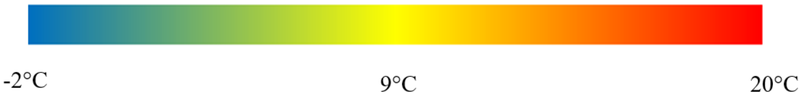
Figure 35: Passenger seated, sensor at 90°





1,25	0,25	0,5	1	-0,5	-0,5	0,75	1,5
1,75	0,75	-0,25	-1,25	-0,5	0,5	1,5	0,75
2	0,5	-0,5	-1,5	-1,25	1,75	2	2,25
1,75	0,25	0,25	0,5	0,25	4	4,25	1,75
3	3,5	5,5	5,75	4,5	5,5	2,25	1,75
4	3,5	4,75	5,25	5	2,5	1,75	2,75
2,75	3	2,5	3	3	3	3,5	4,5
3,5	4,25	4,25	2,75	3	5,25	5,75	6

Figure 34: Empty, sensor at 90°



4

With this angle, the heat signals of the driver and the passenger are quite similar but is harder to distinguish them because they are so close each other.

As we can see in figure 35, without the driver seated, the signal on the right disappears and there is only a signal in the top, which is the head of the passenger and a signal on the left which are the hands of the passenger and the computer we are using for the testing.

As usual, in figure 34 with the car empty, we have some heat signals because of the heating of the seats because of the passengers.

So after seeing these pictures we can see that the pictures of the last two tests are similar, however, in the test with the sensor at 45° angle we can distinguish easier when both the passenger and the driver are seated therefore is more useful for this application.

The overall differences are similar to the previous case: ~12 °C, 11 °C, 6-7 °C.

3.7.2.4 Sensor in the dashboard

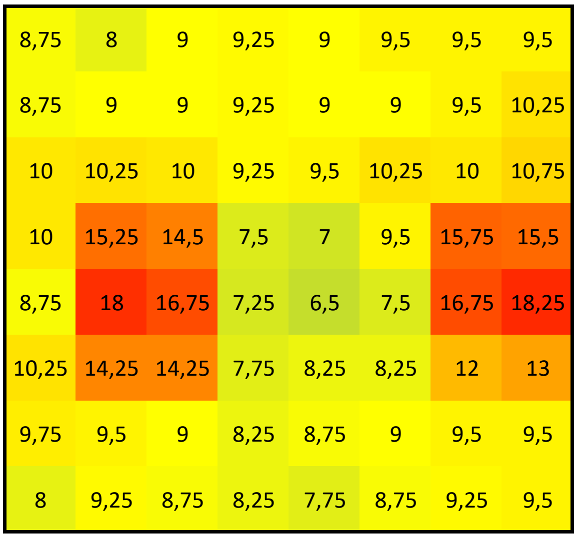
The last location of the sensor is behind the central screen of the car, on the dashboard (Figure 36).

Figure 37: Sensor in the dashboard

That is a central position, so now the sensor has enough range to detect people in almost the entire car.

Firstly I am only trying the front seats of the car in which should be easy to detect people as it is for me the most logical placement for the sensor in the car

In Figure 39 we have both seated, in Figure 38 only the passenger is seated and in Figure 40, the car is empty.

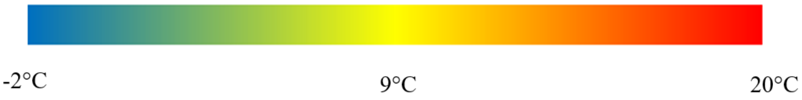


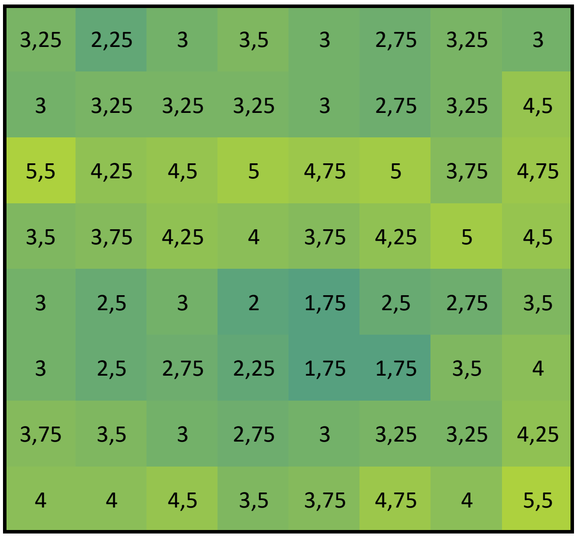
8,75	8	9	9,25	9	9,5	9,5	9,5
8,75	9	9	9,25	9	9	9,5	10,25
10	10,25	10	9,25	9,5	10,25	10	10,75
10	15,25	14,5	7,5	7	9,5	15,75	15,5
8,75	18	16,75	7,25	6,5	7,5	16,75	18,25
10,25	14,25	14,25	7,75	8,25	8,25	12	13
9,75	9,5	9	8,25	8,75	9	9,5	9,5
8	9,25	8,75	8,25	7,75	8,75	9,25	9,5

Figure 39: Driver and passenger seated, Sensor in the dashboard

7	6,75	7,25	7,5	7,25	7,5	7,5	8,75
7,75	7,75	8,5	8,5	8,5	7,75	9	8,75
8	8	8	8,25	8,5	9,5	9	9,25
5,75	6,5	7	6,25	6,25	9,5	15	14,75
8	6,5	7,5	6,25	5,75	7,5	17	15,75
8,25	7,25	7	6,75	7,75	7,75	14,25	12,25
8,5	7,5	7,75	8	8,25	9	9,25	9,75
7,25	8	8,25	7,75	8	9	8,5	9,5

Figure 38: Passenger seated, sensor in the dashboard





3,25	2,25	3	3,5	3	2,75	3,25	3
3	3,25	3,25	3,25	3	2,75	3,25	4,5
5,5	4,25	4,5	5	4,75	5	3,75	4,75
3,5	3,75	4,25	4	3,75	4,25	5	4,5
3	2,5	3	2	1,75	2,5	2,75	3,5
3	2,5	2,75	2,25	1,75	1,75	3,5	4
3,75	3,5	3	2,75	3	3,25	3,25	4,25
4	4	4,5	3,5	3,75	4,75	4	5,5

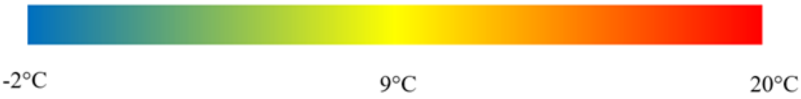


Figure 40: Empty, sensor in the dashboard

With the sensor in this placement we can see very clearly in Figure 39 the face of the driver and the passenger as we have the driver heat signal on the left and the passenger heat signal on the right.

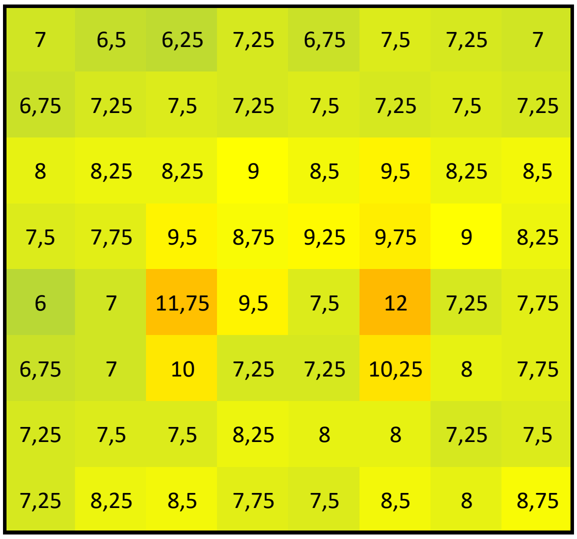
In Figure 38, there is only the passenger inside the car so the driver signal disappears, the rest of the picture stays the same, so that means we can distinguish perfectly driver and passenger in this placement. The overall differences are similar to the previous cases: ~12 °C, 11 °C, and the empty car is more homogeneous with a maximum difference of ~4 °C.

3.7.2.5 Sensor in the dashboard: backseats test

Now, I am keeping the sensor in the same place in which it has been shown that works well to detect people in the front seats but testing the backseats.

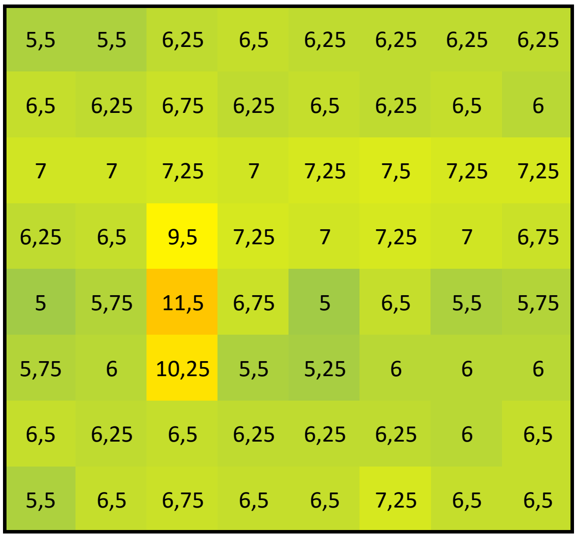
It is not easy because 2 passengers of the back seats are just behind the driver and the passenger so maybe the sensor can not detect them.

For this test I have tried first only with 2 people in the back seats, only one person in the back seats and empty. (Figures 41-43)



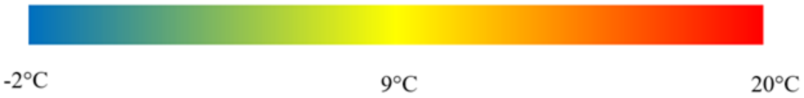
7	6,5	6,25	7,25	6,75	7,5	7,25	7
6,75	7,25	7,5	7,25	7,5	7,25	7,5	7,25
8	8,25	8,25	9	8,5	9,5	8,25	8,5
7,5	7,75	9,5	8,75	9,25	9,75	9	8,25
6	7	11,75	9,5	7,5	12	7,25	7,75
6,75	7	10	7,25	7,25	10,25	8	7,75
7,25	7,5	7,5	8,25	8	8	7,25	7,5
7,25	8,25	8,5	7,75	7,5	8,5	8	8,75

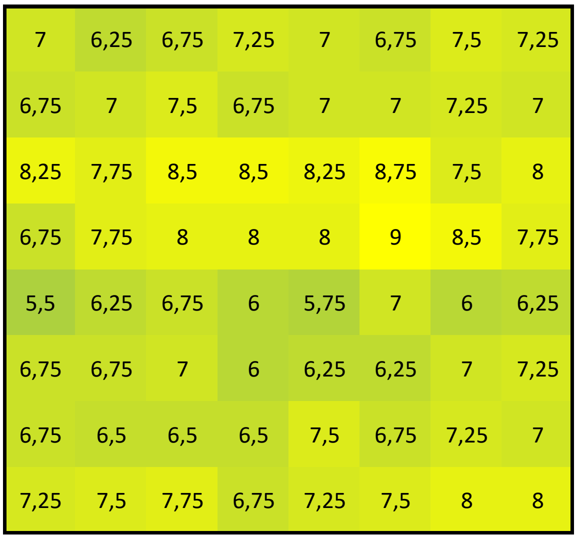
Figure 42: 2 people in the backseats, sensor in the dashboard



5,5	5,5	6,25	6,5	6,25	6,25	6,25	6,25
6,5	6,25	6,75	6,25	6,5	6,25	6,5	6
7	7	7,25	7	7,25	7,5	7,25	7,25
6,25	6,5	9,5	7,25	7	7,25	7	6,75
5	5,75	11,5	6,75	5	6,5	5,5	5,75
5,75	6	10,25	5,5	5,25	6	6	6
6,5	6,25	6,5	6,25	6,25	6,25	6	6,5
5,5	6,5	6,75	6,5	6,5	7,25	6,5	6,5

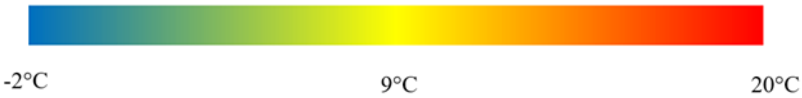
Figure 41: 1 person in the rear-right, sensor in the dashboard





7	6,25	6,75	7,25	7	6,75	7,5	7,25
6,75	7	7,5	6,75	7	7	7,25	7
8,25	7,75	8,5	8,5	8,25	8,75	7,5	8
6,75	7,75	8	8	8	9	8,5	7,75
5,5	6,25	6,75	6	5,75	7	6	6,25
6,75	6,75	7	6	6,25	6,25	7	7,25
6,75	6,5	6,5	6,5	7,5	6,75	7,25	7
7,25	7,5	7,75	6,75	7,25	7,5	8	8

Figure 43: empty, sensor in the dashboard



In Figure 42, with both seated we can see two light heat signals of ±12°C and the rest of the car is between 6°C and 9°C that’s the backseats passengers but it is not clearly a person because the seats are between the sensor and the passengers. It is not easy for the sensor to detect a human presence both sides of the back seats of the car.

In Figure 41, with only one person, the signal of the empty seat disappears as expected and the same happens in Figure 43 with the car empty, no heat signals so, the sensor detects people in the back seats but with very light heating.

The differences are reduced to ~6-6-2 °C, respectively.

For next, the testing with the front seats and back seats occupied followed, to see how the sensor performs with the full car and see how many people can it be distinguished in a car.

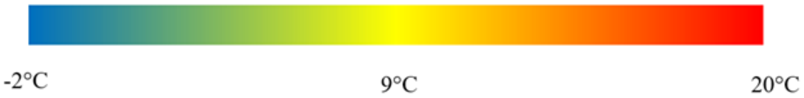
I am starting with full car, then people start leaving the car one by one.

7,25	6,75	7	7,25	7	6,75	7,25	7
7,25	7,25	7,5	7	7,5	7,25	8	6,75
9	8,25	8,25	8,5	8,25	8,75	8,5	8,25
8,75	9,5	9,25	9,25	9,5	9,5	9,75	8,75
11,5	16,5	11,75	12	12,25	12,5	17,75	13
12,25	18,75	10,5	11	11,75	12	20	11,25
9,5	10,25	9,25	9	9,5	10,5	11,75	10,25
7,75	8,75	9,25	8,75	8,75	10	10,25	10

Figure 45: 5 people seated, sensor in the dashboard

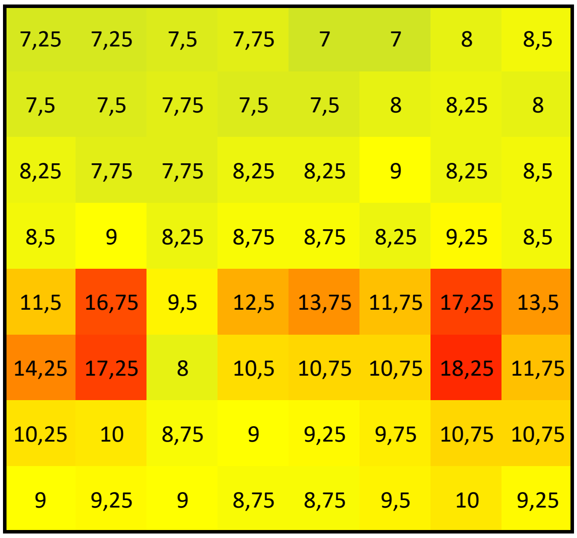
7,5	7,25	8	8,5	7,75	8,25	8,25	9
8,25	8	9	8,75	8,5	8,25	8,75	9
9,25	8,75	9	9,5	9,5	10	9,5	9,25
9,5	9,75	10,25	9,75	9,75	10	9,75	10,25
11,75	16,25	11,5	12,5	13,5	13,25	18,5	14,75
13,5	17,75	11,25	11,75	12,25	11,75	19,5	13,25
11	11,25	9,5	10,5	10,75	11,5	11,5	11,5
9,5	11	10,25	10	9,25	10,5	10,5	10,5

Figure 44: 4 people seated, sensor in the dashboard



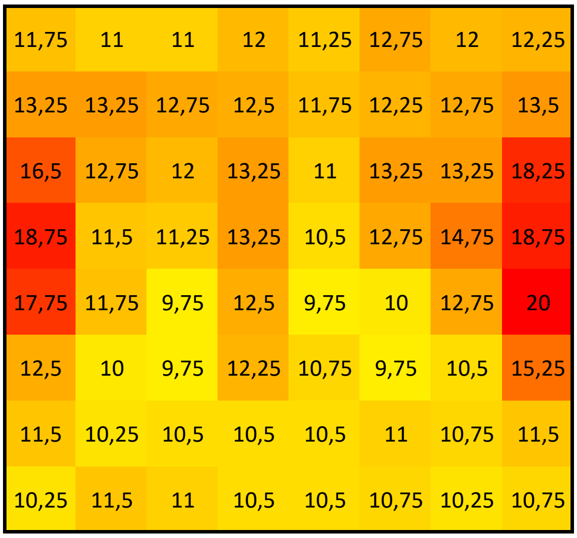
In these two pictures (Figure 45 and Figure 44) I have 4 and 5 people seated in the car and the pictures look very similar. The highest temperatures are for the driver and the front seat passenger and in the same line, we can see a lot of heat signals but we cannot difference between them. The maximum differences are around 12-13 °C.

Let’s try now with 3 people (figure 47) and only with the front seats (figure 46).



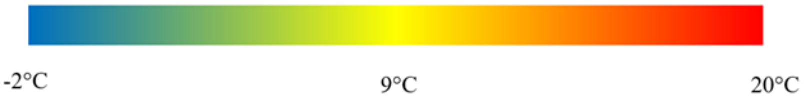
7,25	7,25	7,5	7,75	7	7	8	8,5
7,5	7,5	7,75	7,5	7,5	8	8,25	8
8,25	7,75	7,75	8,25	8,25	9	8,25	8,5
8,5	9	8,25	8,75	8,75	8,25	9,25	8,5
11,5	16,75	9,5	12,5	13,75	11,75	17,25	13,5
14,25	17,25	8	10,5	10,75	10,75	18,25	11,75
10,25	10	8,75	9	9,25	9,75	10,75	10,75
9	9,25	9	8,75	8,75	9,5	10	9,25

Figure 47: 3 people seated, sensor in the dashboard



11,75	11	11	12	11,25	12,75	12	12,25
13,25	13,25	12,75	12,5	11,75	12,25	12,75	13,5
16,5	12,75	12	13,25	11	13,25	13,25	18,25
18,75	11,5	11,25	13,25	10,5	12,75	14,75	18,75
17,75	11,75	9,75	12,5	9,75	10	12,75	20
12,5	10	9,75	12,25	10,75	9,75	10,5	15,25
11,5	10,25	10,5	10,5	10,5	11	10,75	11,5
10,25	11,5	11	10,5	10,5	10,75	10,25	10,75

Figure 46: 2 people seated, sensor in the dashboard



This time, with 3 people, is possible to distinguish the three of them as the back seated passenger is seated in the middle so he does not have a seat between him and the sensor. The heat signal of the passenger in the back seat is so much lighter than the front seat signals as we saw in the previous test with 20°C in the front seats and 13°C in the backseats. Thus it is difficult, but not impossible to differentiate between 3 people in the car, 2 in the front seats and a person in the middle seat of the back.

4. CONCLUSIONS

The objective of this project is the detection of people inside a car, and as we have seen in the previous section, and with all the tests performed, it is clearly seen that the sensor used easily detects the presence of two people in the front seats and with limitations, it even comes to detect a third person in the middle seat of the rear seats.

These tests are done in winter at outside temperatures below 0 degrees, therefore, their practical efficency is proven in cold months.

From the tests carried out in internal tests we could expect that in temperate months and hot months the sensor would continue working well.

Based on an investigation by Nissan about the use of IR sensors for the detection of people[28] we can see that although when the outside temperature is high as in the summer months, the distance at which it is possible to detect people decreases but remains high enough as to detect passengers inside the car since the temperature differences between the environment and the person are at least 5 degrees (Figure 48).

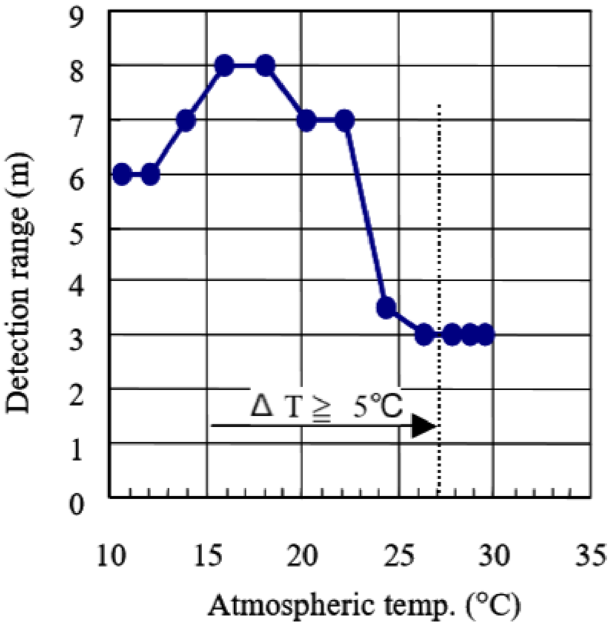


Figure 48: Detection range vs External temp[29]

With all information I assume that the sensor would work correctly at any time of the year with a good temperature range, however future work might involve tests in hot months as well.

Keeping all of the above information in mind, to develop the sensor as a functioning market product we should program it to detect people looking for temperature differences in the range, since the temperatures of a human face are not the same in a cold environment than in a warm one as we have seen in the tests.

For example, a face in the interior test had a temperature of 28 degrees and however in the car test it can only be 15 degrees as it was cold outside.

However, temperature differences were always at least between 5 and 10 degrees, so the ideal way to develop it would be to detect those temperature differences between human faces and the environment.

For the future part of the work, algorithm development, and the detected differences in extreme temperature environment should follow.

5. ACKNOWLEDGEMENTS

I would like to thank the BME-ETT department for the help and the laboratory equipment provided, as well as the help to carry out the tests in the car, and to my flatmates for the tests at home. I especially want to thank my supervisor Géczy Attila for all the help, attention and resources (including his car) that I received to carry out this project.

6. LIST OF FIGURES

7. Annexes

```
#include <Adafruit_GFX.h>    // Core graphics library
#include <Adafruit_ST7735.h> // Hardware-specific library
#include <SPI.h>

#include <Wire.h>
#include <Adafruit_AMG88xx.h>

#define TFT_CS     10 //chip select pin for the TFT screen
#define TFT_RST    9  // you can also connect this to the Arduino reset
                          // in which case, set this #define pin to 0!
#define TFT_DC     8

//low range of the sensor (this will be blue on the screen)
#define MINTEMP 15

//high range of the sensor (this will be red on the screen)
#define MAXTEMP 35

//the colors we will be using
const uint16_t camColors[] = {0x480F,
0x400F,0x400F,0x400F,0x4010,0x3810,0x3810,0x3810,0x3810,0x3010,0x3010,
0x3010,0x2810,0x2810,0x2810,0x2810,0x2010,0x2010,0x2010,0x1810,0x1810,
0x1811,0x1811,0x1011,0x1011,0x1011,0x0811,0x0811,0x0811,0x0011,0x0011,
0x0011,0x0011,0x0011,0x0031,0x0031,0x0051,0x0072,0x0072,0x0092,0x00B2,
0x00B2,0x00D2,0x00F2,0x00F2,0x0112,0x0132,0x0152,0x0152,0x0172,0x0192,
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0x0293,0x02B3,0x02D3,0x02D3,0x02F3,0x0313,0x0333,0x0333,0x0353,0x0373,
0x0394,0x03B4,0x03D4,0x03D4,0x03F4,0x0414,0x0434,0x0454,0x0474,0x0474,
0x0494,0x04B4,0x04D4,0x04F4,0x0514,0x0534,0x0534,0x0554,0x0554,0x0574,
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0x0590,0x0590,0x058F,0x058F,0x058F,0x058E,0x05AE,0x05AE,0x05AD,0x05AD,
0x05AD,0x05AC,0x05AC,0x05AB,0x05CB,0x05CB,0x05CA,0x05CA,0x05CA,0x05C9,
0x05C9,0x05C8,0x05E8,0x05E8,0x05E7,0x05E7,0x05E6,0x05E6,0x05E6,0x05E5,
```

```
0x05E5,0x0604,0x0604,0x0604,0x0603,0x0603,0x0602,0x0602,0x0601,0x0621,
0x0621,0x0620,0x0620,0x0620,0x0620,0x0E20,0x0E20,0x0E40,0x1640,0x1640,
0x1E40,0x1E40,0x2640,0x2640,0x2E40,0x2E60,0x3660,0x3660,0x3E60,0x3E60,
0x3E60,0x4660,0x4660,0x4E60,0x4E80,0x5680,0x5680,0x5E80,0x5E80,0x6680,
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0x8EC0,0x96C0,0x96C0,0x9EC0,0x9EC0,0xA6C0,0xAEC0,0xAEC0,0xB6E0,0xB6E0,
0xBEE0,0xBEE0,0xC6E0,0xC6E0,0xCEE0,0xCEE0,0xD6E0,0xD700,0xDF00,0xDEE0,
0xDEC0,0xDEA0,0xDE80,0xDE80,0xE660,0xE640,0xE620,0xE600,0xE5E0,0xE5C0,
0xE5A0,0xE580,0xE560,0xE540,0xE520,0xE500,0xE4E0,0xE4C0,0xE4A0,0xE480,
0xE460,0xEC40,0xEC20,0xEC00,0xEBE0,0xEBC0,0xEBA0,0xEB80,0xEB60,0xEB40,
0xEB20,0xEB00,0xEAE0,0xEAC0,0xEAA0,0xEA80,0xEA60,0xEA40,0xF220,0xF200,
0xF1E0,0xF1C0,0xF1A0,0xF180,0xF160,0xF140,0xF100,0xF0E0,0xF0C0,0xF0A0,
0xF080,0xF060,0xF040,0xF020,0xF800,};

Adafruit_ST7735 tft = Adafruit_ST7735(TFT_CS,  TFT_DC, TFT_RST);

Adafruit_AMG88xx amg;
unsigned long delayTime;
float pixels[AMG88xx_PIXEL_ARRAY_SIZE];
uint16_t displayPixelWidth, displayPixelHeight;

void setup() {
  Serial.begin(9600);
    Serial.println(F("AMG88xx thermal camera!"));

    tft.initR(INITR_144GREENTAB);   // initialize a ST7735S chip, black tab
    tft.fillScreen(ST7735_BLACK);

    displayPixelWidth = tft.width() / 8;
    displayPixelHeight = tft.height() / 8;

    //tft.setRotation(3);

    bool status;

    // default settings
    status = amg.begin();
    if (!status) {
        Serial.println("Could not find a valid AMG88xx sensor, check wiring!");
        while (1);
```

```
    }

    Serial.println("-- Thermal Camera Test --");
    delay(100); // let sensor boot up

}

void loop() {
  //read all the pixels
  amg.readPixels(pixels);

  for(int i=0; i<AMG88xx_PIXEL_ARRAY_SIZE; i++){
    uint8_t colorIndex = map(pixels[i], MINTEMP, MAXTEMP, 0, 255);
    colorIndex = constrain(colorIndex, 0, 255);

    //draw the pixels!
    tft.fillRect(displayPixelHeight * floor(i / 8), displayPixelWidth * (i % 8),
        displayPixelHeight, displayPixelWidth, camColors[colorIndex]);
  }
  //Printing in the serial monitor
  for(int i=1; i<=AMG88xx_PIXEL_ARRAY_SIZE; i++){
      Serial.print(pixels[i-1]);
      Serial.print(", ");
      if( i%8 == 0 ) Serial.println();
    }
    Serial.println("]");
    Serial.println();
```

delay(5000);

8. References

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