theremino System

Theremino Spectrometer Linear Sensors

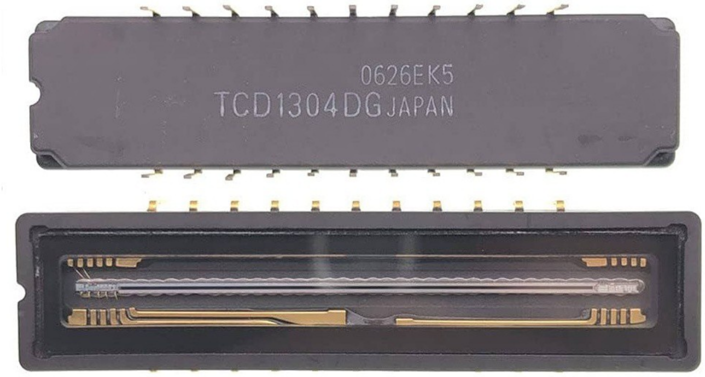
Linear Sensors

With the Spectrometer application and the firmware we developed for the Nano module, you can read the three types of Toshiba linear sensors that are most frequently used in spectrometers. You can find their DataSheets in the "DOCS" folder of the "Theremino_Spectrometer" application.

The first is the**TCD1304DG**.

This model is without a doubt the best.

It goes up to 3600 pixels and we recommend using it instead of the following two.



The second is the**TCD1304AP**.

Be careful when buying them as the letters "AP" instead of "DG" imply worse characteristics.

This "AP" version also contains 3600 pixels, but you get maximum stability and minimum noise only by selecting 600 pixels.

Accepting a worsening of the characteristics, you can get up to a maximum of 1000 or 1200 pixels. So the resolution that can actually be used with this sensor is very low.

And the third is the**TCD1254**.

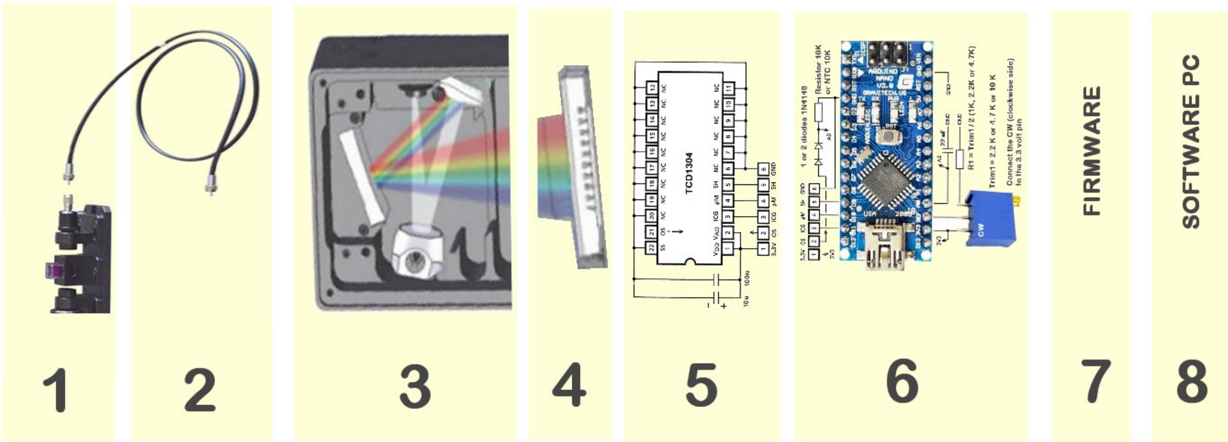
This sensor contains 2500 pixels and they are all actually usable.

We do not recommend using it because it only has 2500 pixels, but also because it does not have pins to fit into a socket and therefore it is more difficult to connect.

And also be careful that the pads are delicate, so if you solder wires onto the pads you may detach them from the sensor (and you will have to throw it away).

We recommend never soldering the sensors, but using strip connectors with turned PINs, like these.

Structure of the spectrometer with linear sensors



Here you can see the entire path from the optical signal to the software. (1) Sample holder. (2) Possible optical fiber. (3) Optical bench of the type with reflection grating and mirrors. (4) Linear sensor. (5) Support module of the linear sensor. (6) Nano module. (7) Firmware that is in the Nano. (8) Software of the Spectrometer app.

Typically these sensors are mounted on benches containing a reflection grating and two mirrors.

You can find them used or you could print them in plastic and just buy the grating and mirrors.

You could also build a bench with a transparent grid like you do with WebCams, but using these benches with reflective grids will waste less light.

Furthermore, the collimating mirror concentrates all the light on the thin line of pixels of the sensor and the sensitivity increases several times further.

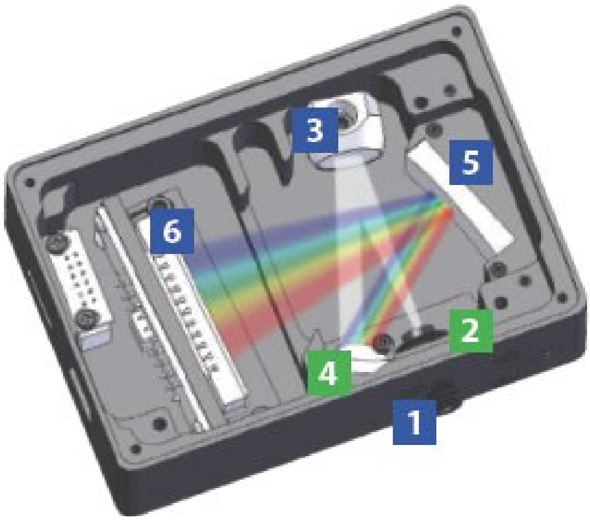
But these benches have two big defects:

- The concentrated line of light must hit the sensor's very thin pixel row exactly. It must also be perfectly parallel to the pixel row and in perfect focus.
- The deformations produced by the mirrors make the horizontal scale of nanometers non-linear, so a calibration with more than two points must be done.

And unfortunately, making these calibrations is very difficult, if not impossible. You improve something but something else goes out of place and you continue like this for a long time, until you give up, until you understand that calibrating them correctly is impossible and you always lose something on one side or the other.

And also calibration is a big problem because we have only two safe and stable calibration points (436 and 546) and to have more you would have to buy at least two or three hollow cathode lamps, which cost more than the spectrometer itself. Also they are fragile lamps both electrically and mechanically and need a special power supply that also costs more than the lamps.

Benches for linear sensors



Typically these sensors are mounted on benches like these with the reflection grating (4) and two mirrors.

The first mirror (3) serves to collimate the beam and the second mirror (5) broadens the spectrum across the entire width of the linear sensor (6), without having to move the sensor too far away and therefore keeping the bench quite small.

The light input (1) has a connector for the possible optical fibre and is followed by a slot (2).

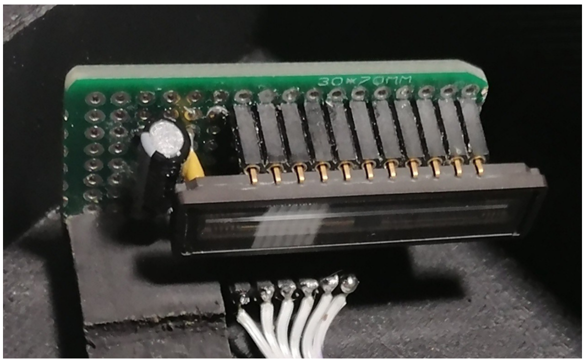
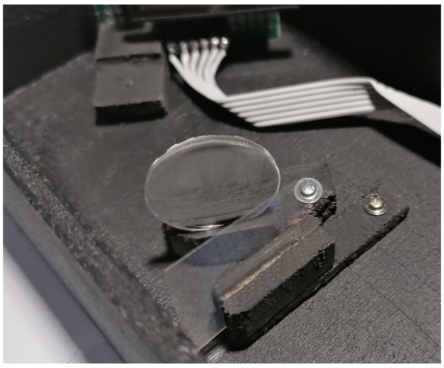
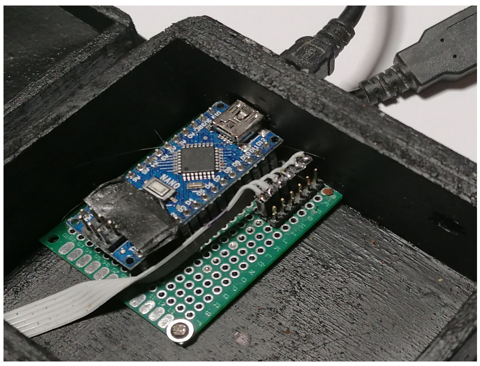
These benches are quite expensive, you can find them salvaged from used and refurbished B&W or Ocean Optics benches.

You can search for them on eBay or other sites, these years (2024) there is the seller "spectrophoton" who sells the complete bench for less than 200 dollars and also the individual components, grating and mirrors. Try ***this link***, it's his eBay store and should last for at least a few years.

Alternatively, you could build a homemade bench, as we explain in the PDFs on building the spectrometer.

If you use a transmission reticle you will have less brightness but the calibration and adjustment will be easier. Since there is no collimator the tolerance to errors in vertical is wider. Furthermore the linearity of the horizontal scale is excellent, so much so that you do not need other calibration points besides the usual two (436 and 546) that you get with a cheap fluorescent lamp.

These pictures show the construction details of one of my wooden tests. You can find more details in the PDF file on the construction of the spectrometer.

In any case, adjust and focus a bench with the linear sensor
And**considerably more difficult**compared to a desk with a webcam.
Use these sensors only if you have a lot of time and patience.

Benches for specialized analysis

In some cases, linear sensors, mounted in a bench with a reflection grating and mirrors, can work better, and even be several times brighter, than the best WebCam.

The benches we are talking about are B&W or Ocean Optics recovery ones like the following.

And the specialized cases we are referring to are analyses on a narrow region of the spectrum, for example medical analyses on some particular spectral lines that are always the same.

If in these benches the collimating mirror is calibrated to concentrate all the light on the sensor, a notable increase in brightness can be obtained, but only in a narrow area of the spectrum, for example from 500 to 650 nm.

This strong increase in brightness is obtained at the expense of all the other characteristics and the negative side effects are notable:

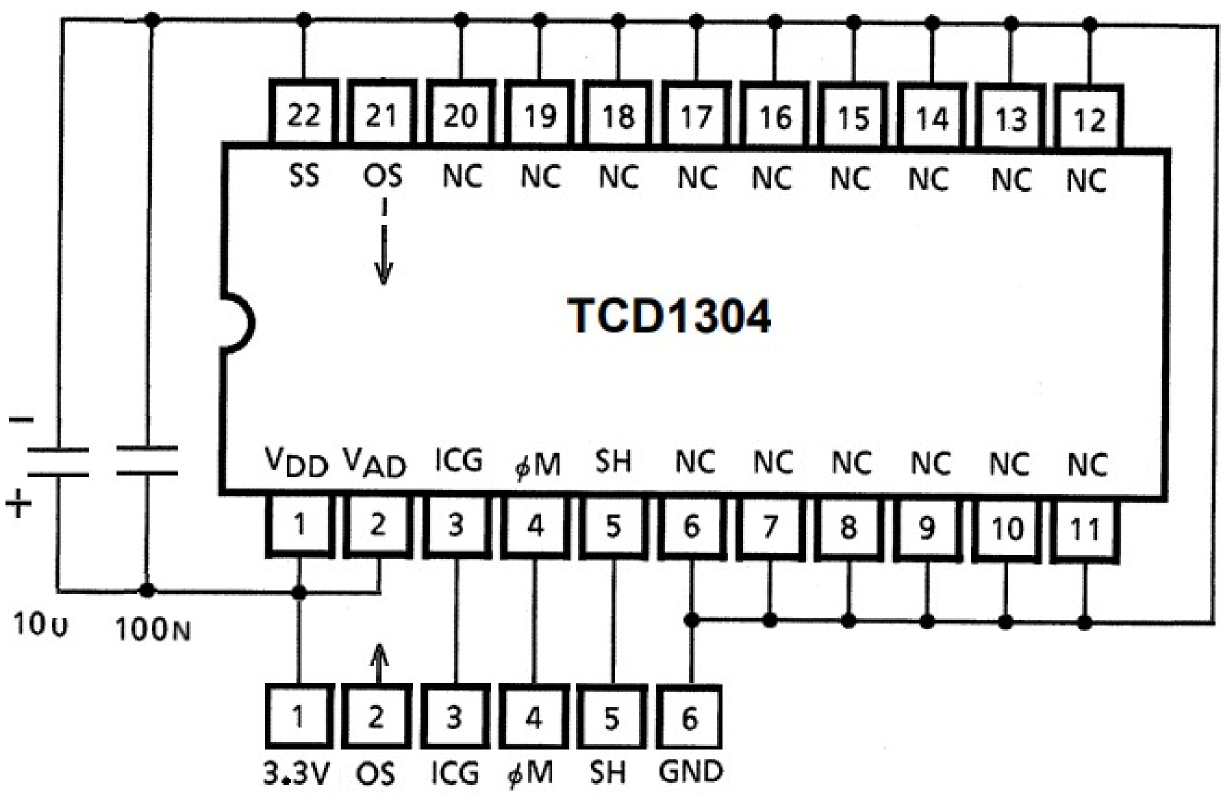
- A bench like this will not be usable for generic analyses on the entire spectrum.
- Calibration is delicate and very difficult to perform, it could be perfect once by chance and not be able to do it again the next day.
- Even the smallest change in the adjustment screws causes significant changes in brightness and therefore also changes in the measured values.
- The part outside the narrow analysis area will be completely out of calibration, out of focus and unusable.
- The linearity over the entire usable spectrum, which is in any case narrow, will be terrible.
- To obtain a reasonable calibration of the horizontal scale you will need to have several precise calibration sources, i.e. at least three or four hollow cathode lamps, which would cost you more than the spectrometer itself.

Ultimately for all of us mere mortals, who want a generic bench, capable of measuring with reasonable precision from ultraviolet to infrared, these sensors and benches are a bad choice.

Sensor holder module

Be careful to use the DG version of the sensor, as explained on the first page of this document.

You can find its DataSheet in the "DOCS" folder of the "Theremino_Spectrometer" application or download it from here: ***https://eu.mouser.com/datasheet/2/408/TCD1304DG_Web_Datasheet_en_20190108-2508269.pdf***

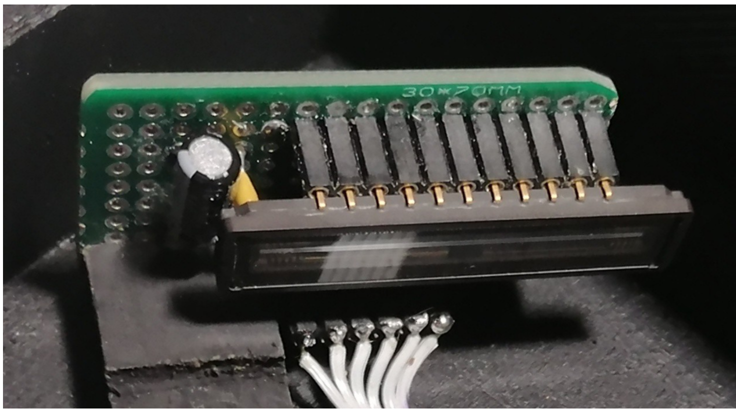


This module is very simple so you can easily build it by soldering two 11-pin female strip connectors onto a PCB.

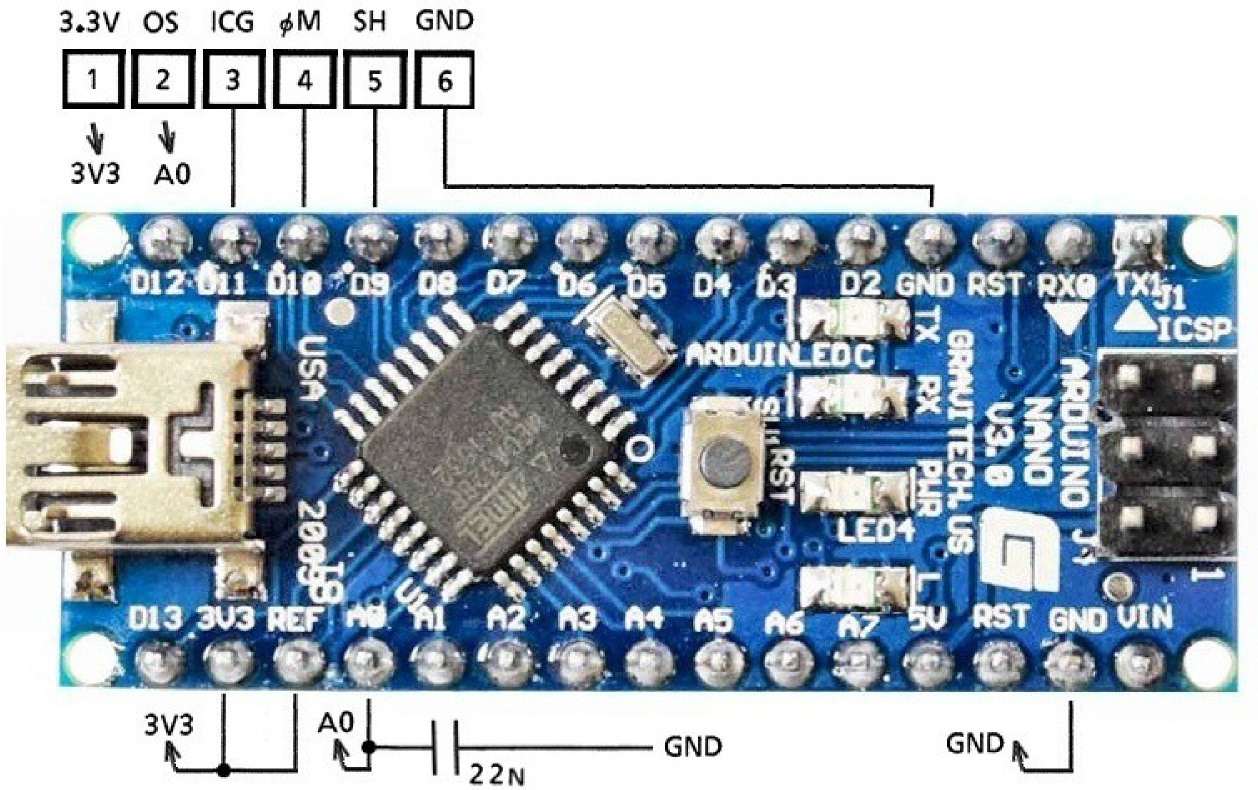
Be very careful, use turned connectors, with round holes, otherwise the contacts with the sensor could be unstable and generate many problems.

The six-wire output connector will be male and the flat cable connecting to the nano module will have turned female connectors at both ends.

In this image you can see a TCD1304DG sensor mounted in a homemade wooden spectrometer. In the lower part you can see the "FLAT" cable (taken from the cables to connect the old Floppy and mechanical HardDisks) with the six connection wires that go to the Nano module.



Nano Module - Simple Version



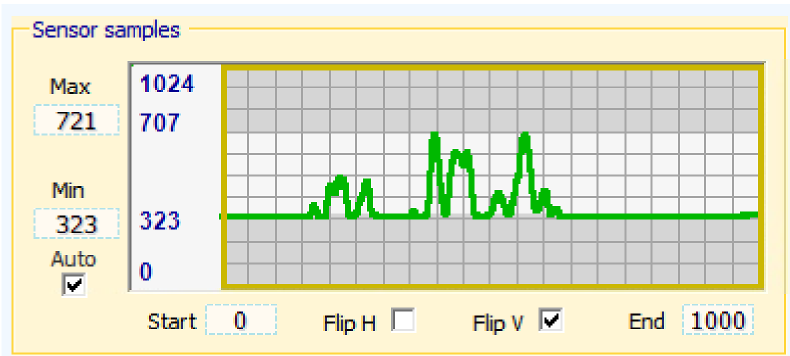
This version is very simple and you can mount it in a few minutes on a multi-hole board using two fifteen-pin female strips.

Use only turned connectors, with round holes, otherwise the contacts could be unstable and generate many problems.

With this version only a third of the values available in the Nano's ADC are used, that is, about 400 values out of a maximum of 1024.

In fact, in the image on the right you can see that the light area is about a third of the total.

The spectrometer works perfectly even like this and in practice there will be no significant differences.

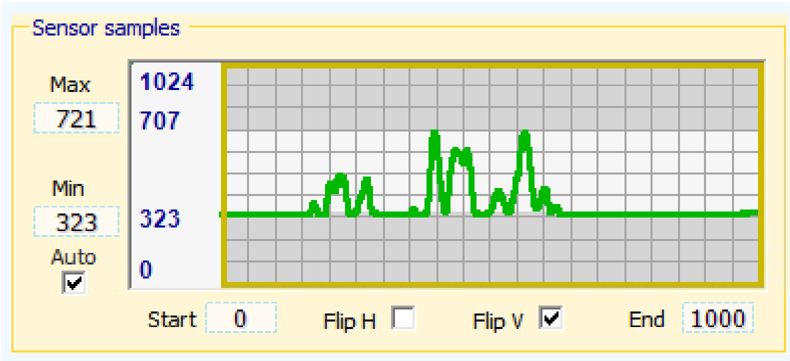


Anyone who wants to use a larger number of steps and see the larger image you can add some components as explained in the next pages.

Nano Module - Improved Versions

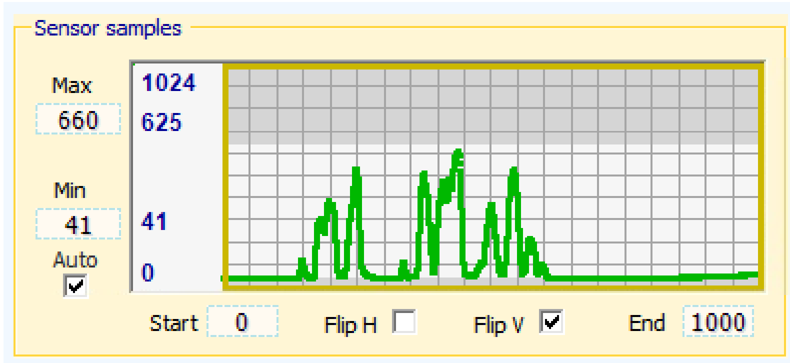
With the simple version on the previous page, about 400 ADC values are used and the image is quite squashed vertically.

The spectrometer still works well but it could be done better.



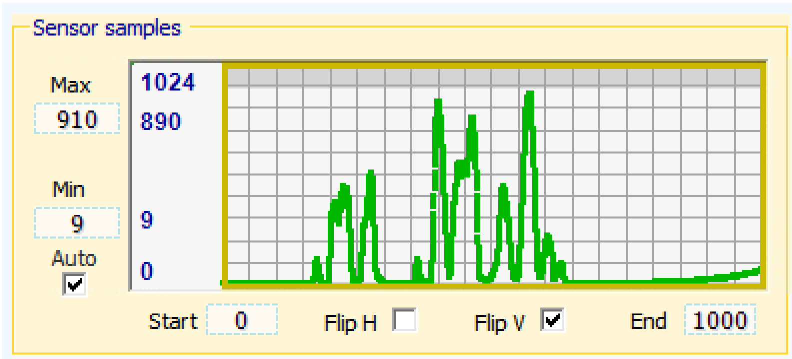
By adding a Trimmer as seen on the next previous page you use about 600 ADC values and the image is already bigger

The gain is only 50% so you might want to consider switching to the more complex version with trimmers and diodes which will be explained on the next page.



Adding also the diodes and a resistor or an NTC, you get about 900 values and the picture is much bigger.

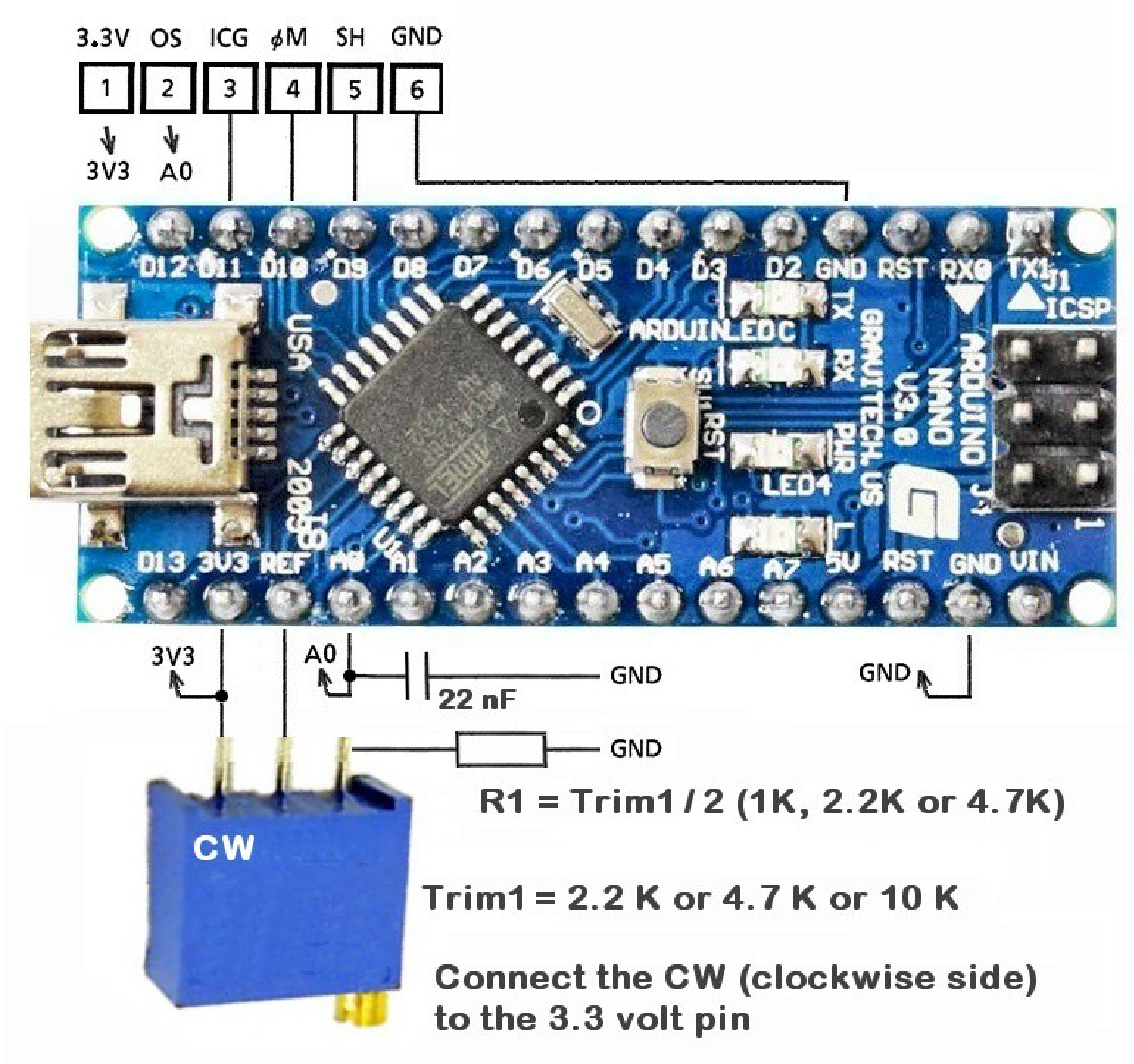
However, this latest version is more complex and includes critical components to pay attention to.



The spectrometer performance does not vary much between the various versions
but construction problems increase and with them also the possibility of making mistakes.

A good tip might be to start with the simple version.
but using a slightly larger hole punch so as to leave space
to add the trimmer and diodes later.

Nano Module - Trimmer Version

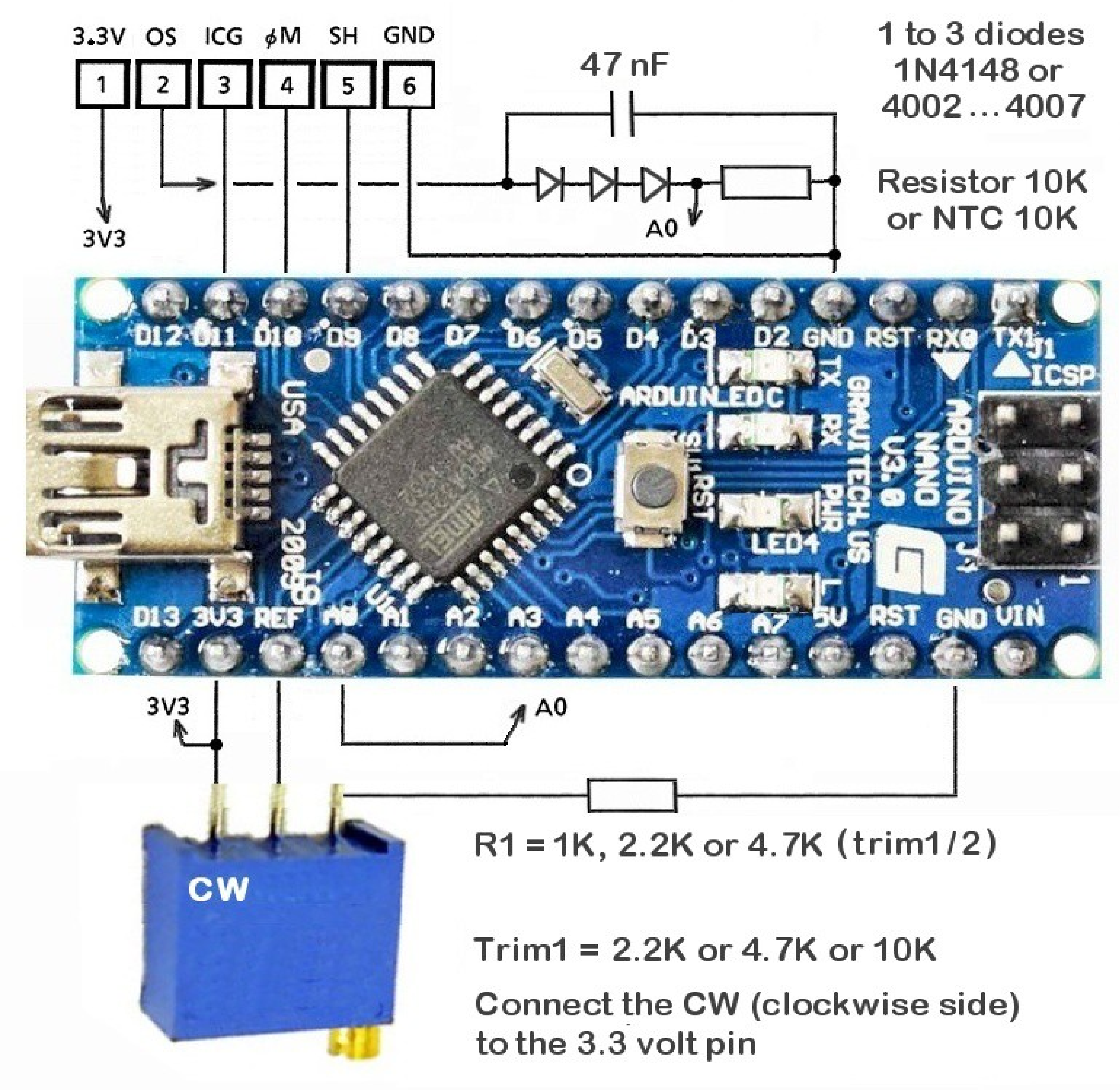


There is not much to say about this version, you add the trimmer and a resistor and you increase the useful range of values by 50%.

- If the trimmer is 2.2K then a 1K resistor is used.
- If the trimmer is 4.7K then a 2.2K resistor is used.
- If the trimmer is 20K then a 4.7K resistor is used.

If you solder the trimmer in the correct direction (with CW where indicated) then by tightening its screw clockwise the measured values will increase.

Nano Module - Version with trimmer and diodes



For the trimmer, do as explained on the previous page. The diodes will instead be added or removed experimentally depending on the characteristics of the sensor. With the TCD1304 there should be two or three, while with the TCD1254 there could be 1 or 2. A good idea would be to solder three diodes and also two male pins in parallel to each diode. So with one or two jumpers you can choose how many diodes to use.

The resistor between the diodes and GND should be fine at 10K but if with three diodes you still don't get to the upper part of the ADC range (saturations around 900) then you could lower it to 6.8K.

The voltage drop of the diodes depends on the ambient temperature, you could compensate almost exactly this variation by replacing the 10K or 6.8K resistor with a NTC of the same value. But the variations caused by the temperature are small enough and you can also do without the NTC.

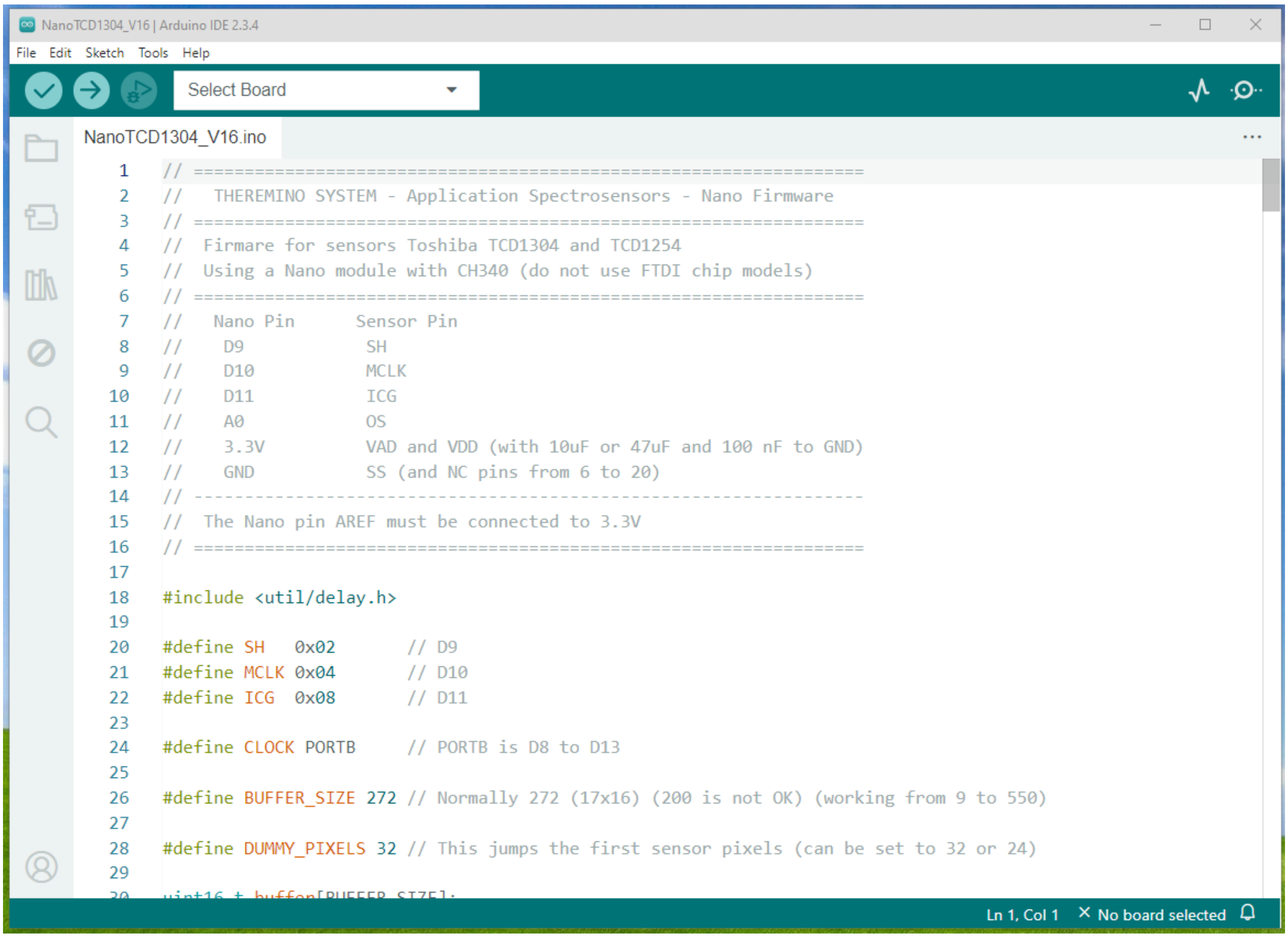
Firmware

You will find the firmware to program into the Nano module in the "Firmware" folder located next to the spectrometer executable file "Theremino_Spectrometer.exe".

You open it with Arduino IDE and program it. You can use Arduino IDE version 1.xx or even versions 2.xx.

In the Tools menu you have to select Nano as the Board type, then you have to choose the COM port it is connected to and you will also have to choose the processor type it has, which must be 328P and not 168P.

If you can't program it then you should choose "328P old bootloader".



In the first lines of the program there are explanations about the Pins used andnumerous configurations. You will not have to change anything unless you are really experienced and want to do some testing or modifications.

Once you write the program in Nano it will run immediately.

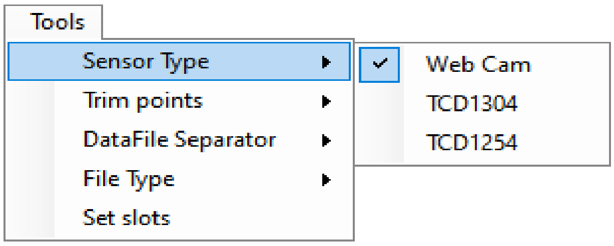
You can try it, following the instructions on the next page, even if you do not have the linear sensor and if you have not yet prepared the connections, just have the Nano connected to the USB.

Testing the Nano module and firmware

Once you have written the program in the Nano, it will work even without a sensor and without connections, all you need is a Nano module, just as you purchased it and not connected to anything other than USB.

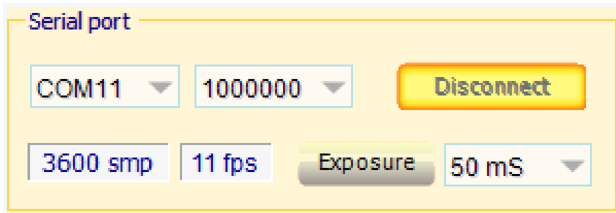
After programming the Nano with the firmware you need to launch the Spectrometer application and check its communication boxes.

In the Tools menu you need to choose the sensor type and it must be TCD1304 or TCD1254.



Then in the "Serial Port" panel you have to open the box that now shows "COM11" and choose the right port depending on where you connected the USB cable.

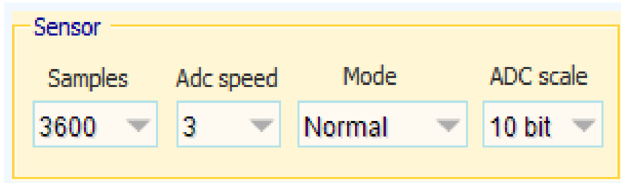
In the second box, always choose 1000000 because the firmware only works at 1 mega baud.



If the port you have chosen is the correct one and the Nano has been programmed, then by pressing the "Connect" button you will see it turn yellow and orange with the word "Disconnect", as in the image above, and the number of samples (smp) and the speed (fps) will appear in the two lower boxes.

Finally we can have test samples sent to us by the Nano module and view them.

In the "Sensor" panel click on the "Mode" box and choose one of the test modes from "Debug 1a" to "Debug 3c"



Depending on the test method chosen and the number of samples, you will see figures with more or less numerous teeth and with different intensities on the vertical scale.