# OPENAR 2.0 DOCUMENTATION

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**CHAPTER 1. How OpenAR 2.0 -glasses work** 2
1.1 Optical setup 2
1.2 3D printed parts 3
1.3 Reflective glasses and the lens-mirror package 3
1.4 Electronics 4
**CHAPTER 2. Building OpenAR 2.0 -glasses** 5
2.1 3D printed parts 5
2.2 Optical components 6
2.3 Assembling the 3D printed parts 12
2.3 Electronic components 16
**CHAPTER 3. Demo program and glass alignment** 19
3.1 Installing the demo program 19
3.2 Aligning the reflective glasses 21

# CHAPTER 1
## How OpenAR -glasses work

The philosophy behind OpenAR is a Do-It-Yourself augmented reality glasses, that can be freely modified and built by anyone who so chooses. This document explains how OpenAR 2.0 -glasses work and how to they were built. Anyone who is willing to spend some time tinkering with 3D printing, electronics and with the straight-forward optical setup can build them. All the 3D models and code that were created for OpenAR -glasses are open access.

### 1.1 Optical setup

OpenAR -glasses rely on reflections of light, like many other augmented reality devices. The light from a programmable LCD screen propagates in the optical system and eventually reaches the eyes of the user. The optical setup consists of an electronic LCD screen, two thin glass planes that are used for reflecting the light, a lens, and a small mirror. The optical setup is shown in image 1.1 below.

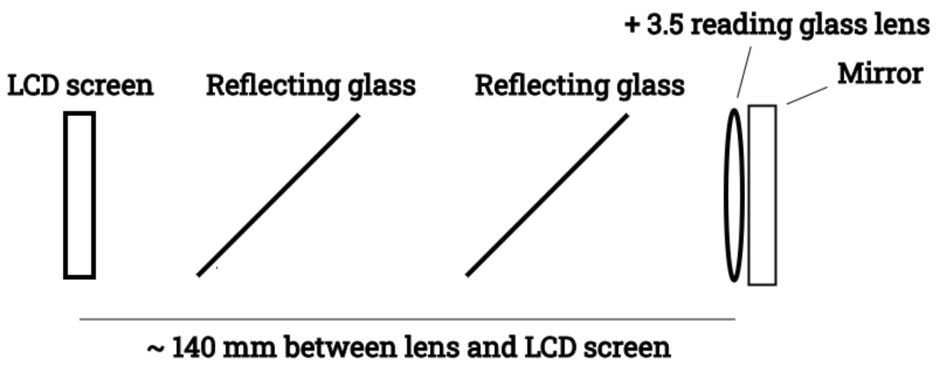


**Image 1.1.** A top-down look at the optical setup of the OpenAR -glasses. Note that the distance between the screen and the lens is dependent on the diopter of the lens.

Looking at the image above, we can see that the two reflecting glasses are placed at a 45-degree angle. The light rays coming from the LCD screen go mostly through the reflecting glasses. Then, the rays reach the lens and the mirror where the rays become collimated. Meaning they all are parallel to each other. Next, the light rays propagate through the optical setup again, but due to the reflecting glasses, a portion of the light rays reflect towards the eyes of the user (which are located at the bottom of the image).

It is important to note that the focal point of the lens is halved due to the mirror. Further, the LCD screen is located at the focal point of the lens. This, and the collimated light rays, allows for a clear and sharp image to be reflected at the user's eyes. Around 6 % of the light emitted from the LCD screen reach the right eye and around 5 % reach the left eye.

OpenAR 2.0 also features stereo vision. This is achieved by rotating the reflection glasses inwards and outwards with a bolt and a small spring. The bolt pushes two levers that the reflection glasses are connected to, creating an impression that the image formed by the electronic display is moving closer and further to the user.

## 1.2 3D printed parts

Most of the work to build the OpenAR -glasses is done by 3D printers. All the 3D models used are available for anyone to print or to modify for their own needs. Modifying the models is most likely required, if you are using different electronics, than what were used to build OpenAR 2.0.

Please refer to the downloadable files to view, edit and read about the function of the printable 3D models.

The 3D models were designed using Fusion 360 and the shared files are .f3d and .stl format. All models were printed with a Bambu Lab X1-Carbon 3D printer, using PLA Basic filament with default settings. Bambu Studio was used for slicing and supports were enabled where necessary.

## 1.3 Reflective glasses and the lens-mirror package

For the optical setup, you need to get two thin rectangular glass planes for the reflective glasses, a simple lens from a pair of reading glasses for example, and a piece of a mirror. For OpenAR 2.0, we measured and cut two glass planes. The thinner the glass the better. We bought a pair of cheap reading glasses from a local hardware store and for the mirror we bought a simple make-up mirror.

The specific dimensions and the methods to build the optical setup is in chapter 2.

### 1.4 Electronics

The following electronic components are needed/were used for OpenAR 2.0.

| | OpenAR 2.0 |
|---|---|
| **Rechargeable battery with a battery protection circuit** | Lithium-Polymer rechargeable battery 3.7V 1500 mAh (Has to have charging current of at least 1 A and a built-in battery protection circuit) |
| **CPU board** | STM32 Blue Pill |
| **USB charger board** | Micro USB charger board |
| **Switch** | |
| **Electronic display** | TFT 240x240 1.3-inch LCD display |
| **Power cable for display** | Self-made |
| **Voltage regulator circuit** | Self-made |
| **Voltage distributor circuit** | Self-made |
| **Programming tool for CPU board** | ST-LINK V2 |

The battery powers the whole circuit, and it can be recharged with the USB charger board. OpenAR 2.0 was built for a MICRO USB charger board, but modifying the 3D models to fit a MINI USB is also a possibility.

Important! Most USB charger boards supply a charging current of 1 A. This means that the battery used should have a capacity of at least 1000 mAh with battery protection circuit built-in! The charging current can be adjusted, but it is not recommended. If you know how to adjust it, then it will be no problem. If you don't, then stick with a 1000 mAh or higher capacity battery which can withstand a 1 A charging current.

The CPU board runs the programmable electronic display which draws whatever it is programmed to draw. The light from the display eventually reaches the user's eyes through the optical setup. The voltage regulator is needed, so that the CPU board has a steady amount of power to operate while OpenAR -glasses are in use. The voltage regulator circuit also includes a circuit to monitor the battery voltage. This connects to the CPU board, so that the current battery voltage can be drawn on to the electronic display (this is optional). Switch is, of course, to turn the system on and off. The voltage distributor circuit is optional, but it is useful in case more electronics are added.

All the electronics, except for the electronic display, are installed onto the OpenAR headband.

For OpenAR 2.0, a simple demo program was made for demonstration purposes and as a proof of concept. You need a programming tool like the ST-LINK V2 to install the demo program to the CPU board. The demo program is included in the documentation folder.

Guide to make the electronic circuit and its installation is in chapter 2.

# CHAPTER 2
# Building OpenAR 2.0 -glasses

These are the following items and tools that are needed/were used to build OpenAR 2.0

- 20 x M3 and 5 x M2 bolts
- 4 x M3 nuts
- Threading drill heads
- Epoxy glue
- UV glue (optional)
- Double sided tape
- A small compression spring (from a pen)
- Nylon straps (for head support)
- Rectangular piece of polycarbonate (optional)
- Glass cutting tool
- A whetstone or some other grinding tool
- Rectangular glass planes
- A lens from reading glasses (+ 3.5 diopter)
- Rectangular piece of a mirror
- Soldering iron and tin
- Electrical wire
- Soldering perfboard (for voltage regulator and voltage distributor circuits)
- ST-LINK V2 Programmer or other programming tool
- A 3D printer

## 2.1 3D printed parts

This is the simplest step in building OpenAR 2.0 -glasses. In the folder “OpenAR 2.0” you can find images and descriptions for all the 3D printed parts. It is recommended to get familiar with the different parts. You can also look at the .f3d files and see how all the parts connect. You can also find the 3D models in .stl format in the folder “Models ready for 3D-printing”. You can choose to print (most of) them all at once or individually.

Note, that if you are using different electronic components, then you might need to slightly modify the 3D models. However, if you are using the same components that are in OpenAR 2.0, then you may not need to modify anything.

Be sure to modify both right and left “glass grabber” -models, if you are using something other than 1.9 mm thick glass for the reflection glasses!

Read the README text files to know which parts need threads. All threads are either M3 or M2.

## 2.2 Optical components

Next, we will go through process of making the two reflecting glasses and the lens-mirror package.

**Image 2.1.** Glass planes of different thickness found in our workshop.

Any transparent glass will work, though the thinner it is the better. In this case, we decided to use 1.24 mm glass. This means that we need to modify the right and left “glass grabber” -models to properly fit the glass into the parts.

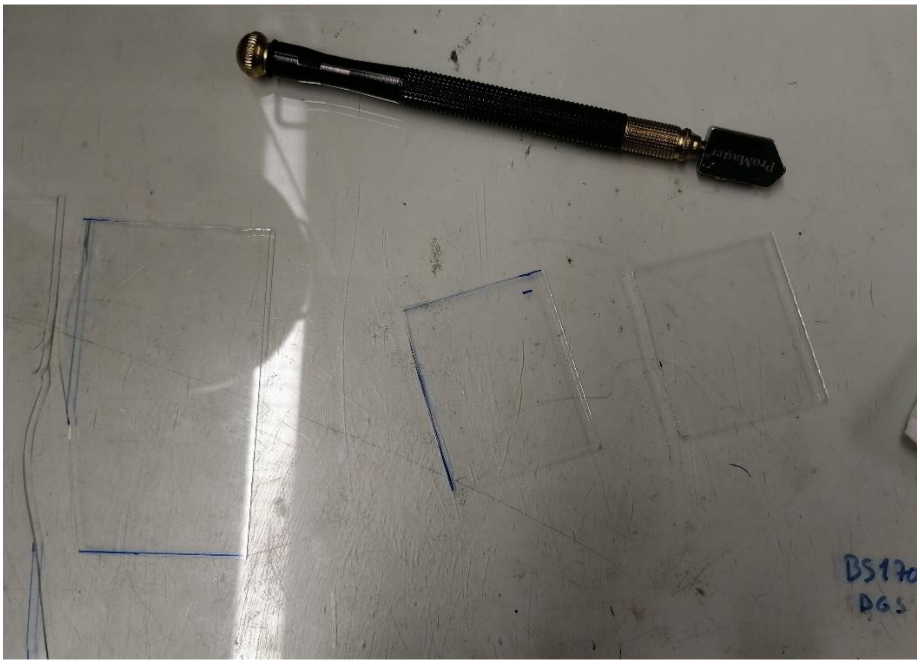

**Image 2.2.** The reflection glasses cut from the bigger glass plane.

You need a tool to cut the glass into smaller rectangles. Aim for a size of about 55 x 45 mm.

**Image 2.3.** Whetstone used to grind the sharp edges of the glasses.

You should grind the sharp edges of the glasses with a whetstone or with some other grinding tool. This makes the glasses much safer to handle.

The same process is done for the mirror.

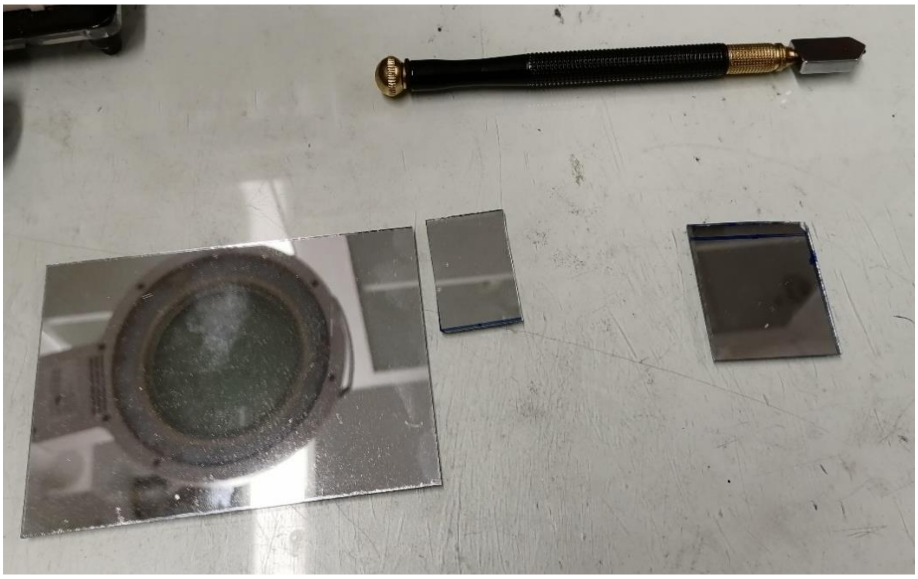

**Image 2.4.** Rectangular mirror piece cut from a make-up mirror.

We used a simple make-up mirror to cut the rectangular piece from. You should aim for a size of 38 x 45 mm.

**Image 2.5.** Removing sharp edges with a whetstone from the mirror.

The edges of the mirror should be grinded with a whetstone. This should be done carefully, as to not scratch the mirror.

For the lens, we bought a pair of cheap + 3.5 diopter reading glasses and removed a single lens from them.


**Image 2.6.** Reading glasses with + 3.5 diopter lenses.

The diopter is important because it determines the focal length of the lens. To find the focal length in metres you just need to take the inverse of the diopter value

$$\frac{1}{3.5} = 0.2857 \text{ m}$$

and since we know that the mirror cuts the focal length in half

$$\frac{1}{3.5} \cdot \frac{1}{2} = 0.1428 \text{ m} = 142.8 \text{ mm.}$$

This is the distance the electronic display needs to be from the lens, to get the image from the display into focus. Diopter of + 3 should work fine, since the 3D printed part "lens-mirror-holder" can be moved further and closer to the electronic display. So, using a lens with a smaller diopter is still viable. Although, a lens with a diopter smaller than + 3 will require the modification of the holder and possibly the optics frame as well.

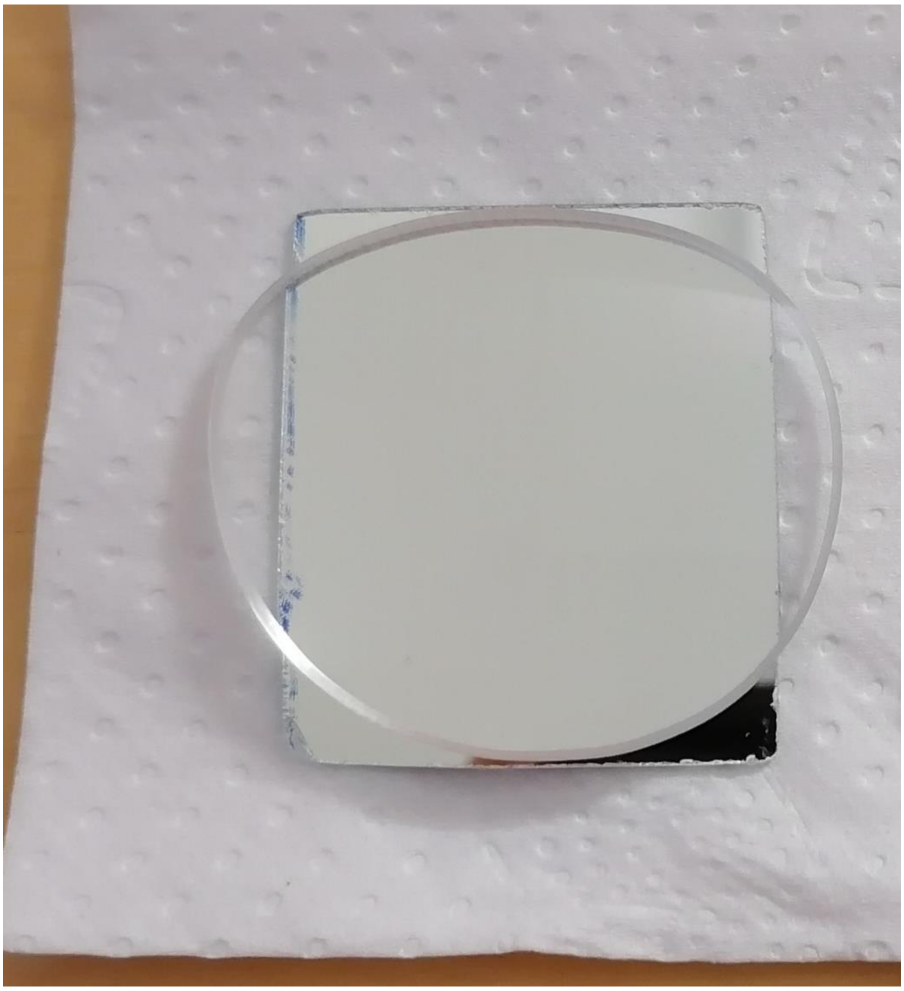

**Image 2.7.** The lens and the mirror.

Next, we want to attach the lens to the mirror with epoxy or UV glue. Epoxy glue gives a more permanent hold, while UV glue is strong, but still easy to detach. Before we do that however, we may want to cut the lens to be the same width as the mirror. This is a purely a cosmetic choice, so it is not necessary.

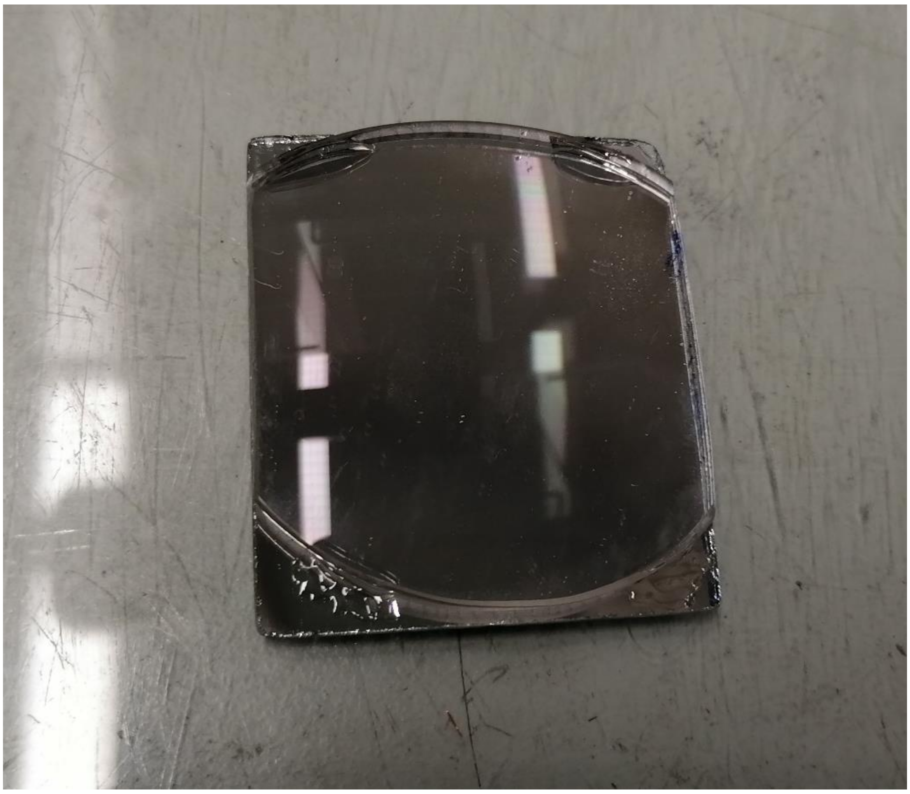

**Image 2.8.** The cut lens glued to the mirror with UV glue.

Now you just need to place the lens-mirror package onto the lens-mirror-holder with double-sided tape. The lens and the mirror part of the optical setup is now ready.

**Image 2.9.** The lens-mirror package on the lens-mirror-holder.

Next, we will finish the two reflection glasses and glue them to the right and left glass-grabbers. Since the glasses have a thickness of 1.24 mm, the two glass-grabbers that were made for 1.9 mm glass need to be modified a bit. The slot the glass is glued into needs to be around the same width as the thickness of the glass. So, we modify the 3D model and print it again with a slot width of 1.24 mm. This makes the gluing easier and ensures that the glasses are not glued in an angle.

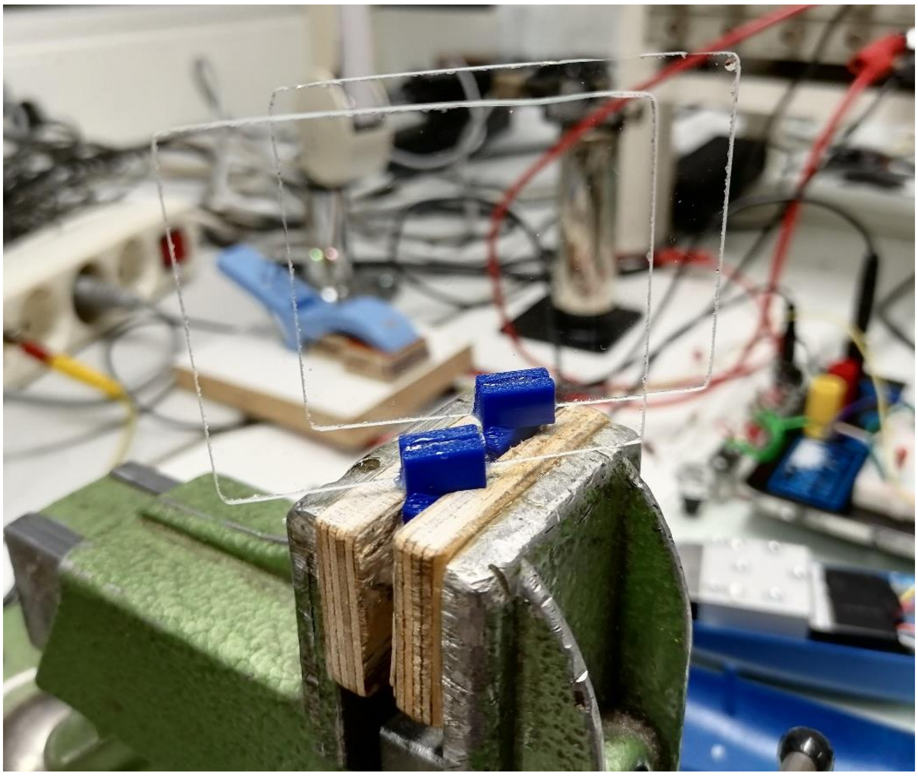

**Image 2.10.** The two reflecting glasses glued to the glass-grabbers.

The glasses should be glued lengthwise. Meaning they are wider rather than taller when inserted into the grabber. Once the glue has dried, the glass-grabbers are then inserted and glued into the glass-sockets.

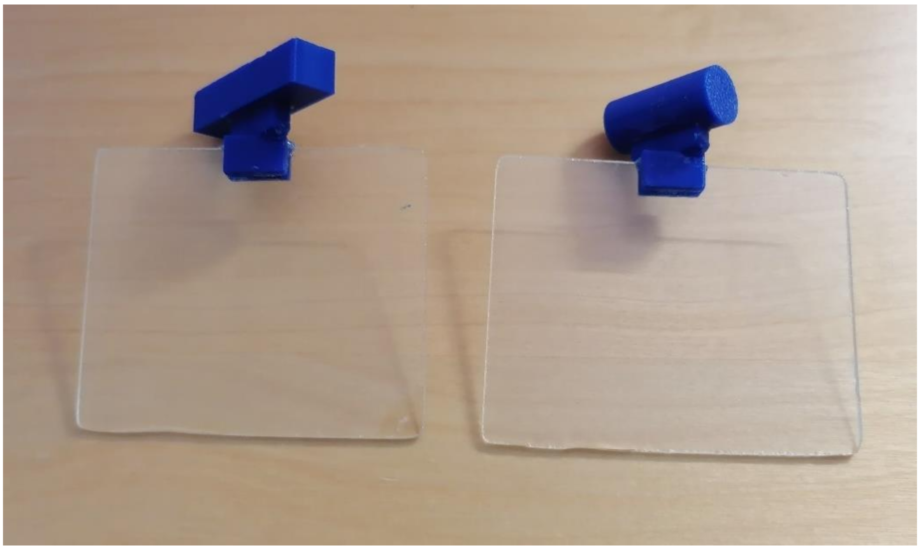

**Image 2.11.** Glass-grabbers inserted and glued into the glass-sockets.

It is important to note that the taller grabber is for the rectangular glass-socket and shorter one for the cylinder-shaped glass-socket. This concludes the optical components assembly. In the next section, we will assemble the rest of the 3D printed parts.

### 2.3 Assembling the 3D printed parts

Referring to the .f3d files for the optics and for the headband is recommended when assembling the parts. The 3D models are set up in a way that showcases where the different parts fit. You should drill the necessary threads on all the parts that have them. Refer to the README file in the Guide to optics parts and Guide for headband parts.

Firstly, insert the two levers into the optics-frame and make sure they can rotate without too much friction, even when the frame-cover is bolted onto the optics-frame. If one of the levers feels tighter than the other one, then try switching their places. Sanding the levers or the holes where the levers are inserted can also help the levers rotate more smoothly.

Once the levers and the frame-cover are attached to the optics-frame, take the right and left glass-holders and glue them into the slots on the bottom of the levers. Note that the holder with the rectangular hole is the right holder and the one with the cylinder-shaped hole is the left holder.

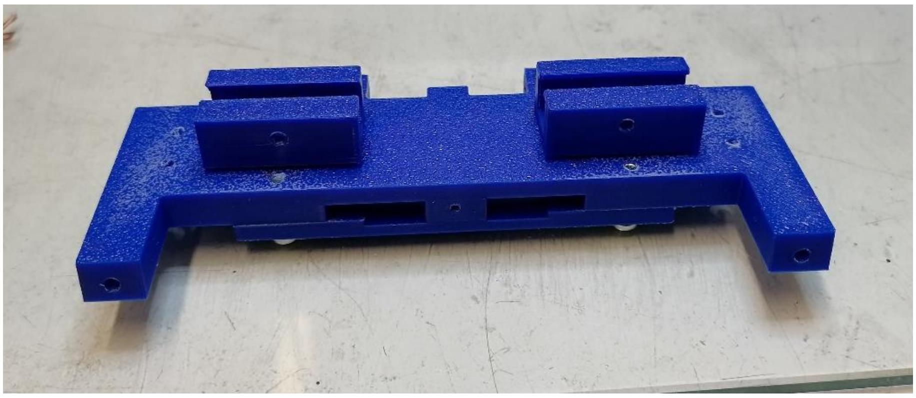

**Image 2.12.** Right and left glass-holders glued to the levers.

You can remove the frame-cover after the glue has dried and the levers will stay in place. Next, you can insert both the right and the left reflective glasses into the holders and secure them in place with a M3 bolt on each holder. You can also adjust the separation between the two glasses. It is recommended to tighten the M3 bolt with just your fingers, as tightening the bolt too much will bend the glass-holders. You can now see how rotating the cylinder socket changes the angle of the left side reflective glass.

Next, you can attach the electronic-display-holder and the lens-mirror-holder to the optics-frame.

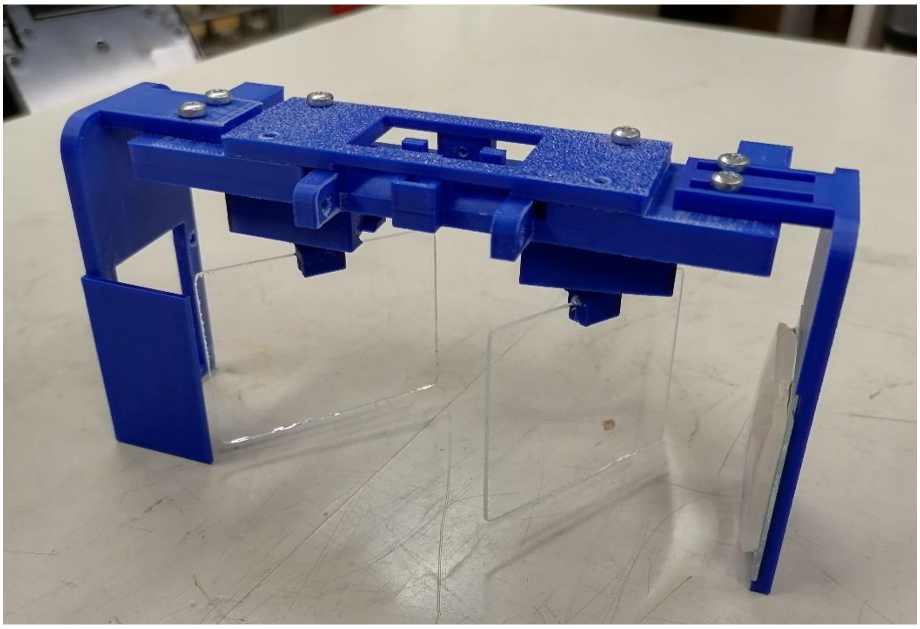

**Image 2.13.** The reflective glasses on the holders. Electronic-display-holder and lens-mirror-holder attached to the optics-frame.

Now, we can install the stereovision bolt, bolt-pin, lever-pusher-for-bolt and lever-pusher-spring into the optics-frame.

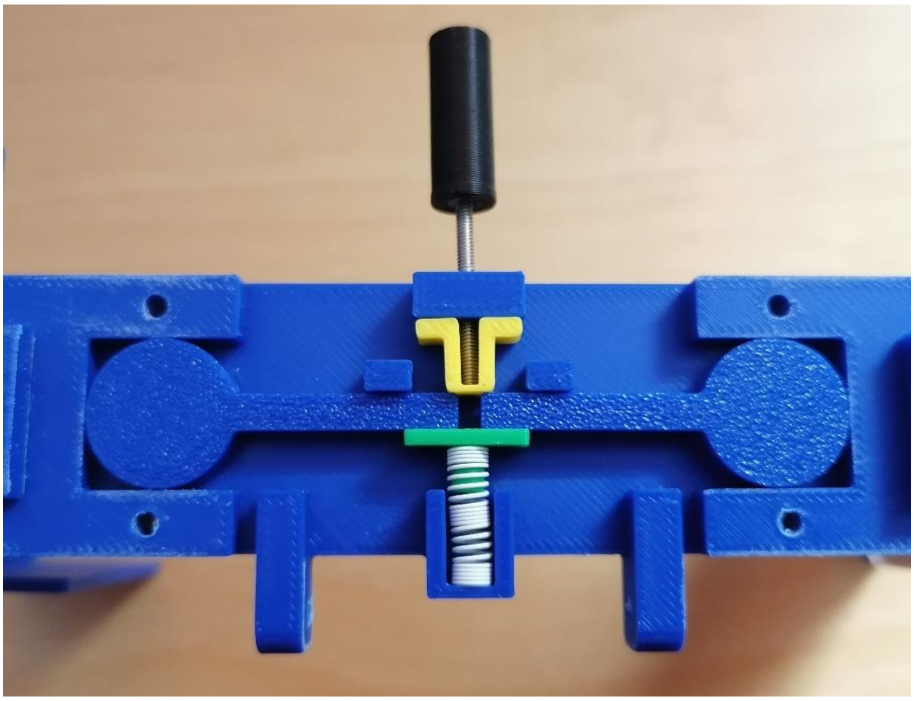

**Image 2.14.** M2 bolt with the bolt-pin glued to it, lever-pusher-for-bolt (yellow), lever-pusher-spring (green) and the spring.

This setup enables stereovision effect for the glasses. Once the left glass is aligned with the right glass, tightening the stereovision bolt makes the image created by the electronic display move towards the user. And loosening the bolt makes the image move further away from you up to a specific point. An interesting thing to note, is that for some people the image gets blurrier as it gets closer. We have noticed that this happens only for those who are nearsighted. If you are farsighted or have normal vision, then the image should be sharp no matter how far or close it seems to move.

The spring used to push the levers is from a common ballpoint pen. The spring is 20 mm in length and around 5 mm in diameter. Both the 3D models for the lever-pusher-for-spring part and the optics-frame can be easily modified to fit a spring of different size. Though, you need to be sure that the levers never get too loose. And a spring that is too strong will make tightening the stereovision bolt harder.

Next, attach the optics-to-headband-locking-piece part to the optics-frame. Here we will use a couple of nuts to ensure the bolts don't get loose with time. Or at least not as fast.

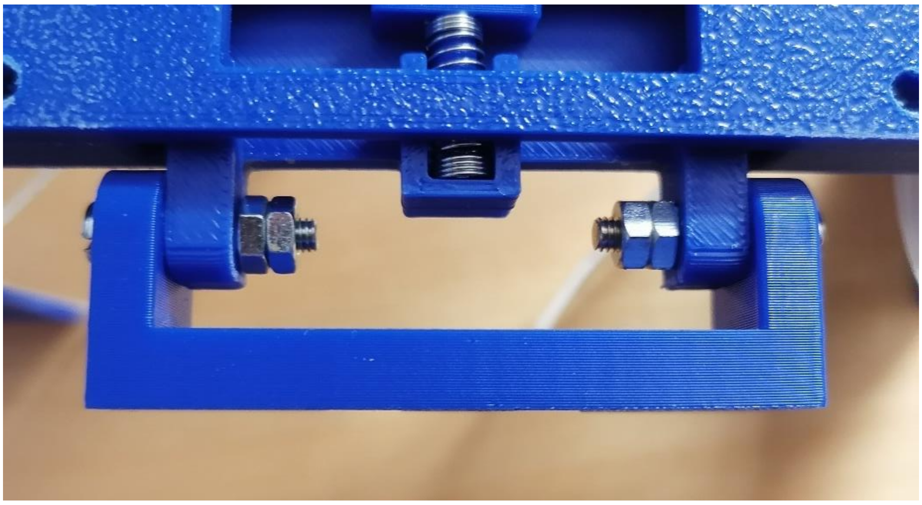

**Image 2.15.** optics-to-headband-locking-piece attached to the optics-frame.

Similarly, the optics-to-headband-socket part is attached to the headband. These two parts then connect, allowing for easy removal of the optical setup from the headband. At this point, you can also attach battery-holder, charger-circuit-holder, voltage-distributor-circuit-holder and CPU-circuit-holder to the headband with M3 bolts.

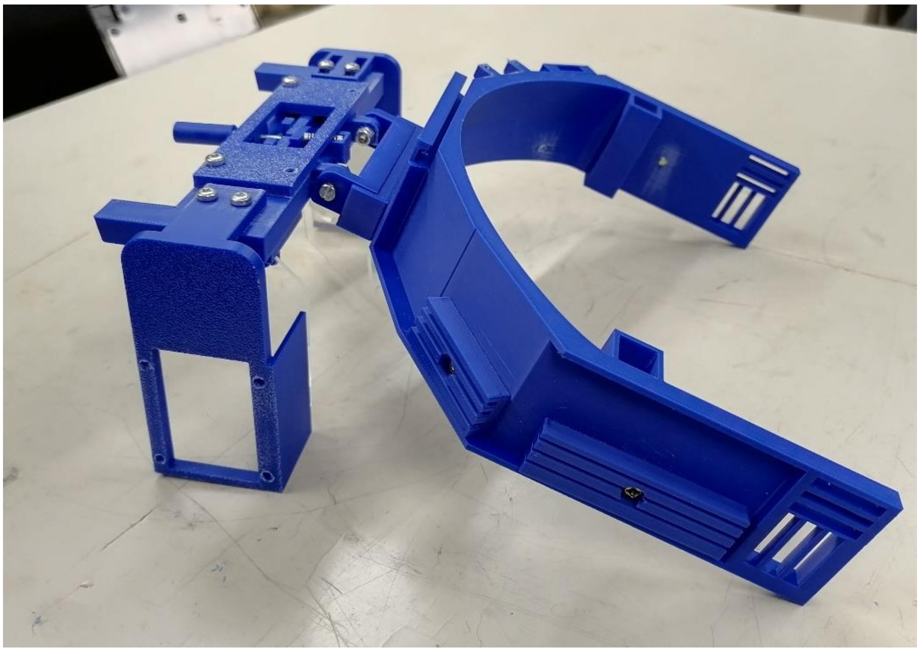

**Image 2.16.** The optical setup connected to the headband.

At this point attaching some nylon straps to the headband for support is recommended. Two straps give adequate support for the top and the back of the head. A soft padding should also be taped or glued to the inside curve of the headband for user comfort.

You can also make a polycarbonate front cover for the optics-frame that can make the image clearer. Both sides of the front cover should be covered with solar window film to reduce the incoming ambient light. The film we used allows for 20 % of incoming light to penetrate the polycarbonate cover.

**Image 2.17.** The polycarbonate front cover.

The polycarbonate front cover in the image above has dimensions 160 x 90 mm. Note, that the two front bolt holes are printed in an angle of about 20 degrees in the optics-frame part. This ensures that the light from the electronic display doesn't reflect to the eyes of the user from the cover.

## 2.3 Electronic components

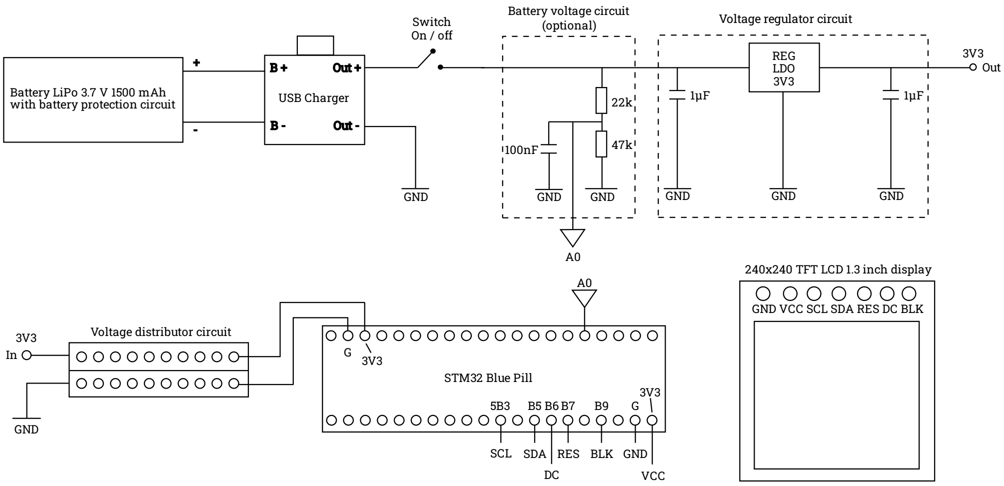


**Image 2.18.** Circuit diagram for OpenAR 2.0.

The battery voltage circuit is useful, if you want the CPU board to monitor the battery voltage. Otherwise, it is optional. The voltage regulator circuit ensures, that the CPU board gets a steady 3.3 V from the battery. The voltage distribution circuit enables more electronics to be added. Sensors for example.

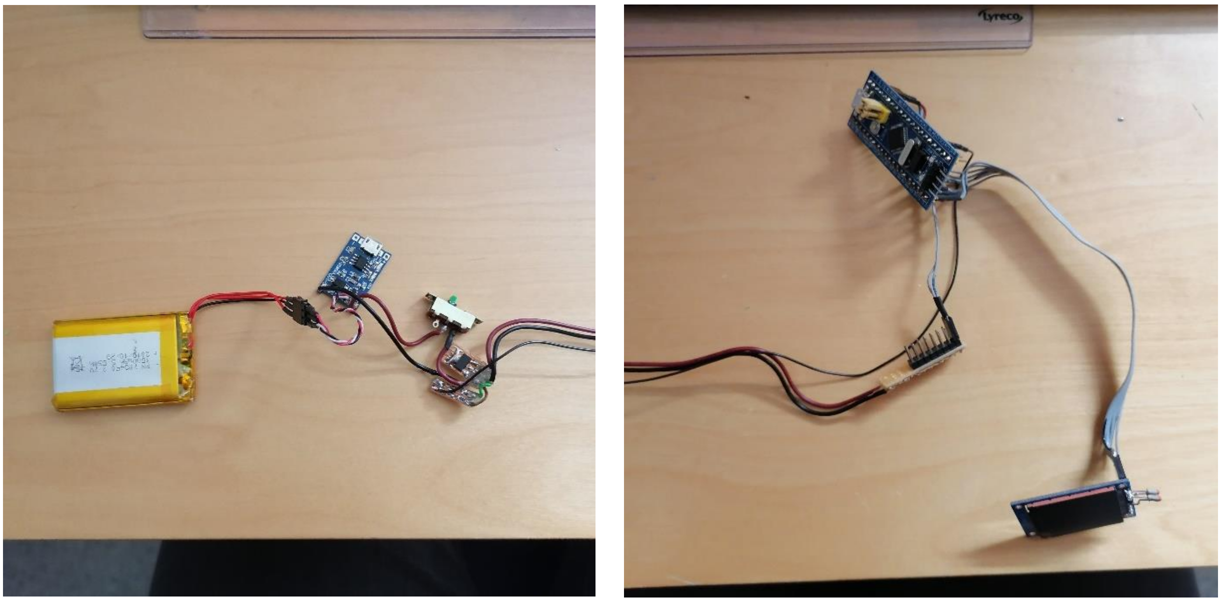

**Image 2.19.** OpenAR 2.0 electronics. From left to right: LiPo battery, Micro USB charger, switch, battery voltage and regulator circuit, voltage distributor circuit, Blue Pill CPU board and LCD display.

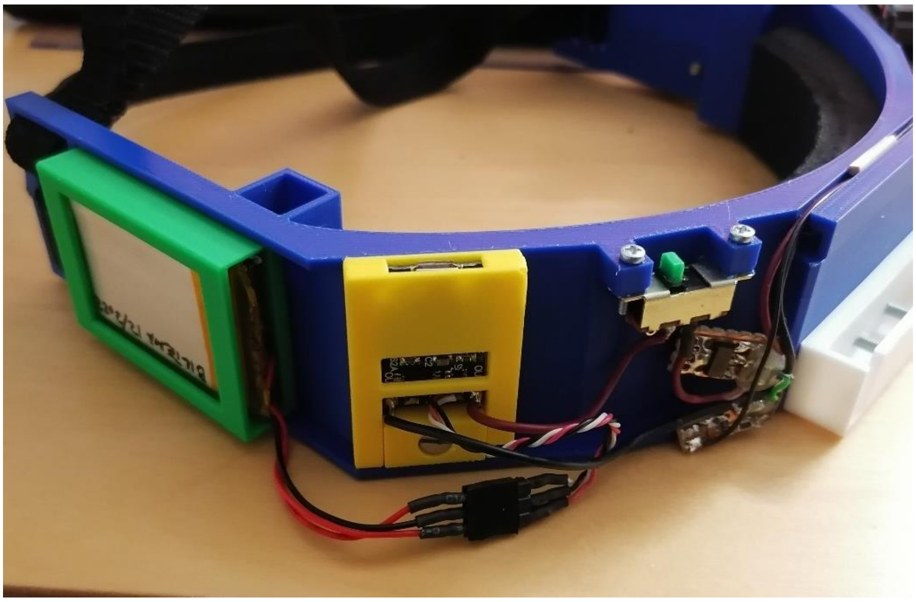

**Image 2.20.** Battery, USB charger, switch, battery voltage and voltage regulator circuits installed onto the OpenAR headband.

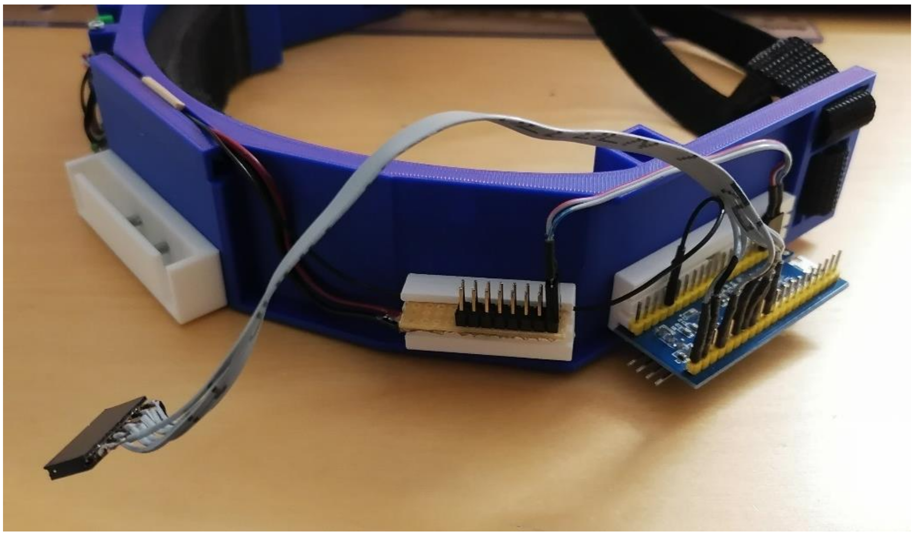

**Image 2.21.** Voltage distributor circuit, CPU board and the display power cable installed onto the OpenAR headband.

The electronic display is attached to an adapter, which is then attached to the electronic-display-holder. This adapter can be modified to fit a different display, than what was used for OpenAR 2.0. If you choose to use the same 240x240 TFT LCD 1.3-inch display, then you can 3D print the adapter made for it.

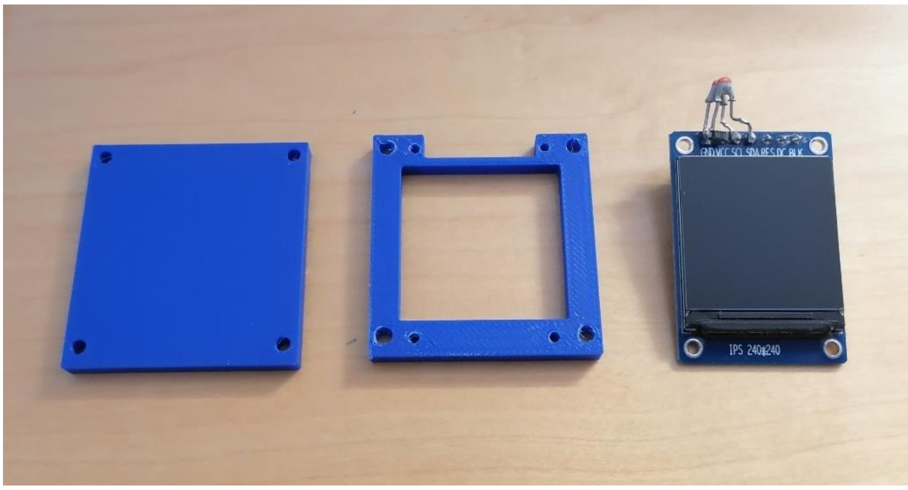

**Image 2.22.** The adapter template and the adapter made for the 1.3-inch display. Note, that the components installed onto the display are not relevant.

Note, that the maximum size of the electronic display is set by the adapter template (maximum size for the display is 30 x 38 mm). Further modifications to the optical setup are needed, if a larger display is used.

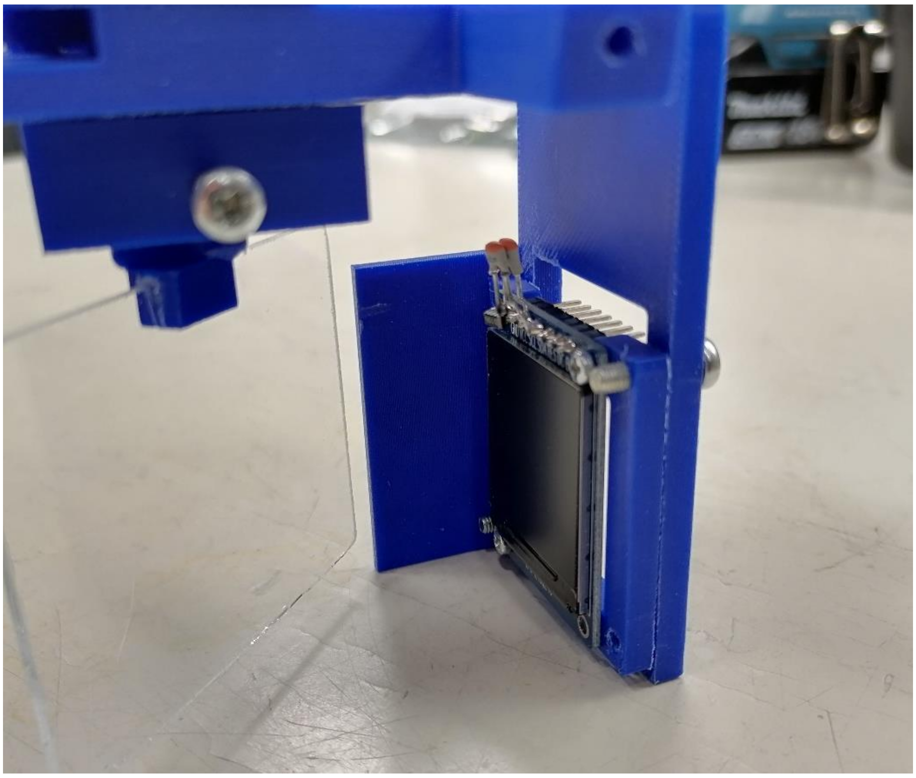

**Image 2.23.** The electronic display on the adapter on the electronic-screen-holder.

Once all the electronics are installed and the optical setup is assembled, it is time to install the demo program and align the reflective glasses.

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# CHAPTER 3

## Demo program and glass alignment

Let us first install the demo program to the CPU board. The program we provide is a simple proof of concept, that shows what kind of features can be displayed through reflections alone. The demo program starts as soon as the power switch is turned on. The program involves various short animations and texts that repeat until the power is switched off.

ST-LINK V2 Programmer was used to install the program to the CPU board. You also need the free official STM32 programming toolkit, if you are using a STM CPU board like we are. Once the program is installed onto the OpenAR -glasses, the only thing left is to align the reflection glasses, so that the displayed image is sharp and clear.

### 3.1 Installing the demo program

ST-LINK V2 Programmer tool is needed to install the demo program to the Blue Pill CPU board. You also need to download and install STM32CubeIDE development platform to your computer.

Blue Pill CPU board has a quick way to change into programming mode. Remember to press the reset button after changing the mode on the Blue Pill, if the board is turned on.

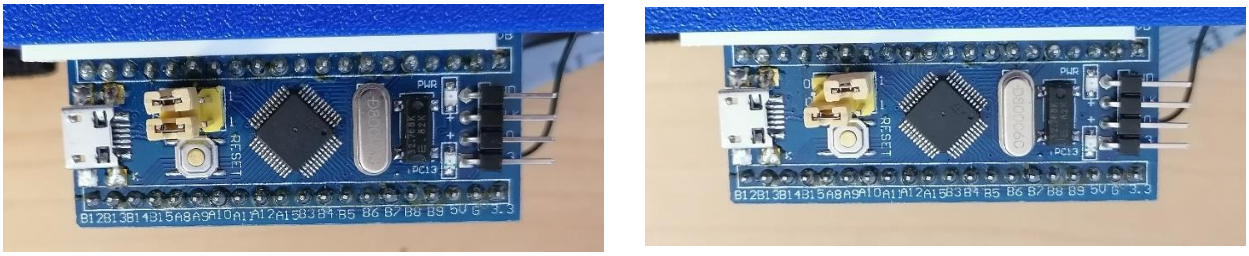

**Image 3.1** Blue Pill in normal mode (left) and in programming mode (right).

Now that the Blue Pill is in programming mode, attach the ST-Link V2 to the pins at the end of the Blue Pill board (refer to image 3.1). Then connect the ST-Link V2 to your computer. Next, in the OpenAR 2.0 documentation, open the folder “screenTest” and launch the .project file.

Wait for the CubeIDE program to start, then on the top left side of the window, open screenTest → Core → Src → main.c. Double click main.c to open the code file. Once it is open, on the top of the window click the green play -button “run screenTest debug”. Once you get the message “Download verified successfully. Shutting down… Exit.”, the program has been installed onto the Blue Pill.

Change the Blue Pill back to normal mode, press the reset button, and the demo program should start running.

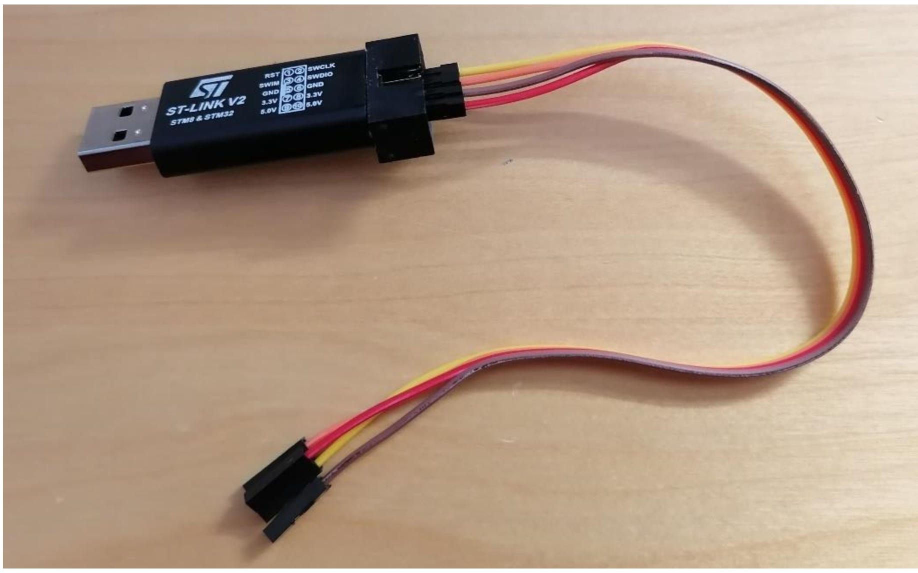


**Image 3.2.** ST-Link V2 Programmer.

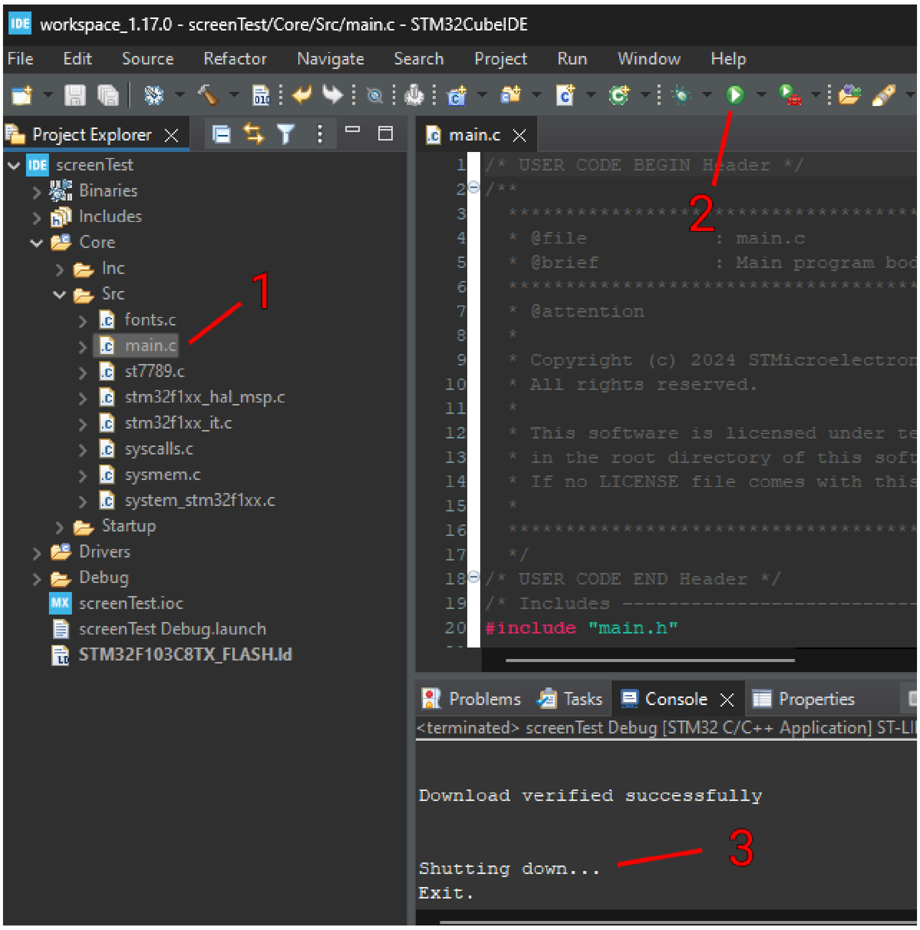


**Image 3.3.** The steps to install the demo program inside CubeIDE.

### 3.2 Aligning the reflective glasses

The aligning is made easy by the fact that the right reflective glass is stationary. So, only the left reflective glass needs to be adjusted. To do this you need to first loosen the bolt on the left glass-holder enough, that by carefully pushing the bottom edge of the left reflective glass, you can rotate the cylinder socket inside the holder. If you do this while the electronic display is on and going through the demo program, then you can keep adjusting the left glass until both images are on top of each other. Note, that they may not be aligned horizontally. This can be fixed by tightening the stereovision bolt.

A combination of pushing the left glass and tightening the stereovision bolt should make the alignment relativity quick. Once the image is clear and sharp, tighten the bolt on the left holder. It is recommended to tighten the bolt with just your fingers, as using a screwdriver can bend the 3D printed holder piece. Tightening the bolt still allows for fine tuning of the position of the left glass and it will not move by itself.

If the images are on top of each other, but the image is blurry, then the display might not be on the focal point. You can adjust the focal point by moving the whole lens-mirror-holder on the optics-frame to the right (away from the display).

If the image seems to be more to the side rather than at the centre of your field of view, then you can rotate the electronic-display-holder or the lens-mirror-holder on the optics-frame. Small changes in the rotation of the holders cause a large change in the position of the image in your field of view. The holders can be rotated even if they are bolted on.