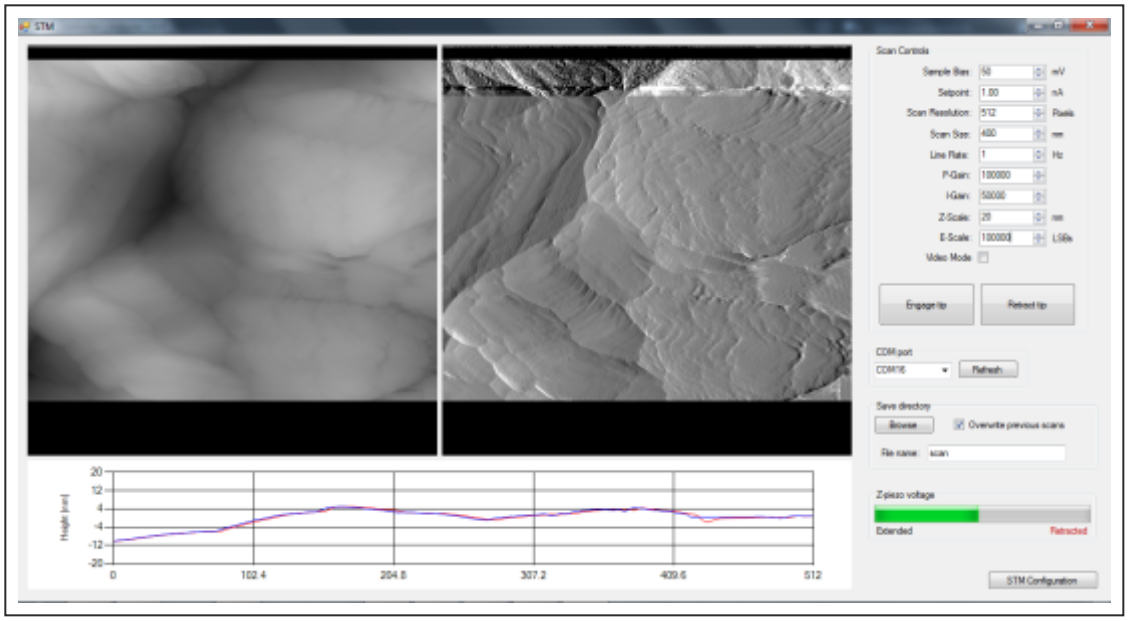
Dan Berard

Posted on **October 15, 2015**



I finally got around to finishing up the Teensy software for my STM! The Teensy controls scanning, PI control of the Z-axis piezo, sigma-delta modulation of the scanner DAC outputs, and serial communications with a PC. I also wrote a C# program (screenshot above) that receives the serial data sent by the Teensy and displays the images line by line, and can set the scan parameters.

Here are the files:

- Teensy files
- PC software
- PC software – source

I'll do a more detailed writeup on this later, but here's a brief summary of how it works: the Teensy uses a timer to call a function at a regular time interval. This function increments the scan, performs PI calculations to update the Z axis, and performs sigma-delta modulation of the scanner DACs. Since the scanning probe is a (sharp, fragile) solid object, it's velocity needs to be controlled at all times. If it moves too fast, it will likely crash into something, so the tip scans in a zig-zag pattern rather than a traditional raster (as in a CRT or SEM for example). Since the STM is always incrementing the scan at the same time interval, doing a slower scan will acquire more data. All data acquired between pixels is averaged, so you'll get less noise in a slower scan. Once a line of the image has been scanned in one direction and re-scanned in the other direction, the Teeny sends the Z data and error signal data over USB.

If you need to invert the Z-axis signal, find the "#define INVERT_Z true" at the top of the Teensy code and change it to false.

The PC software receives the data, does some basic processing, and adds it to the images on the screen. The left image is the topography (Z signal) and the right image is the error signal. The error signal looks like the gradient of the Z signal and has more high-frequency content. The topography data is displayed line by line in the graph at the bottom of the window. The red curve corresponds to the most recent scan line, and the blue curve is the same line scanned in the opposite direction. Ideally, these curves should be identical, but the agreement will never be perfect due to piezo hysteresis and things like that. If they don't agree at all or show oscillations, try lowering the line rate, proportional and/or integral gains. For scans larger than ~500 nm or so, you'll probably want to scan at ~0.5-2 Hz or so. For scans < 10 nm, you'll want to go much faster to minimize thermal drift effect, ~10 Hz or more. You can also decrease the number of pixels to increase the speed.

Connect a LED to pin 0 on the Teensy. This is used to indicate serial communication is active. Connect another LED to pin 1. This one lights up when tunneling is achieved.

To use the software:

1. Upload the code to the Teensy
2. Turn the microscope on and start STM.exe
3. Select the Teensy's COM port from the list
4. Do coarse approach until tunneling is achieved
5. Press "Engage tip". All this does at the moment is start the scan. You should see data coming in.

Images are saved as 16-bit, multi-page, uncompressed tiffs whenever a scan completes. You'll want to use a program like Gwyddion to process the images, otherwise they'll mostly just look

noticed that scan lines in the saved images are sometimes missing. CPU usage tends to be high when scanning at higher line rates. I'll hopefully have a fix within a week or so and will update this post once I do.

If you find any other issues or have suggestions for improvements, please let me know in the comments!

This entry was posted in **STM** and tagged **C#**, **software**, **STM**, **Teensy** by **Dan Berard**. Bookmark the **permalink [https://dberard.com/2015/10/15/stm-software/]** .

38 THOUGHTS ON "STM SOFTWARE"

ecamumbai
on **November 14, 2020 at 5:16 pm** said:

Hi Dan,

Thanks for sharing this amazing project. Its really fun. For the electronics PCB board, did you assemble the components by yourself or did you use a vendor to assemble them for you? I was planning to use JLCPCB's SMT service but they do not assemble all the components used in your schematic. I want to use reflow soldering using stencil only as the last resort. Please advise.

Thanks
Aksh

★ Like

Dan Berard
on **November 15, 2020 at 11:23 pm** said:

Hi Aksh,

I hand-soldered everything, but I've made a few copies of the board with a stencil and reflow soldering in a toaster oven. I've used Macrofab's assembly service before for another project, and found them quite easy to use.

Vishnu Mohan
on **June 4, 2020 at 5:18 am** said:

Hey there, Dan. I know this comment is kinda late. Thanks a lot for your in-depth tutorial!! I was wondering if there was any way to utilise or modify the code written so that the tip stops at a certain point and causes formation of a nano pore, in the material, like described by this paper : https://onlinelibrary.wiley.com/doi/full/10.1002/smtd.201900147

★ Like

Dan Berard
on **June 6, 2020 at 4:38 pm** said:

Hi Vishnu,
I happen to know most of the authors on that paper from McGill Physics, and have used the AFM in that paper several times 🙂
Like in the paper, you'd need an AFM with a conductive tip to replicate their pore formation. Since silicon nitride is an insulator, an STM can't detect its surface. You could form small indents in a conductive surface by plunging the tip a short distance into the sample but to form pores through a membrane in this way you'll likely need an AFM.
Dan

★ Like

Vishnu Mohan
on **June 10, 2020 at 4:19 am** said:

Thank you, Dan. I just had one more quick query. What positional resolution along XY could you achieve using simple piezo buzzers?

★ Like

The resolution can be subatomic, as long as you have good vibration isolation. A buzzer is more sensitive to vibrations than a tube scanner or piezo stack, so it's more challenging but doable.

★ Like

Karl Sahlén
on **April 29, 2020 at 6:45 am** said:

Hey Dan! Can you share your rawdata from your scans you have done with your STM so that we in our group project can test our image processing? Thank you for the inspiration.

★ Like

Dan Berard
on **May 1, 2020 at 10:29 pm** said:

Hi Karl,
Here are a few examples. They are multi-page TIFs where page 1 is topography and page 2 is tunneling current.
https://drive.google.com/open?id=1WAAiuuArSmt8U53tZjRW8GaIEE_-zy2j
Hope that helps!

★ Like

Karl
on **May 4, 2020 at 6:32 am** said:

Hej Dan, thank you very much for the picture. Is there any possibility to get the measuredata/datapoints aswell?

★ Like

Hey Karl,
Those files are the raw data, more or less. The 16-bit pixel values are the raw ADC/DAC values. The images are constructed in the software from pixel values that the Teensy sends over USB, one scan line at a time. You can see the raw pixel values in Gwyddion or ImageJ for example, or load the images into e.g. MATLAB if you want the data in matrix form.
Cheers,
Dan

★ Like

Zübeyir OFLAZ
on **July 23, 2019 at 6:09 am** said:

Hello Dan,
First I need to thank you for sharing such an awesome project with so much detail. I have been so excited about it that it has been constantly running on my mind for weeks, and now that the summer break has come I will attempt this project with one or two friends. I had a small question regarding the software you shared. Is this version of software completely compatible with your previous electronics setup? I want to do my own system and I felt like until then a temprary system on a breadboard would be ideal. If the software doesn't have any difference I would prefer to start with the old electronics guide that you provided.
Thank you in advance for your attention and sorry if I asked an obvious question due to my ignorance

★ Like

Dan Berard
on **July 25, 2019 at 11:48 pm** said:

Hi Zübeyir,
Unfortunately the software won't work with my older electronics setup. You would

★ Like

Zübeyir OFLAZ
on **August 1, 2019 at 5:52 am** said:

Thank you very much for your reply! We decided to use Veroboard to follow your new circuit diagram. I will ask one or two more questions in related pages, but they are just some brainstorming questions so feel free to not re-spond or respond really shortly.
Again thank you for such an awesome DIY site for such a cool project

★ Like

genisberta
on **August 10, 2018 at 4:40 am** said:

what is the CNV pin for? and where should it be connected in the STM PCB?
We really do not know what to do with it.

★ Like

Dan Berard
on **August 12, 2018 at 9:49 pm** said:

A rising edge on the LTC2326-16's CNV pin initiates a conversion. It should con-nect to Teensy pin 4 as described here: https://dberard.com/home-built-stm/electronics/

★ Like

I have a doubt about the coarse approach, does it run it automatically when the teensy is on or do I have to select it to do so somewhere?

★ Liked by 1 person

Dan Berard
on **July 29, 2018 at 10:06 am** said:

This version of the software is for use with manual approach only. The feedback loop is always active. You have to manually bring the tip into tunneling and then click “Engage tip” in the software to start the scan. I had planned on adding motorized coarse approach to this software but ended up rewriting the whole thing, and haven’t published it here yet.

★ Like

David D
on **May 18, 2018 at 1:37 am** said:

Hi Dan,
Finally finished new mechanical system. I added stepper motor to automate the approach. It works well. These links show my first images of HOPG. A little blurry, but not bad for a first try.

https://1drv.ms/u/s!AtFzHNfhgozugQjbsjdeY6Df3JaD
https://1drv.ms/u/s!AtFzHNfhgozugQZbz9qnIrZa6aN3
https://1drv.ms/u/s!AtFzHNfhgozugQeWyrxymk04kj1F
-David

★ Liked by 1 person

Dan Berard
on **May 18, 2018 at 8:43 pm** said:

★ Like

Genis Cabañas
on **May 17, 2018 at 9:49 am** said:

Hi Dan,
Great work on that project!
We would like to know if there is any other option instead of using the DAC8734, just because it has been so hard to find for us.

★ Like

Dan Berard
on **May 20, 2018 at 2:49 am** said:

Hi Genis,
Thanks! Yes there are many other options that will work. I use the DAC8814 in my current design for example, it's shown in the schematics on the electronics page.

★ Like

David D
on **May 20, 2018 at 2:59 am** said:

I used the LTC2664-16 for the DAC and the LTC2326-16 for the ADC.

★ Like

Dan Berard
on **May 21, 2018 at 1:34 pm** said:

That DAC has quite a bit more noise than the DAC8814, good to see it still

genisberta
on **June 28, 2018 at 3:44 pm** said:

Ok, that was so useful!
Also, should assume that the connections and pins are the same as the ones shown in the schematic using the 8734?

★ Like

Dan Berard
on **June 28, 2018 at 9:50 pm** said:

Hi Genis,
The DAC8814 and DAC8734 have different pinouts and require different external components. The DAC8814 requires an external reference and serveral external op-amps, while the DAC8734 does not. Take a look at the analog PCB schematics that you can download on this page for the DAC8814: https://dberard.com/home-built-stm/electronics/
Dan

★ Liked by 1 person

genisberta
on **August 27, 2018 at 11:31 am** said:

We used the DAC8734 and the ADS8517 in our STM, we tried to give a try with your software but as expected it did not work at all. We believe that by changing the libraries and changing some sentences should be enough, is there something else we must change?

★ Like

Dan Berard

LTC2326_16.cpp, and LTC2326_16.h), to work with the DAC8734 and ADS8517 SPI protocols instead. These files are pretty simple so it shouldn't be too much trouble. Let me know if you run into issues.

★ Like

Jon Sump[ter
on **October 8, 2017 at 5:24 pm** said:

Dan,
Great work. I am wondering how your STM will work with biological specimens? I would love to get up close and personal with some nematodes. As usual buying my own STM is way out of the question. I think i can afford your design.
Jon S. Waldport Oregon

★ Liked by 1 person

Dan Berard
on **November 12, 2017 at 11:22 pm** said:

Hi Jon,

Sorry for the late reply! Unfortunately STM isn't suitable for imaging something the size of a nematode. The scan range of an STM is typically only ~1-10 um or so. The sample also needs to be conductive (or a single molecular insulating layer on a conductive surface). Sounds like an optical microscope of SEM would be more useful.

Best,
Dan

★ Like

David D
on **September 6, 2017 at 1:44 am** said:

Hi Dan,
I just wanted to take a moment to thank you for documenting your work on your STM. I'm happy to say that I just got mine up and running too. I made the scanner several years ago, and it's just been sitting on my desk until this week. I'm imaging gold plated connector contacts. It's amazing how well this fairly simple machine works.

★ Like

Dan Berard
on **September 9, 2017 at 1:06 pm** said:

Hi David,
That's awesome to hear! I'd love to see the results if you can share them!
Cheers,
Dan

★ Like

David D
on **September 9, 2017 at 1:26 pm** said:

I wanted to share some results and attach pictures to my post, but I don't see that option. Any way to do that?
Also, I was wondering if you could share typical scope captures of your Z and error signals during scanning. My setup is having some trouble keeping the error steady during scans — especially the faster scans.

★ Like

Dan Berard
on **September 9, 2017 at 1:48 pm** said:

you want to see. Don't worry too much if the error signal seems to be jumping around a lot.
For faster scans you're ultimately limited by the scanner rigidity, and I find that for a ~1 um scan I get good images around a 1 Hz line rate or lower. Keep in mind most of the images I've posted here are of very smooth samples, so you might find you need to slow it down a bit. Try 0.5 Hz, and set the P-gain to zero to start, then adjust the I-gain to maximize image detail. If you start seeing oscillations in the tunneling current signal, lower the I-gain. If the image is a complete mess, the I-gain might be way too low which can cause a crash, and you might need to change tips.

★ Like

David D
on **September 10, 2017 at 12:54 pm** said:

Hi Dan,
You can see a couple of the scans here:
https://1drv.ms/i/s!AtFzHNfhgozuap6v1dKLwJJfBkA
Next, I'm going to work on improving the mechanics.
Thanks! -David

★ Liked by 1 person

Dan Berard
on **September 17, 2017 at 12:05 pm** said:

That's awesome! 20 Hz is a bit fast for a scan that size, you should be able to get more detailed height images if you slow it down to ~1-5 Hz or so.

★ Like

on **October 15, 2015 at 10:38 am** said:

Whoops, sorry! Should be fixed now.

★ Like

Gabriel
on **November 17, 2016 at 11:32 am** said:

The download link of the software is not working. Please, fix it, we admire your work.

★ Like

Dan Berard
on **November 17, 2016 at 12:29 pm** said:

Hi Gabriel,
Which file are you having trouble with? They're all working fine for me. Each link should allow you to download the corresponding files via Google Drive.

★ Like