PROJECT TITLE:

Contactless Temperature Sensing

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UNIVERSITY: *Karlsruher Institut für Technologie*

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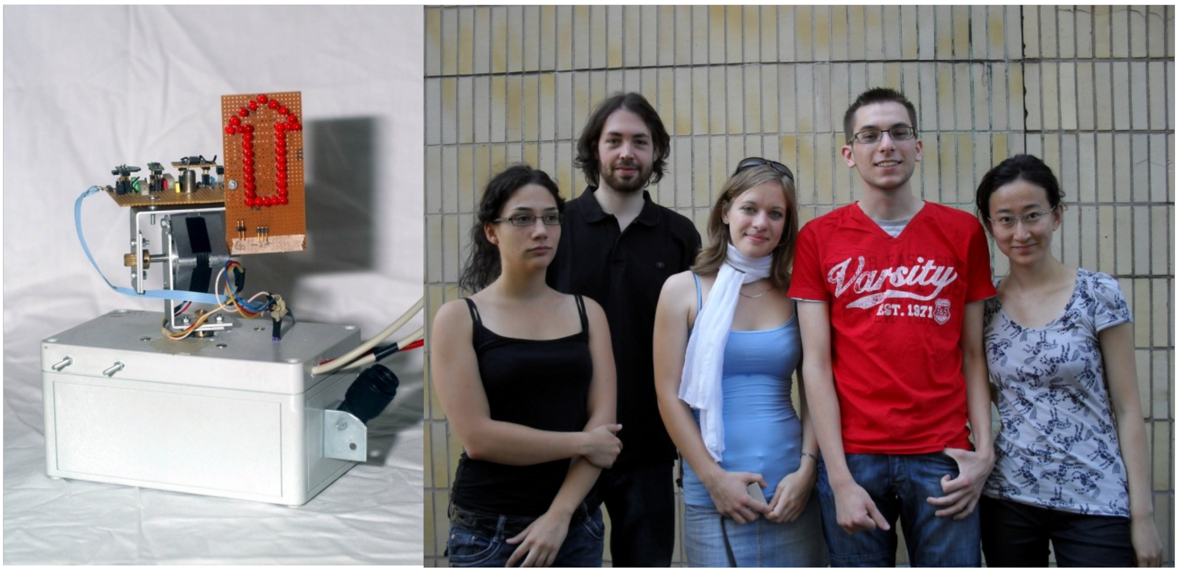
TI PARTS USED IN PROJECT:

2 x drv8811, http://focus.ti.com/docs/prod/folders/print/drv8811.html

1 x Msp430f2013, http://focus.ti.com/docs/prod/folders/print/msp430f2013.html

2 x Opa2735, http://focus.ti.com/docs/prod/folders/print/opa2735.html



PROJECT ABSTRACT

Our efforts dealt with contactless temperature detection in rooms using a movable thermopile infrared sensor. The design we created for this purpose consists of an infrared sensor (Perkin Elmer TPS334L10.6). This sensor can be rotated and tilted in order to change the direction of its view. This enables us to measure the temperature in different locations and create a spatial image of the temperature.

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1. Introduction and motivation for our project

Nowadays, you can barely imagine public buildings or even private homes without smoke detectors destined to alarm in case of fire. However, those devices aren’t triggered until there is a certain amount of smoke generation. That means that the fire must have erupted and the source and surrounding objects may already have received irrevocable damage, once the burning is stifled. Consequently, there has to be a better alternative to ideally protect one’s home and belongings.

That problem motivated our team to come up with a possibility to remotely detect heat sources before they result in a blaze. Starting with this, we evolved the idea into a device for spatially partitioned non-contact temperature measurement using thermopile infrared sensors. Their basic mode of operation was briefly broached in one of our lectures which additionally motivated us to carry out our project in order to gain practical experience instead of just listening to theory.

2. Theoretical background

For better comprehension, we will now give some theoretical background concerning the main components. A thermopile sensor operates as follows: it generates a voltage commensurate to the infrared (IR) radiation power. Therefore, one can employ a method called pyrometry which consists in the deduction of an object’s temperature by making use of the fact that every object emits IR radiation with a power which is a strict function of its temperature. For a fixed ambient temperature, that correlation will give the correct result. However, the output signal will change when the ambient temperature varies. Any IR temperate measurement system needs to compensate this effect. Most commercially available sensors feature a thermistor internally connected to the sensor housing to derive the ambient temperature. In our design, the compensation should be achieved by employing an analog circuit which will be further explained in the description of the implementation.

Our design employs a Perkin Elmer TPS33L10.6 thermopile sensor with integrated Lens an thus small field of view (6°-8°).

To reach our goal of getting a heat image of a room with a single thermopile sensor, we have to move the sensor in the room and cover as much space as possible. For we want to deduce the position of an object emitting heat, we have to know the position of the motor(axis) in relation to a zero position. Because position control is hard to achieve with regular brushed DC electric motors, stepper motors seemed a reasonable choice. Their step width is fixed and constant as long as the torque stays below holding torque. Furthermore, their speed can easily be adjusted with a digital signal modulated by frequency in contrast to a DC Motor that needs an analogue voltage.

For the selection of a stepper motor controller many aspects have to be considered, to wit: The stepping frequency determines (in dependency of stepper motor) the maximum operating speed. Furthermore, the maximum winding current a controller can provide is related to the available torque of a stepper motor. Additionally, the step modes are important to reach smaller steps than your motor initially supports. At last, the controller should have a low resistance power driver to avoid big power dissipation.

There are some additional aspects to optimize the design. To avoid imprecision of a heat spot on the wall, a step should always have the same angle. Unfortunately, medium-class motors have at least 5% deviation from specified step angle. In order to not further decrease step accuracy, the controller shouldn't have a low deviation of winding current between the two motor-windings. Additionally, the motor voltage should be similar to the one pertaining to the controller, and the digital levels should comply with those of the micro controller to avoid level shifters. For embedded system it is advantageous that the controller is small and accessible with few external components. Also, a sleep mode which disables power driver and makes the motor windings become current-less can be useful to safe power.

3. Implementation

The explanation of our project’s implementation starts with the description of the basic configuration.

Figure 1 shows the individual subsystems, with lines representing their respective interconnections. The main unit in the center is our project’s "heart" which will be further described later on. This device gives orders to the two motor control boards which actuate the respective step motors, a process to which further details will be given. The ALERT indicator board, consisting of an LED arrow, is designed to point in the same direction of the sensor and is triggered by the main unit in case of a temperature hazard. At last, the sensor board is in charge of realising the ambient temperature compensation and contains the microcontroller that converts the sensor voltages into processible data, i.e. calculates the temperature. The board communicates with the main unit via SPI and is operated as an SPI slave. The board comes with its own power supply of +/-5 V and 3,6 V and contains the MSP430F2013 as well as two OPA 2735.

Those TI chips have several advantages. The OPA2735 features low offset or drift, which comes in handy because of the thermo-voltage being very low. The MSP430F2013 contains a SD16A sigma-delta analog to digital converter which. This benefits our project, since its suited best for measurement applications by being very precise. Furthermore, the chip features four chanels, a quantity we need because we have to convert three voltages, to wit: the compensated voltage at the outlet, the thermistor voltage and the thermopile voltage. Moreover, the MSP430F2013 offers an internal reference voltage of 1,2 V which we use by applying it at the thermistor. At last, the chip features an USI (Universal Serial Interface) which contains an already completed SPI communication in the hardware, so that we didn't have to programm it.

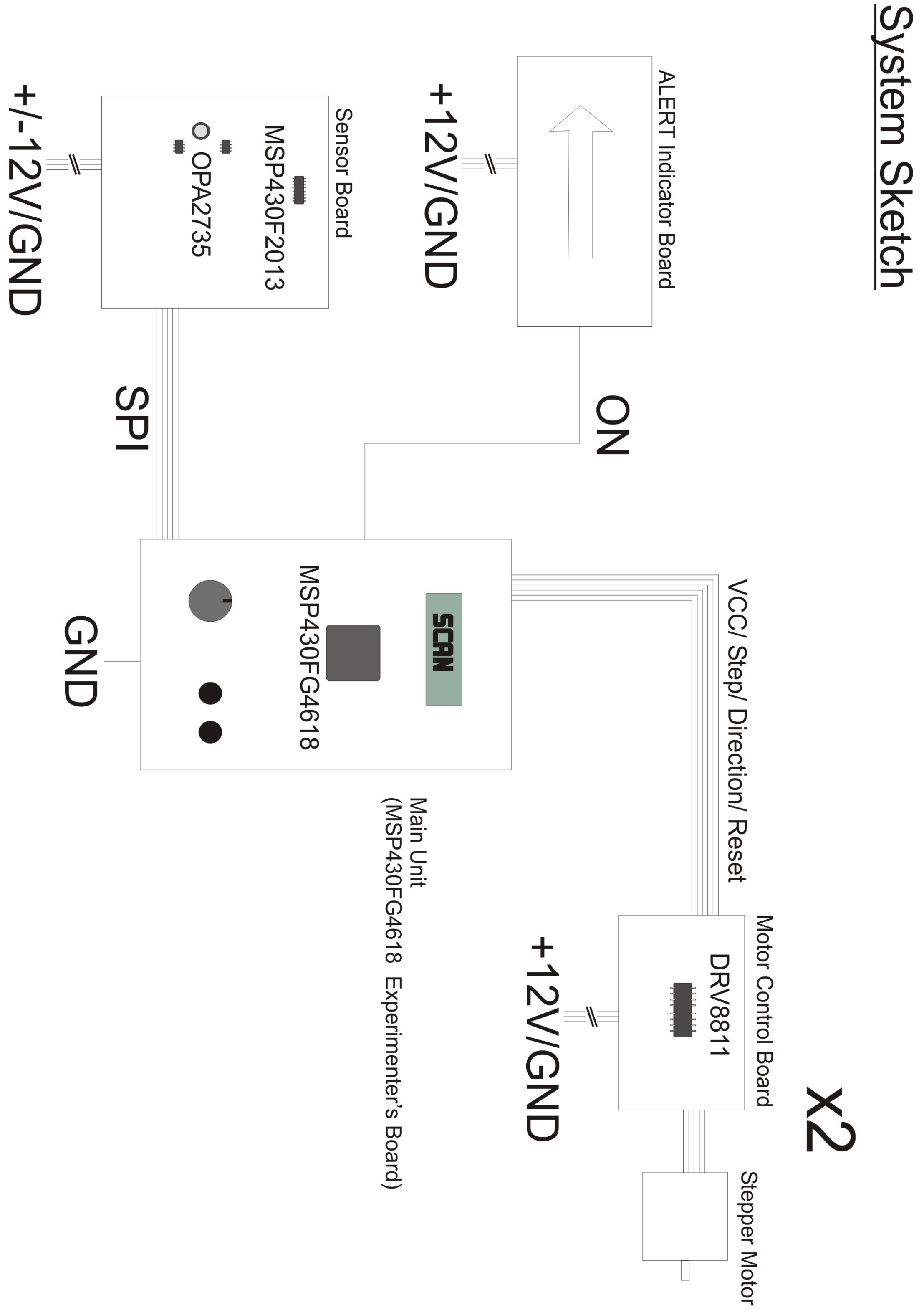


Fig. 1 System Sketch

The sensor circuit (schematic in the appendix) should work in the following manner. First, it separately amplifies both the voltage at the thermistor and at the thermopile unit. Subsequently, it subtracts those voltages together with a certain weighting which, if done properly, should provide the previously described ambient temperature compensation. The outcoming voltage is converted by the micro controller which then calculates the temperature and displays it via SPI.

We will now further discuss the the main unit’s components and mode of operation.

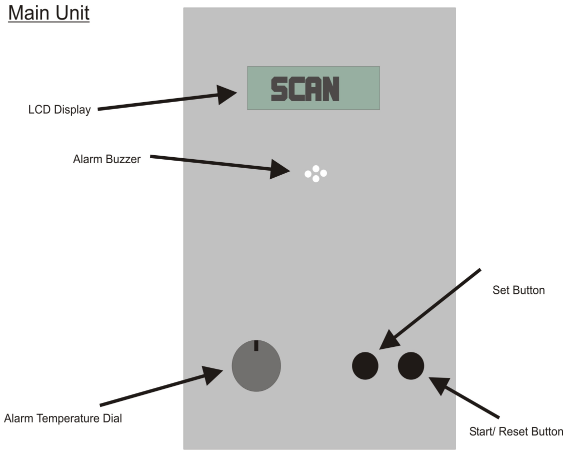


Fig 2. Main Unit layout

The main unit consists of an MSP430FG4618 Experimenters Board from TI. It is were the whole system’s operation takes place. For this purpose, it has two press buttons which actuate the orders Start/Reset and Set. Additionally, the rotary knob at the left bottom side is used to adjust a temperature difference. Measured temperatures that exceeds this difference to a reference temperature trigger the alarm. The system employs an LCD display for user feedback. In case of alarm, alert is given both by an internal Piezo buzzer and by the previosly mentioned LED arrow. The main unit works by reading values given by the sensor, saving a reference “picture” of the measured area and comparing temperatures. Furthermore, as above mentioned it controls the stepper motors and poses as the SPI master.

In the following paragraph, we will describe how to operate the main unit. After starting the device, it is in SET mode. The desired temperature discrepancy can be adjusted via the previously mentioned rotary knob. Pressing the Start Button will start the scan procedure. All three actions can be read off the display. The first run of the motors is used to save reference temperatures at certain spots that later on are compared to the temperatures gathered at following runs. With the device in scan mode, pressing the Scan Button again stops the motors and the measurement while “reset” flashes at the display. The motors have to be manually rotated back to starting position and you are back at set mode.

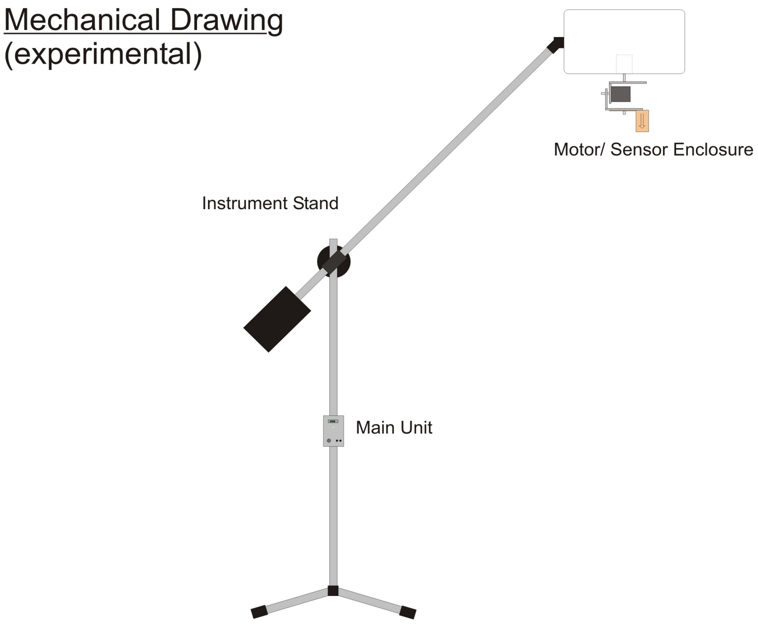


Fig 3. Mechanical Drawing

Figure 3 shows our preliminary model for the experimental setup. For testing our sensor system, we used a tripod, since putting the device on its destined location, i.e. the ceiling, would make it inaccessible for potential changes. We weighed down one side of the stand's cross axis to ensure stability for the motor/sensor enclosure. The main unit is fixed on the rod.

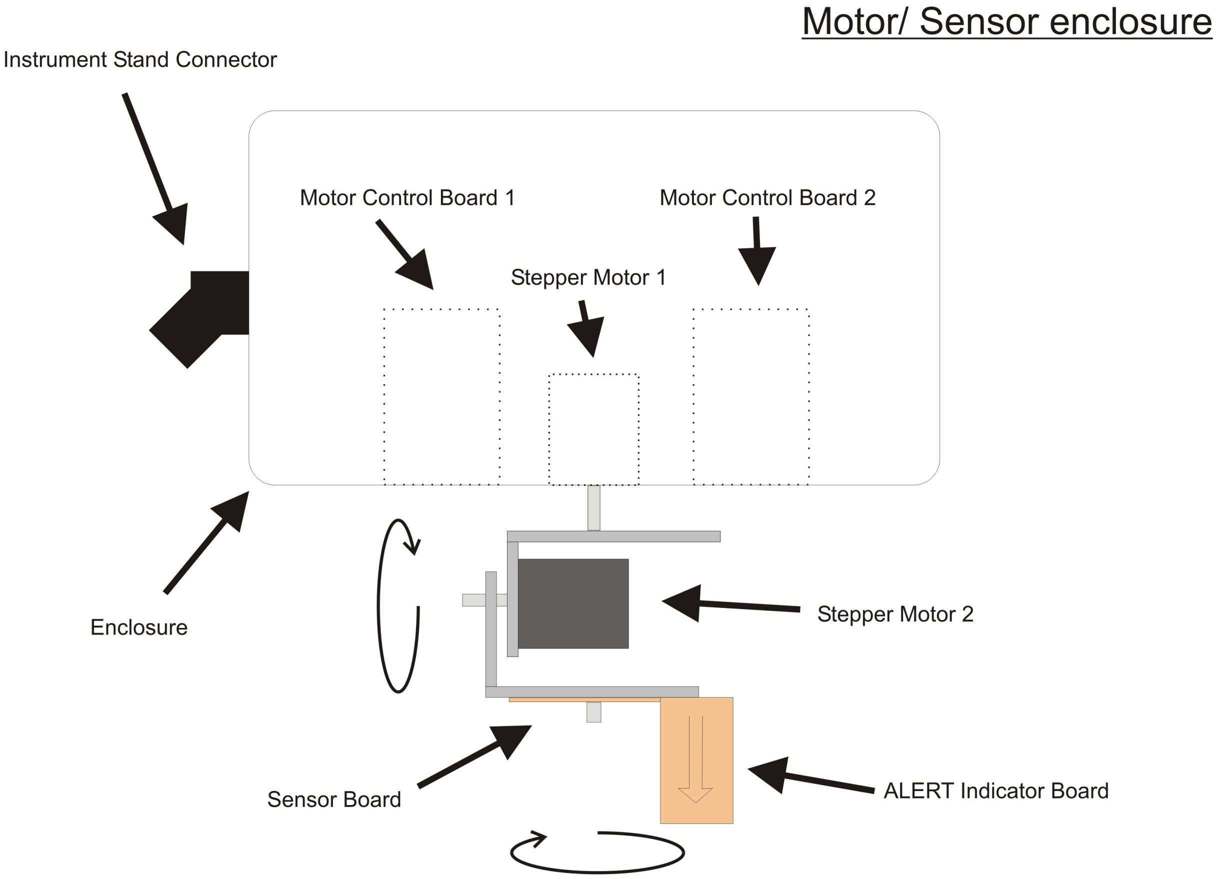


Fig. 4 Motor/Sensor enclosure

As seen in figure 4, we chose an applicative housing made of hard plastic which is used for enclosing the two motor control boards and one of the stepper motors. The housing is connected to the instrument stand by two angle brackets. Grub screws are fixed to the respective motor axis which in addition connects the L-form angles made of aluminum.

At the axis pertaining to stepper motor 1, which is fixed inside the plastic housing, a grub screw connects the axis with one side of an aluminum L-angle. This angle's other side fixes the body of stepper motor 2. The axis pertaining to stepper motor 2 is connected to the second aluminum L-angle by another grub screw. That is where both the sensor board with the thermopile and the alert indicator board, which points at the affected area in the room, are located.

To cover the whole room, stepper motor 1 turns 360 degrees, whereas stepper motor 2 performs a turn of altogether 90 degrees at the respective steps of stepper motor 1. Thus, the sensor points respectively at the floor and step by step lifts the angle until it reaches 90 degrees and therefore points parallel to the floor.

We will now discuss the assembly and mode of operation of the stepper motor controller. The System employs TI DRV88XX series stepper motor controll chips. Two DRV8811 are used, because our room is scanned in height and width. Unfortunately the DRV8821 which would offer this solution on one chip wasn't available as of yet.

The main advantage of a dedicated motor controller is the combination of logic and power drivers. The maximum possible power dissipation at 1A winding current lies at 3W. The DRV8811 can cope with a logic high level down to 2,52V which fits with the 3,6V the MSP430 series chips are run off in our system. With DRV8811 we can use 1/8 step mode so (cheaper) motors with bigger step angles can be used or accuracy may be increased. DRV8811 also has an overcurrent protection so failure in motor or circuit won't damage chip and conduction paths.

The stepper motor controllers use a standard circuit derived from the datasheet. The schematic can be found in the appendix.

Based on the HTSSOP housing of DRV8811 an the ThermalPAD using breadboard prototyping wasn't a feasible option, so a one sided printed circuit board was produced.

4. Experimental results

We started our experiments with testing the motor controllers. Our results were that the steps seem to be quite accurate, but that accuracy decreases with smaller step-modes. Increasing the winding current means increased accuracy. The motors aren't symmetrically constructed, so that they can be very accurate for many steps but then the grid moves some degrees. That means that the motor runs continuously with an "angle offset" till the asymmetric part is passed. Furthermore, we noted that the specified steps are always kept. Our test consisted in measuring the step accuracy using a disk with printed angles which is turning with motor-axis.

Next, we tested the ambient temperature compensation. Since the calculation of the exact amplification (needed to properly compensate ambient influences) involves complicated mathematics in which some components were unknown to us, we decided to determine the amplification by experimenting. The results of those experiments can be found in the appendix. First the sensor was pointed at an object with a fixed temperature and the case temperature was varied with a heated wire. (Table 1). Measurements of the thermistor resistance and the thermopile output voltage were taken at specific temperatures. The data shows an increase in thermopile voltage with increasing ambient/case temperature, which should be compensated. The compensation is achieved by amplifying the thermistor voltage with a gain of A_1 and adding it to the (negative) thermistor voltage. Table 2 shows a comparison between several A_1 and their resulting average compensated output voltages and the standard deviation in the measurement set. Obviously a Gain of 280 seems to give the best results and is accordingly employed in our system (Sensor Module schematic R12=5K3). Further Measurements were taken with fixed ambient temperature and varied target object temperature to derive a formula to computate the target object temperature (Table 3 and chart). This is used to derive the object temperature from the AD readings in the MSP430F2013.

In the end, experiments under real conditions showed that we couldn't completely compensate the ambient temperature and derive a precise formula for the thermopile, presumably due to inaccuracy during measurement and deviation of the components. That means that variations between the measured temperatures and the ones in reality can be quite high, in the worst case up to 20°C.

6. Conclusion and summary

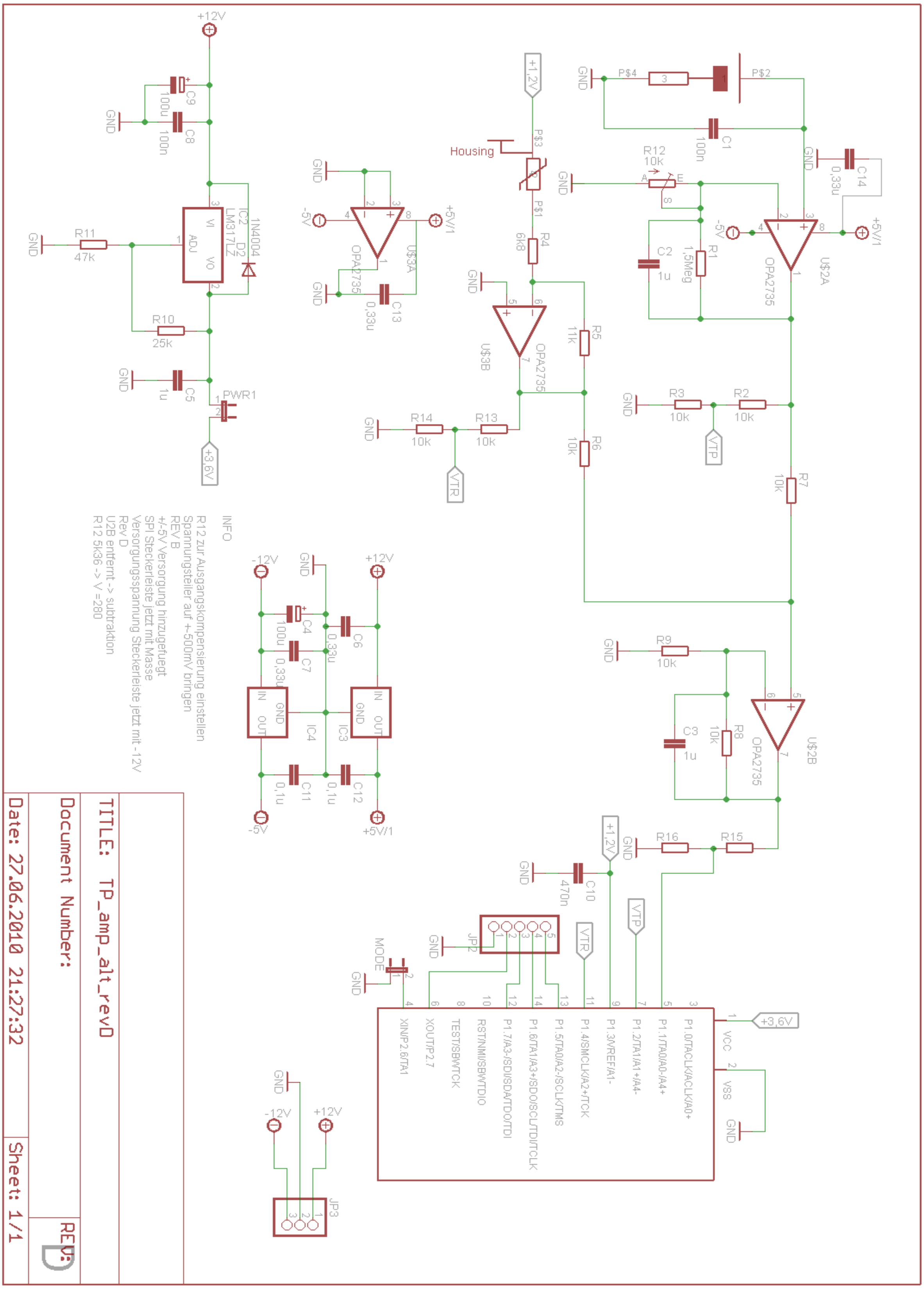
In conclusion, we could see that our principle idea is working. There are certain application areas in which our device may be used. We can measure the temperature in different locations and thus create a spatial image of the temperature. Consequently, our project could be developed to be considered a better alternative for smoke detectors since it would alarm in case of heat source before a fire breaks out. However, in its current state it can't already be applied to warn in case of fire because we had to face several problems in our experiments. First of all, the ambient temperature compensation doesn't work properly so that variations of the temperature in the room in which we want to install the device would lead to false alarms or similar errors since the processing of the data would be deficient. Furthermore, the rotations aren't yet fast enough, so that it's possible that a fire brakes out before our device reaches the spot in question. Additionally, the problem can appear that the distance between sensor and object is too wide. The sensor has a certain field of view so that the scanned area grows with increasing distance. This can be disadvantageous because the sensor generates an average value between the heated object and the cooler surroundings so that the resulting calculated temperature will be lower than it is in reality.

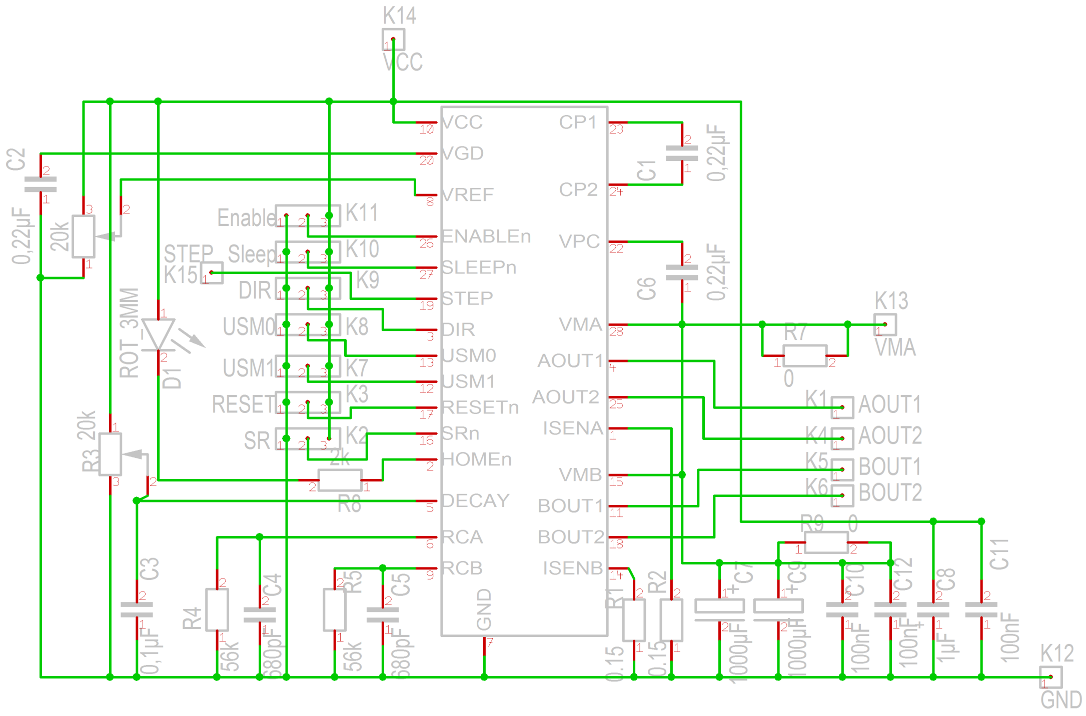
7. Future plans

Our future plans with the project will involve the elimination of said problems and the optimization of the motor controllers. In this context, we came up with the following suggestions of improvement. Since we didn’t manage to ideally compensate the influence of the ambient temperature, it could be advantageous to use a digital design instead of an analogue one. Moreover, this would add superior precision compared to anything we could achieve by using the analogue version. Furthermore, we consider using more than one sensor which could help with our problems concerning length of time and distance. The motor design could be improved by using one DRV8821 instead of two DRV8811 which would be a more elegant solution. Heat dissipation isn't optimal on single-side low cost layout, so it should be considered if a two layer layout is necessary.

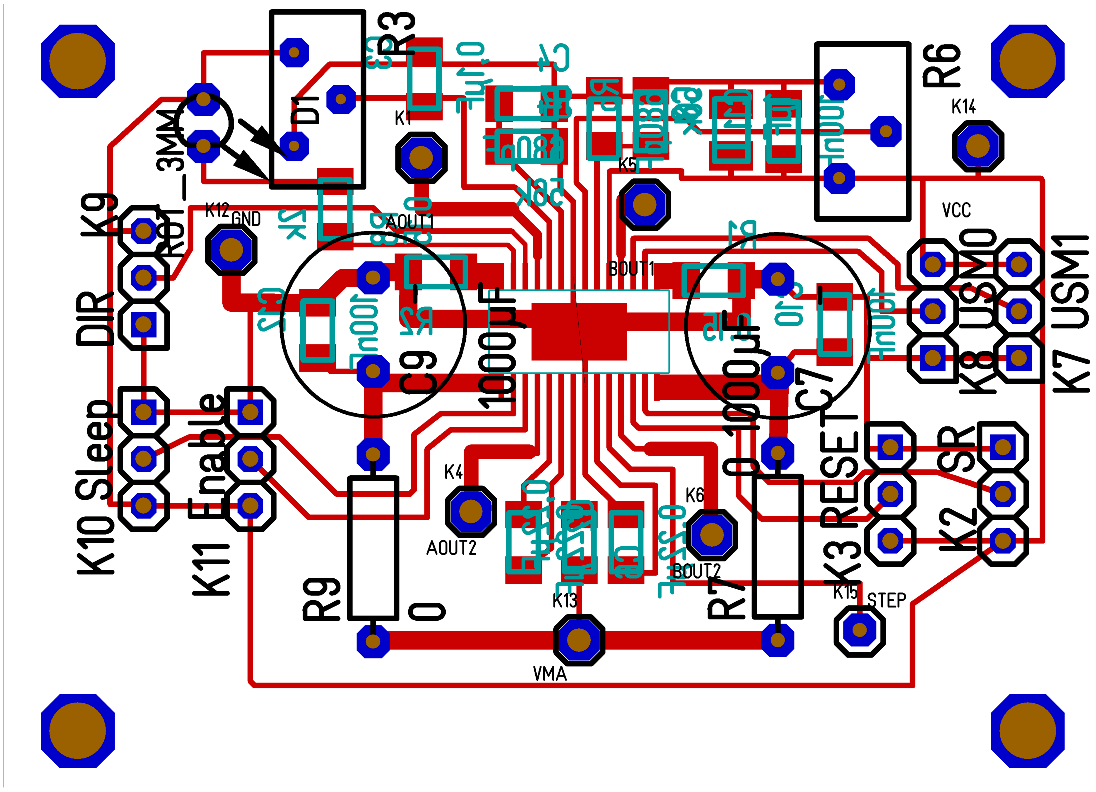
Appendix

Sensor module schematic





Stepper motor controller schematic

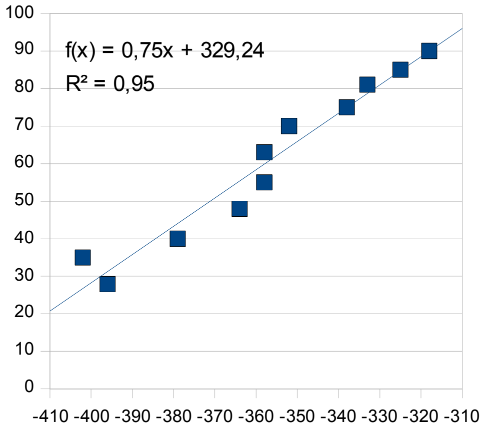


Motor controllers: mounting

Sensor Temperature /°C	Thermistor Value /kR	Thermopile Voltage / µV	Amplified Thermistor Voltage
28	26,45	39	-0,396396
30	24,3	158	-0,424437
35	19,93	390	-0,494382
40	14,66	820	-0,613925

Gain Thermopile	avg. Compensated Output /V	Standard Deviation
100	-0,447110	0,062516
150	-0,429523	0,045308
200	-0,411935	0,028121
250	-0,394348	0,011057
280	-0,383795	0,002448
300	-0,376760	0,006868

Object Temperature /°C	Temperature Voltage /mV
27,9	-396
35	-402
40	-379
48	-364
55	-358
63	-358
70	-352
75	-338
81	-333
85	-325
90	-318



Ambient compensation/ sensor test data