

FTIR multi-touch display how-to guide

(alpha version 0.2)



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Introduction

My name is Harry van der Veen, callsign Gravano.

I'm a 25 year old Communication & Multimedia Design student, located at the NHL (Noordelijke Hogeschool Leeuwarden) in Leeuwarden (Holland), participating in the fourth and final year of that education.

I'm writing this FTIR multi-touch display how-to guide, because I want to make it easier for other people to build their own multi-touch display.

My intensions are to make this guide understandable for people, in the age of approximately twelve to about seventy years.

I would like to point out, that in this guide, I describe "a way" to build a multi-touch display. I'm not saying it's THE way. There are numerous of ways to build screens, this is just one of them.

There's nothing you should know about any difficult technologies. I'll try to explain everything as simple and thorough as possible.

Only thing you must be able to is, actually buy or own the materials and have some basic handyman's work skills like drilling, sanding, sawing, polish. If have two left hands myself and even I succeeded, so you should be fine.

After walking through this guide, you should be able to understand the technology behind this project and be able to build your own multi-touch display, to let it collaborate with your own computer.

This is only possible with the appropriate software.
Only the hardware is discussed in this guide.

There's the possibility, to write your own software for the multi-touch display.
This however, is a whole different aspect. Which as mentioned above, is not discussed on this paper.

When finished with this guide, you'll have a general understanding of why which materials are being used and what the alternatives are.

By this way I would also like to thank everybody from the NUIgroup (Natural User Interface) open source multi touch community, for all their efforts and contributions.

I hope you enjoy this guide and that you have a working multi-touch display as well in no time, so you can collaborate with us inside our community.

If you have any questions or suggestions, feel free to contact me at harryvdveen@gmail.com

If you're looking for more information regarding this subject, visit our community

Blog: <http://www.nuigroup.com>

Wiki <http://www.nuigroup.com/wiki/>

Forum <http://www.nuigroup.com/forums/>

Join us on irc.freenode.net on #tir

Or drop by on my personal blog, located at: <http://www.multitouch.nl>

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Requirements

Tools

Power drill + 5mm drill
Standard size screwdriver (flathead & cross)
Small sharp knife
Scissors
Different grits of sanding paper
Wooden cubical object to wrap sanding paper around
Copper or silver polish + towel
Synthetic material saw

Building materials

Screws	€ 5
Glue (hotglue / white glue)	€ 10
Frame material (for example wood, aluminium or PVC)	€ 5 (depends on construction)
Connector strips	€ 5
Electronic wire (0,5 mm)	€ 5
IR-LEDs + resistors	€ 30
Acrylic also known as plexiglas	€ 25
Black photo negatives	€ 5
Power source	€ 10
Power cable	€ 5
Webcam	€ 15
Projector	€ 200+
Projection material (tracing paper)	€ 5
Silicone rubber	€ unknown (35 max)
Working computer	
Mirror (optionally)	

So basically the projector is the most expensive part of the device. You can make a multi touch display without a projector and use your monitor as an output, which is like totally not cool ;)

So for an amount of about € 350, you'll be able to build a cool multi touch display.

You could also go with a more expensive webcam, filter or projection material, for better performance, but for the proof of concept, this will do.

Software

Computer applications are necessary to communicate between a multi touch display and a computer. These applications can be developed within several languages / programming environments. For example: Processing (P5), VVVV, Flash, C, C++, Java and others.

Because of the usability of certain API's and the relatively simple visualisation possibilities, I reckon P5, VVVV or Flash 9, in combination with Actionscript 3.0.

The above can be downloaded from the following locations:

Processing (P5) - <http://www.processing.org>
VVVV - <http://www.vvvv.org>
Adobe Flash 9 - <http://www.adobe.com/nl/downloads/>

Applications built within these API's, are freely available, on the forum of the online Open Source Multi-touch Community, called NUIgroup (Natural User Interface), located at:
<http://www.nuigroup.com/forums/>

Technology explanation

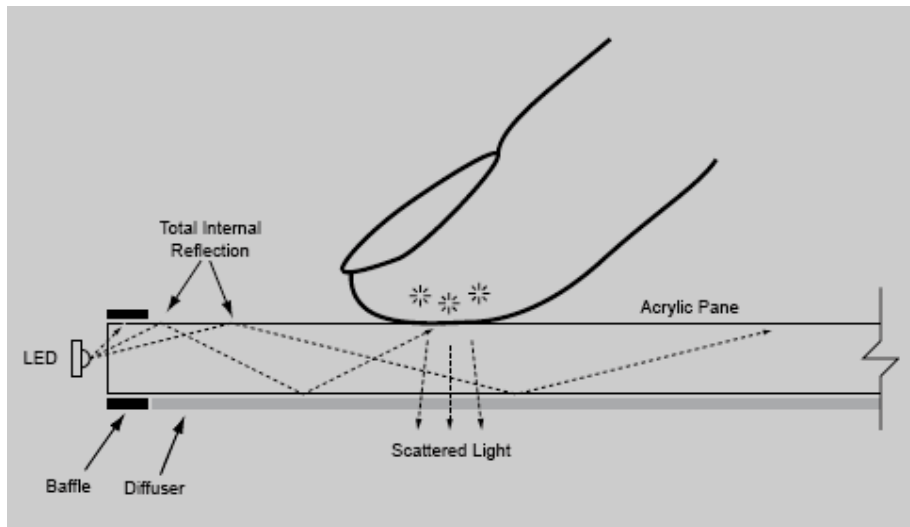


Image 1: FTIR explanation © Jeff Han

The applied technology, within this project, is called FTIR (Frustrated Total Internal Reflection). FTIR describes the internal reflection of light, inside a certain material. In our case, it will be infrared light, that internally reflects inside is a piece of acrylic, also known as plexiglas.

IR-LEDs (Light Emitting Diodes) are placed along the edges of the acrylic.

This way, infrared light is beamed inside the acrylic and reflects internally.

In a simple way, you can say that, IR-light bounces inside the acrylic, from one side to another.

As soon as a finger touches the acrylic surface, the internal reflection of the IR-light, is interrupted.

The infrared light scatters on the finger tips.

Infrared light is invisible to the human eye, but by placing an infrared camera behind the acrylic your fingertips will be visible on the infrared camera.

The images that are generated by the camera, contain white blobs (caused by the fingertips).

These blobs will be analyzed by software.

Every blob corresponds to certain coordinates.

Software can by analyzing these coordinates perform certain tasks, for example move, resize or rotate objects.

There's also a projector located behind to acrylic, that's connected to a computer that projects the image.

A rear projection screen is located just underneath or above the acrylic, to project the image on.

Global building process

The building process consists of the following 5 main elements

Modifying a webcam

A normal webcam will be modified to a webcam that can detect IR-light.
The IR-block filter inside the webcam will be replaced by an IR-pass filter.

Treating acrylic

The treatment of the acrylic will be discussed.
Our main objectives will be sawing, sanding and polishing.

Building a frame

The build of a frame will be mentioned. What material to use etcetera.

Wiring an electronic circuit

There will be an explanation about how to create an electronic circuit containing LEDs, resistors, power supply and wires.

Projection

Here you will find information on what kind of projection material and beamer you can use and how to make a silicone rubber sheet as a coupling layer between the acrylic and the projection screen.

Detailed building process / material information

Modifying a webcam

Needed material:

- webcam
- lens
- black photo negative
- tape, glue or any other material that can hold the black photo negative in place

Modification of a webcam is necessary to detect the IR blobs that are generated by your fingers. IR is not visible to the human eye, neither is it to most of the webcams. Some webcam's detect IR, but not as clear as it should be, for this project.

Every webcam can detect IR, but this option is not available because, there's an IR-block filter inside the webcam that blocks IR. So the camera is able to detect all visible light, but not the IR.

To see to it, that the webcam detects the IR, we need to remove the IR-block filter from the webcam. So it will detect all visible light including IR.

For removing this IR-block filter, we have two options:

- removing the IR-block filter manually
- replace the current lens with another lens that has no IR-block filter

With some webcams it's relatively easy to remove the IR-block filter.

For my first multi touch display, I used a cheap (€ 10/15) Sweex webcam ([Sweex WC001 webcam](#)), that had a IR-block filter in front of the lens. I broke the IR-block filter (some sort of glas material), so I could remove it.



Image 2: A Sweex WC001 webcam

In some cases the IR-block filter is painted on the lens and you can scratch it off. But be careful that you don't leave scratches on the lens.

But in most cases, it's impossible to remove the IR-block filter, without damaging the lens, because it's glued to the lens.

In that case, it's wise to replace the default lens with a special lens that doesn't have a IR-block filter attached to it. Try to find a lens that looks like the one below.



Image 3 : The 4.3MM CCTV Camera board Lens IR DVR

Lens specifications:

- Glass Lens
- Aperture F/1.8
- Image format 1/3 inch
- Angel of view 68°
- M12x0.5 mount
- Size ?14x14.75

\$14.99 + \$8.50 (shipping) = \$23.49 total

In my example, I used a Philips SPC900NC webcam, which has a difficult to remove IR-block filter attached to the lens. That's why I choose to buy and replace the default lens, with a special lens, from ebay, without IR-block filter. It's a 4.3MM CCTV Camera board Lens IR DVR.



Image 4 : The 4.3MM CCTV Camera board Lens IR DVR without IR-block filter and Philips SPC900NC webcam.

Once the webcam is modified to being able to see normal light as well as IR-light, you need to apply an IR-pass filter. This IR-pass filter, lets all the IR through, but blocks out most of the visible light.

There are different materials that you can use for this purpose:

- IR-pass filter
- IR-band pass filter
- Remote control filter
- Black photo negatives

IR-pass filter



Image 5: An IR-pass filter

An IR-pass filter is a special filter that only passes through IR on a certain frequency (760 nm to for example 1000 nm). So it basically blocks out all other light, that's not within that region, that would be most of the visible light.

IR-band pass filter



Image 6: An IR-band pass filter

The IR-band pass filter only passes through IR on a specific frequency.

For example: 880 (nm)

So if you'll use 880 (nm) IR-LEDs and you use an IR-band pass filter of 880 (nm) as well, you'll get the best optical performance, because all the light is blocked out, except for the specific IR from the LEDs.

I haven't tested the IR-pass filter nor the IR-band pass filter, because they are relatively expensive. 80 euro for a IR-band pass filter. But from what I've heard, they work very well.

The IR-band pass filter works better then the IR-pass filter.
Which will hopefully make sense after what I've wrote just above.

Remote control IR filter



Image 7: The front of a remote control

The filter on the front of remote controls (deep dark red/black piece) isn't very handy to work with, because of the different shapes it may have and the result is almost the same as one layer of dark photo negative.

Black photo negatives



Image 8: Photo negatives

So because of a low budget scenario and usability, I reckon you use several layers of entirely black photo negatives. You'll probably know them. They are usually among the negatives of your holiday pictures etcetera. It's those completely dark negatives that appear when pictures are misfabricated. Three layers will do the job nicely. If you use too many layers, your blobs become less visible as well. Attach them in front of your lens.

First you have removed the IR-block filter and then you applied an IR-pass filter. The webcam modification is finished.

You can test your camera by pointing at a money bill or cola. Or by checking if it detects the IR-light from a remote control.



Image 9: 50 euro in infrared



Image 10: Cola is transparent in infrared

Treating acrylic

You'll need the following materials:

- Acrylic also known as Plexiglass
- Sanding paper (for example: grit 100, 200, 400, 600)
- Wooden cubical object to wrap sanding paper around
- Copper or silver polish + towel
- Synthetic material saw

Acrylic will be the material that internally reflects the IR-light.
This material is strong and works very well as an optical waveguide.

You could also use polycarbonate, which has a plus compared to acrylic, namely it's unbreakable.
But the optical waveguide performance is a few percent worse.

You can get acrylic at glass stores, but I found out, that most of the time, you pay ten times the amount, compared to buying it online. So I suggest you buy it online from ebay or equivalent.

If you can get it cheap from a glass store or a handy man's shop, go and ask if they can cut the acrylic in the dimensions you desire, so you don't have to cut or saw it yourself.
In most cases, they can even buff the edges transparent, so you don't have to treat your acrylic at all and you can continue with the next step: **Building a frame.**

Most of the time, acrylic has transparent cut edges when it leaves the factory.

Most people I know made 4:3 ratio multi touch displays. So unless you are going to use a 16:9 ratio projector, to project your image, I suggest you cut your acrylic with a 4:3 ratio as well.

I bought a piece of acrylic (dimensions: 460*900*8 mm) for about 25 euro's from <http://www.marktplaats.nl> (a dutch equivalent of ebay).

I sawed off my piece from that bigger piece. Sizes: 460*320 mm (4:3 ratio) 8mm thick.
8 mm thick is the least you should go with, because the LED's you're going place along the edges, will be 5 mm thick. Especially if you're building larger screens, you want to go with a thicker piece, because it needs to be robust. So even when, you push in the middle, the acrylic doesn't bounce.

If you need to saw your acrylic yourself, at least use the finest saw you can find, so you can try and keep the edges as smooth as possible.

If there's a protective film material on the acrylic, keep it on as long as possible, so you'll prevent the acrylic from being scratched.



Image 11: Transparent acrylic with protective film material, square piece of wood, sanding paper

If you have sanding tools, I suggest you use them, instead of doing it by hand.

Make the edges of the acrylic as transparent as possible, to increase the amount of IR-light beamed into the acrylic

Try to find the highest grits of sanding paper. I believe there's even grit 2000 sanding paper.

Higher grit > finer scratches > better transparency

Wrap the sanding paper around a piece of flat wood, to prevent round and to ensure flat edges

Start off sanding with a low grit sandpaper

Increase the grit step by step (for example 100, 200, 400, 800)

When using the highest grit sandpaper, put olive oil or equivalent, on the edges and continue sanding

Finish the edges by polishing them with copper or silver polish and a towel

When finished, the edges should be pretty transparent.

I sanded all four edges, eventough I'm going to place leds along two sides. This because I want, light that bounces out of the sides, to be able to bounce back easily through the aluminum that I will put along the edges.

I namely experienced IR-light leakage on the sides during my first prototype. That's why I want to bounce the light back into the acrylic.

I decided not to flame polish the edges afterwards, because I thought the edges were already transparent enough and you don't want to accidentally destroy parts of your acrylic.

Because, when you flame polish them wrong, you might create small air bubbles, inside the acrylic or it might turn out black.

Building a frame

During the build of the first proto I found out that I wanted some kind of reflective material against the edges to bounce back leaking IR light. With my first proto I used aluminum tape, but it intends to stick to everything, so basically alot of annoyance.



Image 12: Acrylic in aluminum frame (mount in progress)

So I decided to make an aluminum frame around the acrylic, which can also hold the leds at the same time. It makes your screen look alot better then with shabby tape hanging around.



Image 13: Acrylic mounted in aluminum frame

I used 4 pieces of aluminum rail. 2*50 cm and 2*38 cm both 10 mm (acrylic= 36 * 48 cm, 8mm thick) So the acrylic would stuck inside the aluminum rail perfectly, it seemed it first. Lateron I founded that the rail on one side was a little hard to get around the acrylic, so I used brute force with a hammer.

I sawed of the edges of the aluminum with a 45 degree angle, so they would perfectly fit against eachother.

Afterwards I drolled 5mm holes in the 2 rails that will hold the leds. 10 holes on each rail. I choose 5mm holes so the leds would get stuck pretty good, since the leds theirselves are also 5mm.



Image 14: Drilled holes in aluminum U-frame



Image 15: Drilled holes in aluminum U-frame

Then I placed the leds in the holes to see if I had the wished for result.

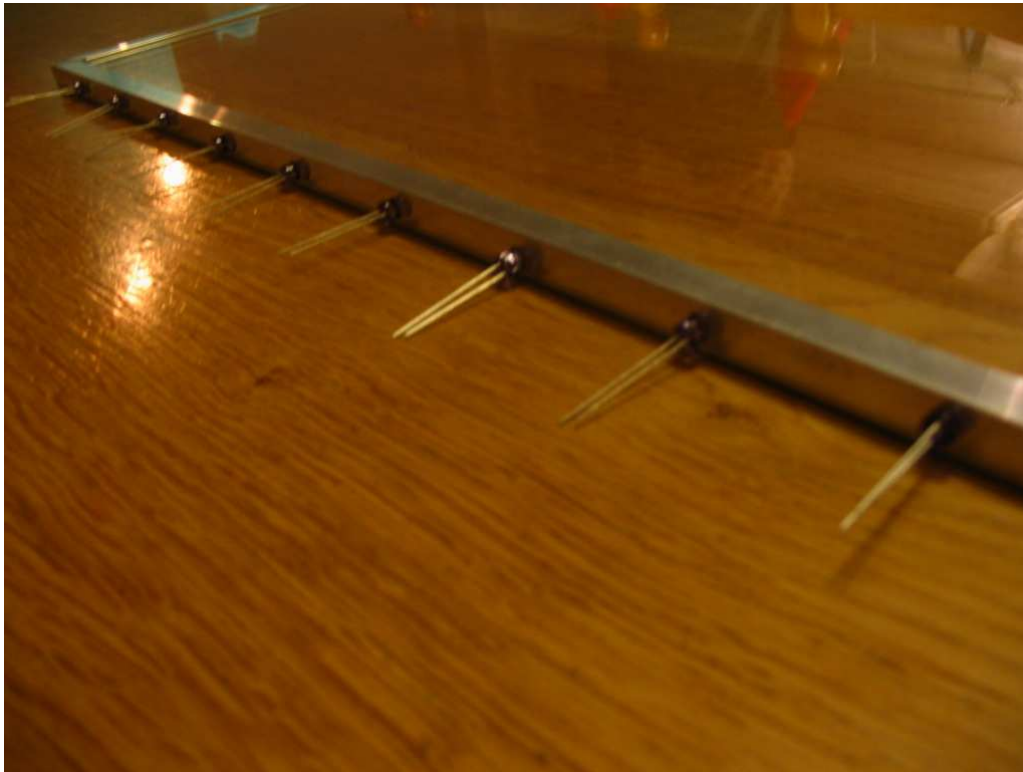


Image 16: Leds put through the drilled holes in the aluminum U-frame

Because of the space inside the aluminum, there's just enough room to hold the head of the led.



Image 17: Wooden frame around the aluminum framed acrylic

My wooden frame has arrived. My uncle makes wooden frames for paintings and since they only cost 5 euro I asked him if he could make one for me. The acrylic/aluminum part leans on the wooden frame on the left and the right side and a little bit on the top and the bottom as well. Notice I have space left on the bottom and the top side to wire the leds and resistors.

Wiring an electronic circuit



Imag 18: IR led powered by a 5 volt USB connection

LEDs (Light Emitting Diodes) need a power source to produce light.

There are several ways to power your LEDs. For example by batteries (1,5 volt), USB (5 volt) or a 12 volt adapter. But you could also connect your led's to the 12 volt molex connector on a computer power supply.

I used 100 (mA) miliampère LEDs, so I needed a pretty good power source.

Using batteries doesn't make alot of sense, since you would need quite a few and you would need alot of wire as well, because of the inefficient power circuits.

Using USB is possible, but I would only choose that option, if you are going to use 20/30 (mA) led's and even than, a computer power supply would make more sense, since you can put more led's in a row.

Why not use a computer powersupply? Your screen is going to be near a 220 volt power source anyway, since you have to use a projector and a computer as well.

You can use one of the molex connectors on the computer you are working on, to supply the leds with power. But you could also use it without the motherboard in between.



Image 19: 6 IR leds powered by a 12 volt molex connector inside a computer

There's a pretty easy solution to hotwire a computer power supply.

If you look at the ATX connector, you see several colored wires:

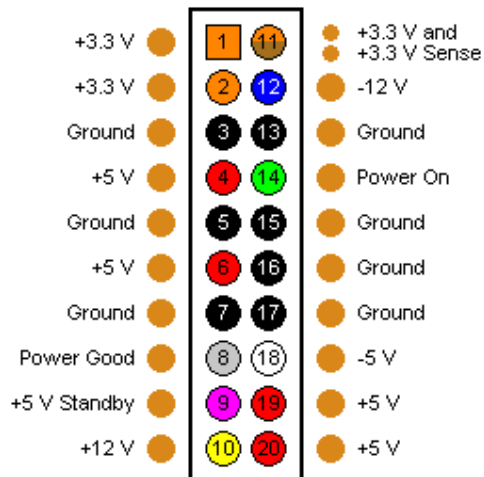


Image 20: ATX connector

To hotwire your computer power supply, simply connect the green wire with any black wire (ground) of the pin out and you will be able to connect your LEDs to one of the molex connectors, without the help of a motherboard, turning the power supply on.

During the build of my first prototype I used 36 [880nm 60 degree 5mm cl IR leds](#) (1,8 V, 20 mA, 11,0 mW/sr).

Lateron I discovered that there were leds that were even better, namely the [Osram SFH485](#), specifications: 1.5 V 100(mA) 880 (nm) 5mm. These were a bit more expensive but more powerful, so I would be able to use less leds.



Image 21: An Osram SFH485 IR LED

I decided to go with 10 leds on both horizontal sides, so 20 leds in total.

After filling in the specifications of the power source and the leds in this [led wizard](#) , I found out that, I had to make 4 strings of 5 leds, each with a 47 Ohm resistor of 1 Watt. An electronics teacher at school gave me a few 51 Ohm resistors of 4 or 5 Watt. He told me that would do the job pretty well, since the higher Watt was only about the amount of heat that a resistor could handle. So it would just handle an higher amount of heat without influencing the brightness of the leds. And the difference of 4 Ohm (51-47) was not noticeable, according to him.

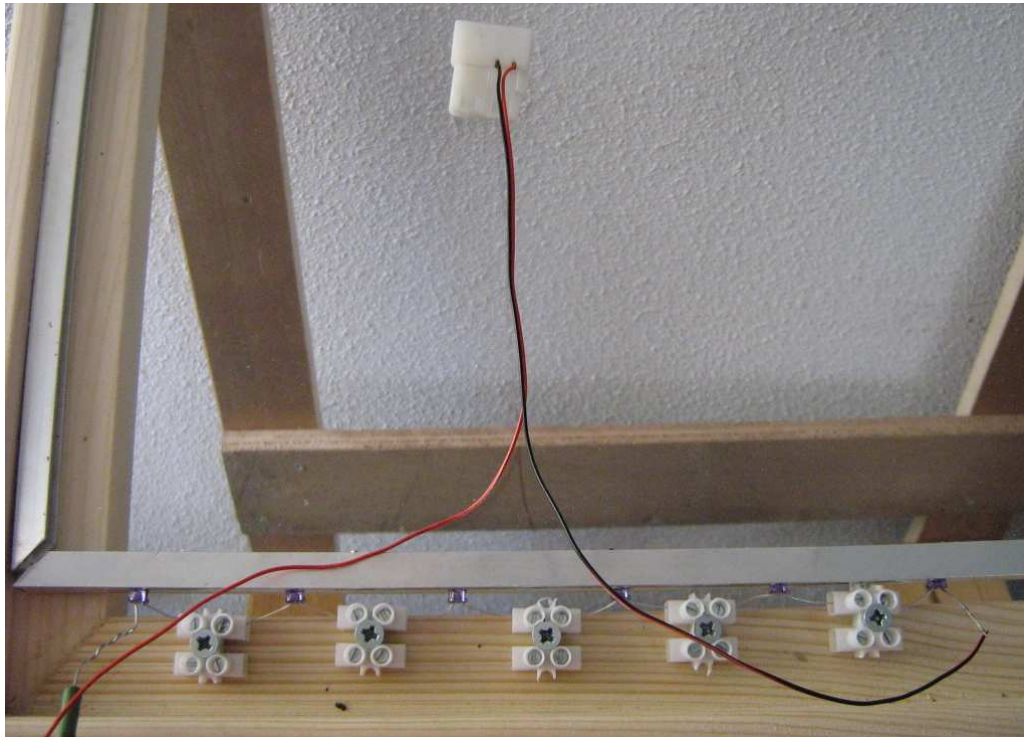


Image 22: 6 connected leds for testing purposes. Green thing in the lower left corner is a resistor.

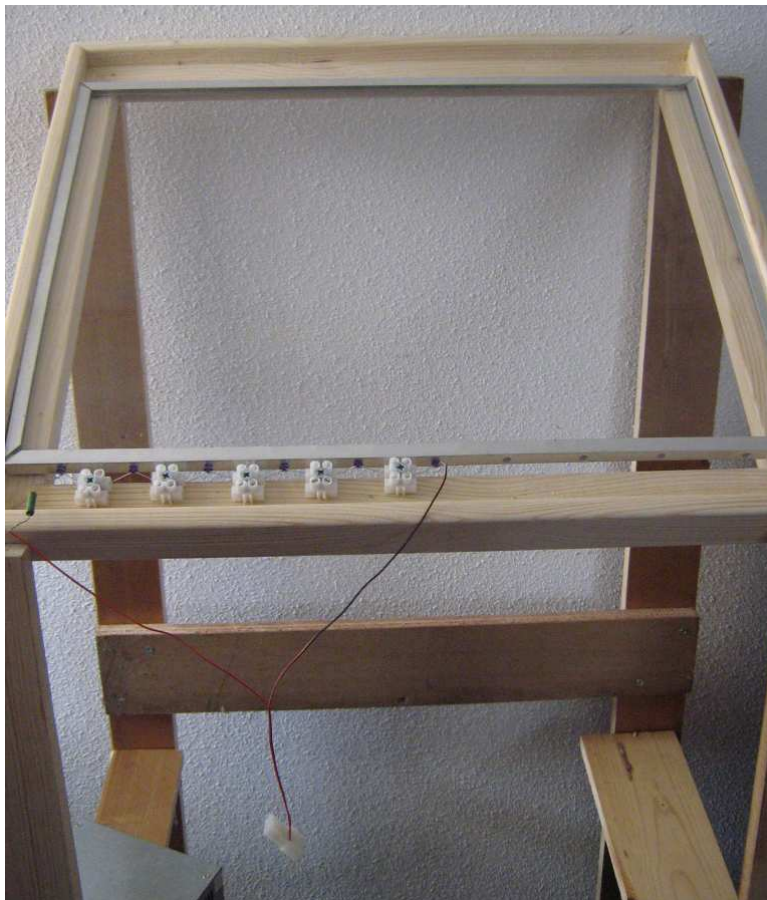


Image 23: 6 connected leds for testing purposes

I connected the leds on 2 different molex connectors (12 volt), but I might as well have gotten around with just using one.

I just happened to have 2 molex connectors, so I used 2 (which is pretty useless actually).

The wires I used were pretty short, so you might want to use longer ones, so it will be more flexible. I used 0,5 mm thick wire.

I did the entire circuit without soldering, for a change, which seemed to work just fine. So why spend a lot of time on soldering if you can do without.

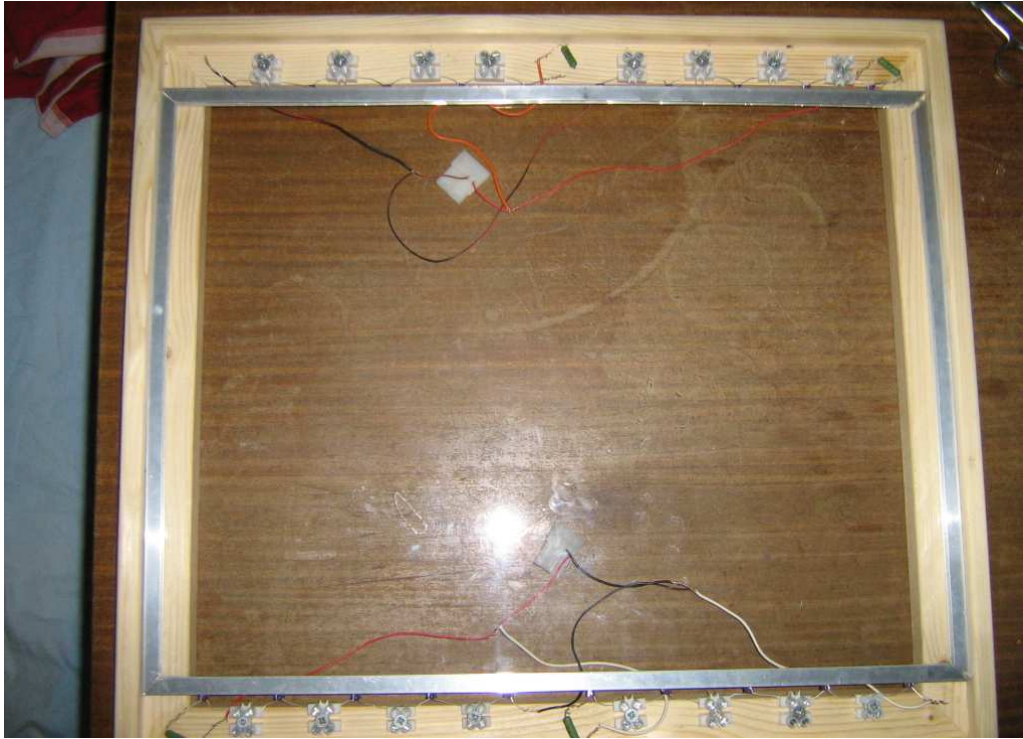


Image 24: Front of screen

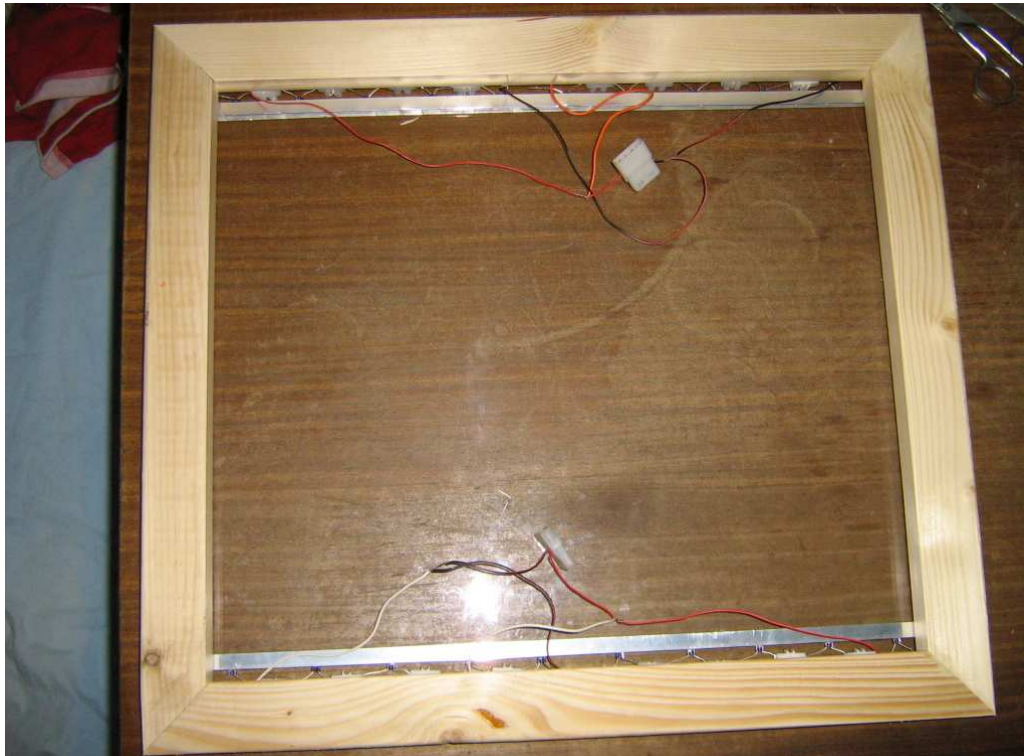


Image 25: Back of screen

I connected the leds with each other by using strip connectors ("kroonsteentjes" in Dutch).

My first intention was to do the entire setup without the strip connectors and just let the holes in the aluminum rail hold the leds. But because of the fact that some holes were a bit to big (matter of tens of a millimeter) to hold the leds pretty steady, I decided to use the strips anyway, because else the leds would be too loose.

You might as well go for the solution below, which is a solderless ledholder. You can easily click the led into this holder, so you won't be bothered with soldering anything.



Image 26: Solderless led holder

After connecting all the leds I tested the entire setup by checking for fingers on the computer (image below).

Which seemed to work pretty fine.

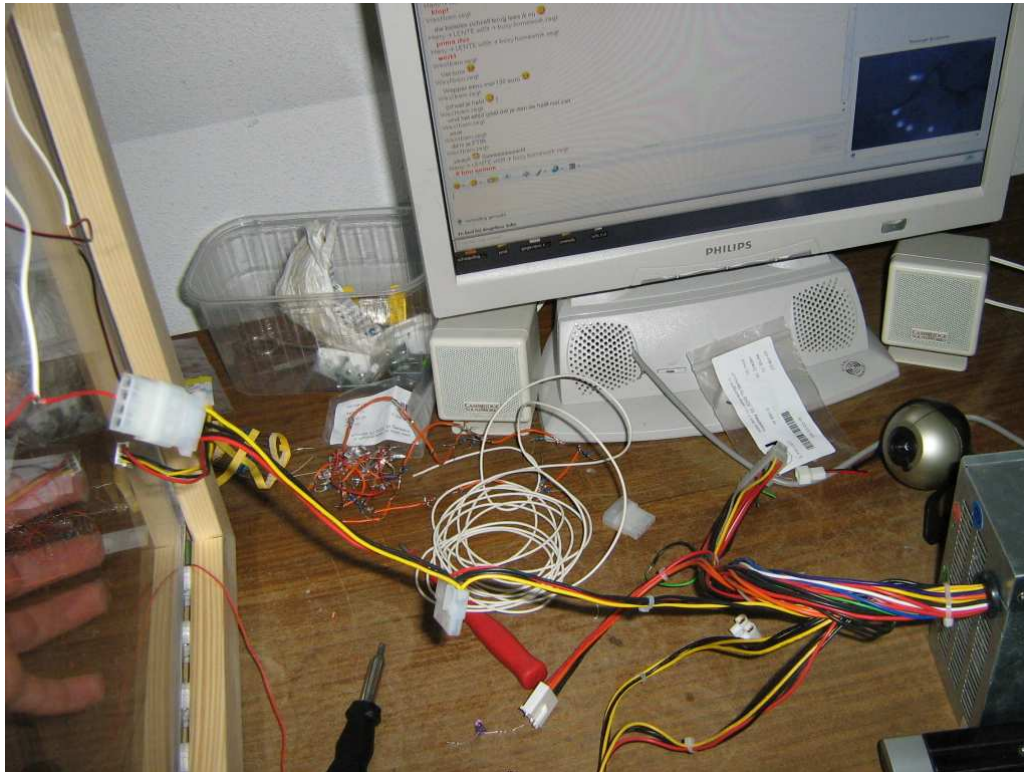


Image 27: hand placed on screen, detected by webcam, displayed on monitor, power supplied by computer power supply (molex 12 volt)

Note:

With most leds the longest pin of the led, is the plus and the short one is the minus.
But with these leds (Osram sfh485) it was the other way around.

Projection

To project the image from a computer, you'll need a projector and a projection screen.

The projector beams an image on a projection screen, that is placed underneath or on top of the acrylic.

A plus of placing the projection screen material on top of the acrylic is that you can directly interact with the image. There is no visual imperfection contrary to placing the projection material underneath the acrylic. If you place it underneath the acrylic you'll still have to optical difference of the thickness of the acrylic. In this case you can also let the projection screen function as an ambient IR block filter, but more about this lateron.

In case you want a closed box solution for your multi touch, you may want to consider using a mirror to reflect the image that comes from the projector, so you can shorten the distance. Keep in mind that there can be ghosts images (vague double projections), caused by the acrylic bouncing back the image to the mirror and back to the acrylic again.

Projection screen material

There are different materials you can use as a projection screen:

- Rosco grey rear projection screen
- Mylar
- Tracing paper

And I bet there are tons of other materials you can project on. For the project I did in Sweden we used some kind of white plastic paper material which they use to make designer lamps.

Rosco grey is a very good projection screen, but it blocks IR, and it therefor diffuses the blobs, if you place it underneath the acrylic, and makes them rather unusable for software analysis.

If you place it on top of the acrylic the blobs are a bit less vague, but still very diffuse, because there's no good coupling between the acrylic and the Rosco.

Furthermore Rosco is relatively expensive compared to the other two materials.



Image 28: Piece of Rosco grey on top of my first prototype

The cheapest solution is tracing paper.

But since you want your multitouch display to work in all kinds of environments, don't want ambient infrared light to interfere with it. Therefore you have to use a projection material on top of the acrylic that blocks IR. Rosco grey is one of those rear projection screen materials.

Silicone rubber

The problem with placing the Rosco grey on the bare acrylic is, that it hardly generates usable blobs. The blobs are pretty vague because of the bad coupling between the acrylic and the projection material.

You have to press pretty hard to generate a workable blob. And that's not something you want. This has to do with physics. It's about relative index of refraction. For example, when you touch the acrylic with your bare fingers, there is still some miniscule air in the space between the acrylic and your fingers. So when you wetten your fingers, these miniscule air holes get filled, so your finger has a better coupling with the acrylic. This way the blobs are brighter with wet fingers opposed to dry fingers. Therefore we needed to find a material that prevented those small airholes as much as possible, so that there would be a better coupling, resulting in brighter more clear blobs.

A lot of people within the NUIgroup community have experimented with different materials and we got pushed in the direction of silicone rubber being the best solution to this problem.

Here at the university in Sweden we made two samples of silicone rubbers sheets, a 1mm and a 2mm thick. The 1mm thick sample worked better, since the blobs were brighter. We haven't tried thinner sheets, but 0,5 mm may even work better. But that's all up to you if you want to experiment with that.

Material details

The silicone rubber sheet we prepared are made out of 2 fluids that you combine and then they cure over time. The fluids come from a company named Wacker Chemie AG. Their website is located here: <http://www.wacker.com>

This company only sells these products in amounts of 20 kg's. But since we are doing research for Lulea University of Technology (Sweden), we have a supplier that cuts the 20 kg amounts into smaller pieces. So we were able to order just one kg.

The company that divided the 20 kg's into smaller amounts, is called ABIC Kemi.

The brand of fluids we used go by the name of ELASTOSIL® M 4641.

ELASTOSIL® M 4641 is a pourable, addition-curing, two-part silicone rubber that cures at room temperature.

Special characteristics

- Very good flow properties
- Fast and non-shrink cure at room temperature which can be accelerated considerably by the application of heat
- Medium hardness (Shore A approx. 43)
- Good transparency of the cured rubber
- High tear strength
- Outstanding resistance to casting resins, particularly polyurethanes and epoxies, for long service life of the molds

You can download a PDF with more specifications [here](#). (English version)

Or download a German version, [here](#).

Making a silicone rubber sheet

- First you have to make a frame of some kind that will hold the acrylic in place and that has some kind of border that is 1 mm higher than the height of the acrylic, when you placed it in the frame.
- Then you have to decide on how much silicone rubber you want to use.
- Afterwards you weigh and mix the two components and stir them until they are properly mixed.
- Pour the silicone rubber liquid onto the acrylic and divide it with an object (a plastic knife or so).
- Immediately when you equally divided the liquid, flatten it by using a strip of material (preferable **NOT** metal, PVC might work)
- Now let it cure several hours (14 hours with our liquid).

The longer the curing process the smaller the chance of bubbles in the silicone rubber sheet. We didn't have any bubbles anyway on our 1mm thick piece.

Make sure you let it cure in a place that's not very dusty or cover the setup while curing.

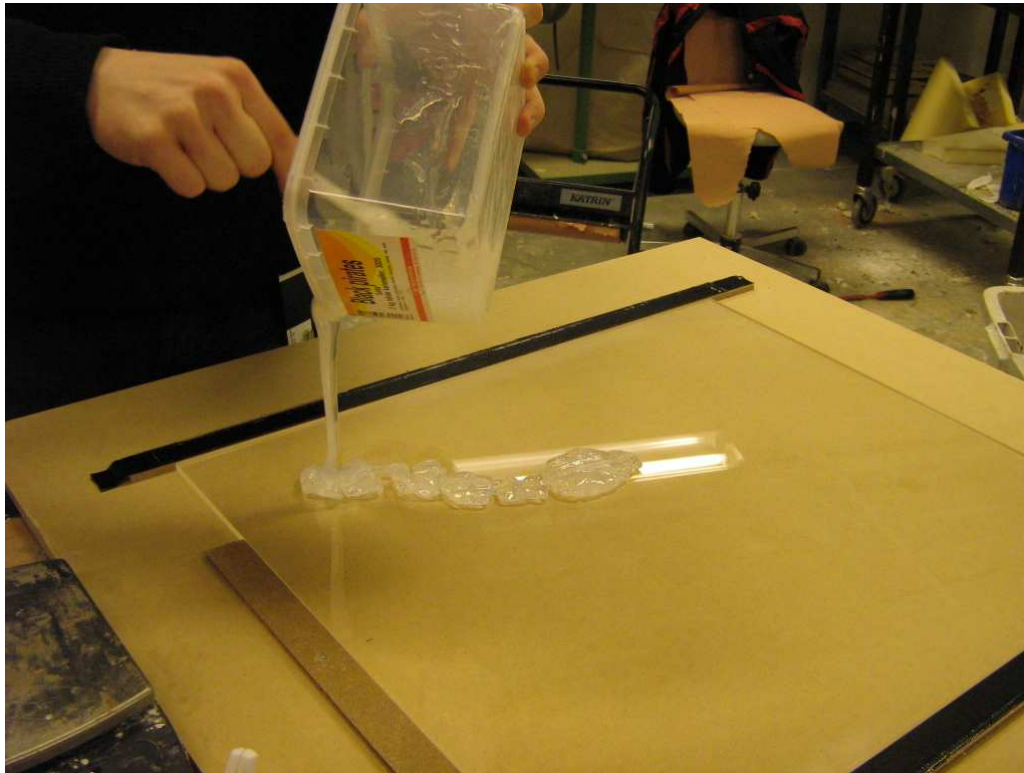


Image 29: Pouring the silicone rubber liquid onto the bare acrylic



Image 30: Dividing the silicone rubber over the entire acrylic surface

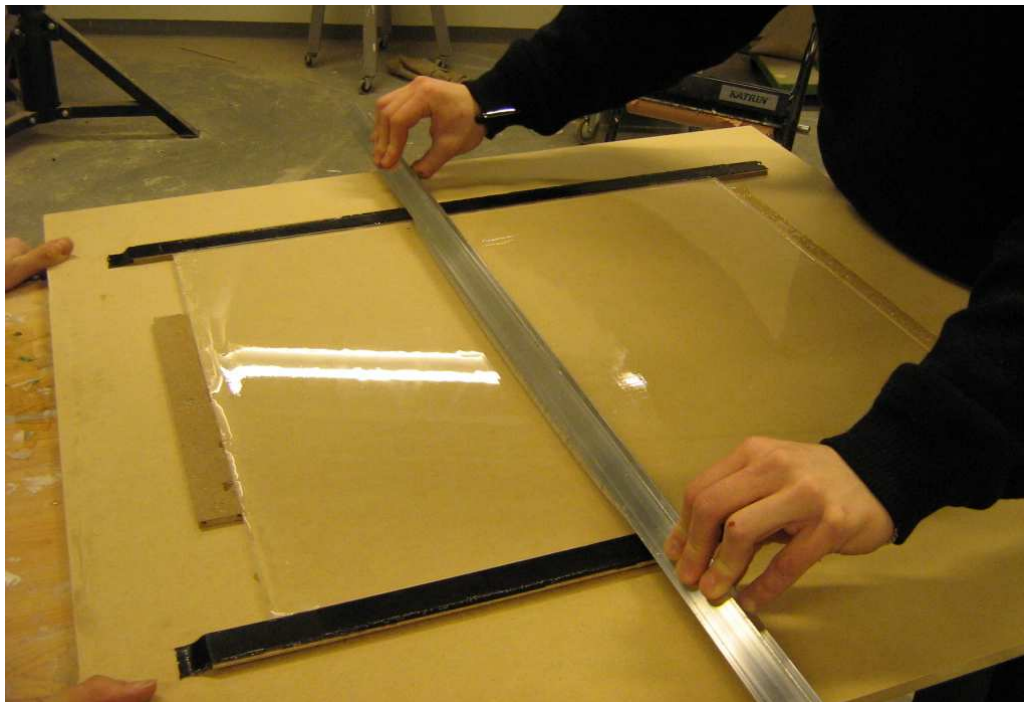


Image 31: Flatten the silicone rubber surface with a strip

Now the silicone rubber sheet that's placed between the acrylic and the projection screen material is finished. Now just cover it with a piece of projection material and you should be good to go. Make sure you test what side of the projection material up, creates brighter blobs, there's a difference! With the Rosco one side on top is different to the other side on top.

The layering is like this:

Acrylic with the silicone rubber sheet on top of that. On top of the silicone rubber sheet you place a projection screen. Make sure the projection screen doesn't stick to the silicone rubber sheet, because otherwise the fir effect will be set off.

So basically it looks like this:

- your fingers
- projection screen
- silicone rubber sheet
- acrylic
- image source

Projector

What kind of projector you want to use, is all up to you.

You can choose a HD-projector, LED-projector or even a 16:9 projector.

But keep in mind, that with this guide I used a "normal" 4:3 ratio projector.

You don't have to use a projector. You could also just go with the entire setup without projector and projection screen and navigate with the multi-touch display and look at the output on the monitor of your computer.

In case you want to work with a projector and don't have enough room to properly project the image on the projection screen. You might want to use a mirror to redirect the image.



Image 32: Redirecting the beamed image with a mirror.