OpenFlexure Microscope

Abstract: A 3D-printed microscope, including a flexure-based XYZ stage with sub-micron precision and 8mm range.

Description: The OpenFlexure microscope is a customisable optical microscope, using either very cheap webcam optics or lab quality, RMS standard microscope objectives. It uses an inverted geometry, and has a high quality mechanical stage which can be motorised using low cost geared stepper motors. Optomechanics is a crucial part of any microscope; when working at high magnification, it is absolutely crucial to keep the sample steady and to be able to bring it into focus precisely. Accurate motion control is extremely difficult using printed mechanical parts, as good linear motion typically requires tight tolerances and a smooth surface finish. This design for a 3D printed microscope stage uses plastic flexures, meaning its motion is free from friction and vibration. It achieves steps well below 100nm when driven with miniature stepper motors, and is stable to within a few microns over several days. This design aims to minimise both the amount of post-print assembly required, and the number of non-printed parts required - partly to make it as easy as possible to print, and partly to maximise stability; most of the microscope (including all the parts with flexures) prints as a single piece. The majority of the expense is in the Raspberry Pi and its camera module; the design requires only around 100g of plastic and a few nuts, bolts and other parts. The optics module (containing the camera and lens) can be easily swapped out or modified, for example to change the magnification/resolution by using a microscope objective, or adding a filter cube for fluorescence (build instructions not done yet). This design is (c) Richard Bowman 2017, released under the CERN open hardware license. You can also buy a kit or an assembled microscope from http://www.waterscope.org/.

A 3D-printed microscope, including a flexure-based XYZ stage with sub-micron precision and 8mm range.

License: CERN Open Hardware License

Notes: This is the third "stable" release of the microscope; ongoing development lives on the Github page https://github.com/rwb27/openflexure_microscope and the accompanying paper is available at http://dx.doi.org/10.1063/1.4941068 (the paper is open-access). This microscope is available through http://www.waterscope.org/, as a kit (with or without printed parts and Raspberry Pi) or fully assembled.

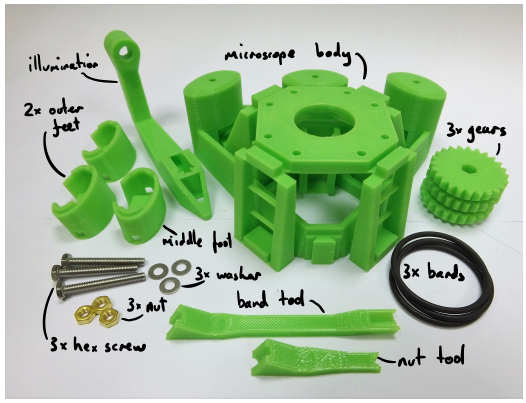
Requires:

- **Optics module:** Raspbery Pi Camera Mount/Extension Tube **x 0,** High-resolution Optics Module **x 0**
- **Illumination:** Illumination Arm (fixed) **x 0,** Illumination Arm with Condenser **x 0**
- **Fine positioning control:** Actuator assembly **x 0**
- **Microscope Feet:** Camera lens removal tools **x 0**
- **Mechanical stage:** Microscope Body **x 0**
- **Sample Holder:** 8mm M3 screws, Qty: 2 or 3 **x 0,** 8mm M3 screws, Qty: 2 or 3 **x 0**
- **Control Computer:** Raspberry Pi **x 0**
- **Printer test object:** Microscope leg test object **x 0**

Instruction:

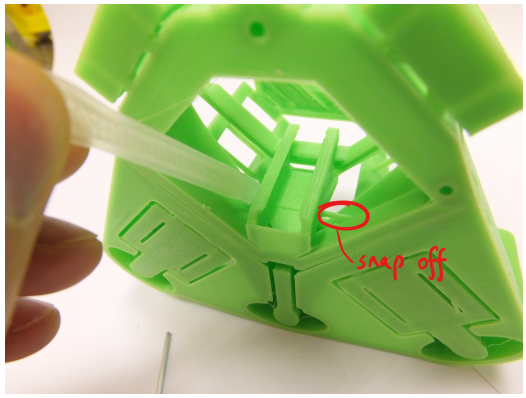
Step 1. First, you will need to print or obtain the 3D printed parts. If you bought a kit, skip this step! The microscope is designed to print without support material. This is quite important; if you use support material it will require a lot of cleaning up, and you may well damage the mechanism. I usually print with a layer size of 0.24mm on my Ormerod, which takes 8 hours for the main structure. “low” quality on an Ultimaker 2 (0.15mm layers) produced similar results in about 5 hours. If your printer has a standard-sized bed (180mmx180mm should be fine) then it should be possible to print the complete microscope in one go. I do this if I’m using a machine that is well calibrated and reliable. However, I find that it’s often more reliable to print in batches (as small parts at the edge of the print bed can detach and cause it to fail). I would recommend: Batch 1: Microscope, illumination and Optics module (main part) Batch 2: Feet, gears, camera cover, camera board gripper, camera lens remover, gear riser There is a test file that prints a single leg of the microscope - the Microscope leg test object. It's worth printing this first to check your settings are OK.

Step 2. Make sure you have all the necessary parts and tools. The parts should all be listed in the bill of materials, but for clarity you will need: Plastic parts: * 1x microscope body * 1x optics module * 1x illumination and rear foot * 2x tilted foot * 1x untilted foot * 3x gear * 1x camera cover * 2x sample clip (optional) Plastic tools (optional but helpful): * 1x camera board gripper (for v1 or v2 of the camera board) * 1x camera lens remover (for v1 or v2) * 1x gear elevator (optional) Metal hardware: * 3x M3 hexagon head 25mm screws, stainless steel * 3x M3 brass nut * 3x M3 stainless steel washer * 2x M3 8mm cap head screw (optional, for sample clips) * 2x M2 6mm cap head screw (optional, to secure camera more strongly) Electronic parts: * White LED, resistor, wire, and 2-way JST header connector (assembled as one cable in the kit) * Raspbery Pi camera module (v2, though v1 works if you substitute the relevant STL files) * Raspberry Pi (with associated power supply, keyboard, monitor, etc.) Tools (not supplied in kit): * 2.5mm hex key (optional, for attaching sample clips) * 1.5mm hex key (optional, for double-securing camera board) * tape (electrical tape or PTFE plumbers tape work, though regular sticky tape is also fine) * sharp craft knife (for trimming tape) * 3mm drill bit in hand chuck (if you printed the parts yourself and need to open out the holes) Don't forget the raspberry pi, camera module, and associated screen, power supply, SD card, keyboard, mouse, etc. (I have not listed these explicitly, but they're needed to run the Pi).

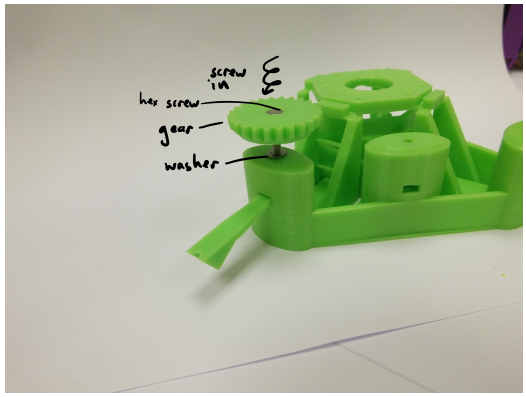


Step 3. If you printed the parts yourself, start by opening out the three holes in the microscope body with a drill as shown. Make sure to go all the way through. If you don't have a drill, you can improvise by screwing in an M3 screw all the way, then forcibly rotating it with a screwdriver. While you're at it, do the same for the illumination mount. Also, remove any loose strings of plastic from the underside of the actuator housings or sample stage, using a pair of pliers. The last step shouldn't be necessary if your machine is calibrated nicely for printing bridges. If you purchased a kit, this may well have been done for you.

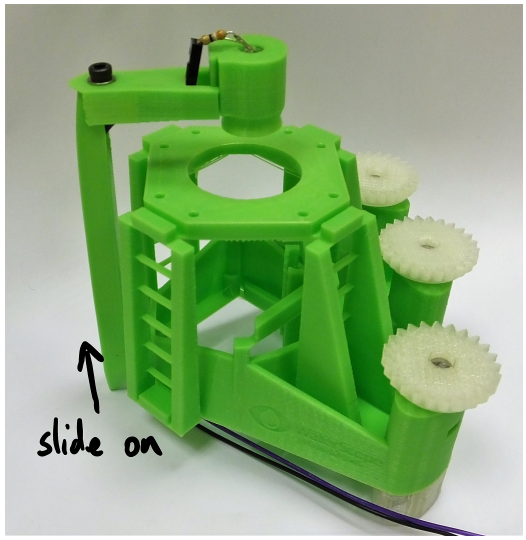
Step 4. Depending on which version of the microscope body you have, there may be thin supports linking the mount for the optics module to the frame. Snap these off with a craft knife, screwdriver, or elastic band tool.



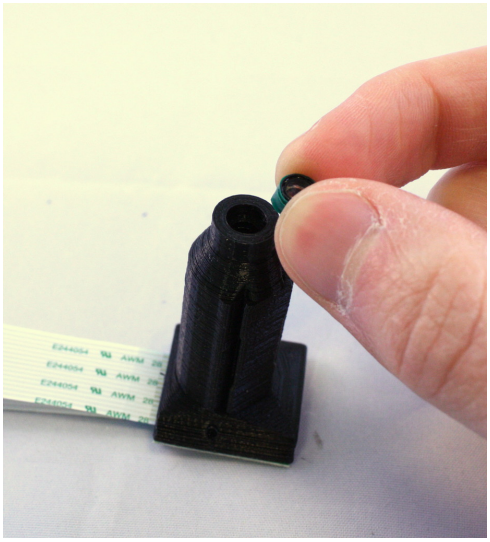
Step 5. First, assemble the three actuators, as described in the ["anti-backlash flexure actuator"](#brick_909106319) brick - it's the same procedure done three times, once for each actuator. You might find the central actuator is the best one to start with. This accounts for most of the time assembling the microscope. NB the instructions for this are later on in this file; if viewing it in Firefox, click "OpenFlexure Microscope" on the left, then pick it from the list of links that appears.



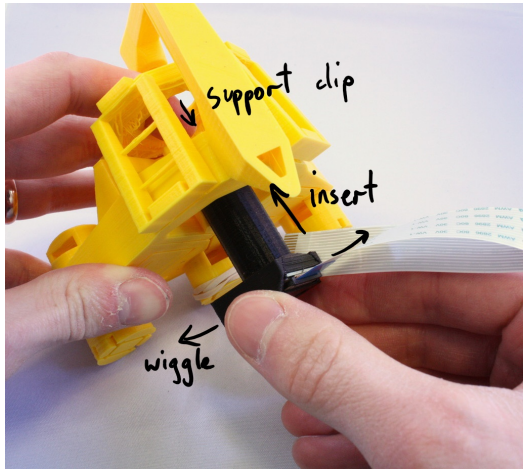
Step 6. Assemble the illumination, according to the illumination arm brick (there are two versions, for fixed LED and adjustable condenser lens).

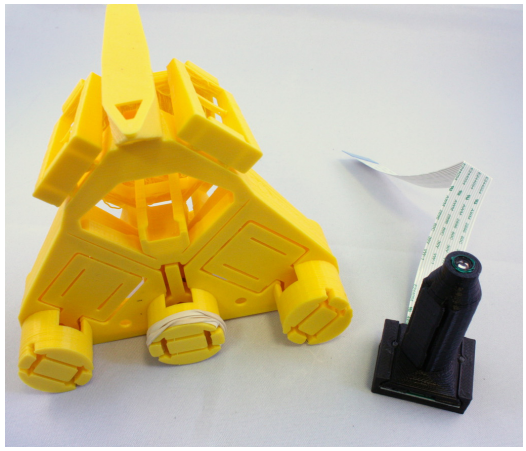


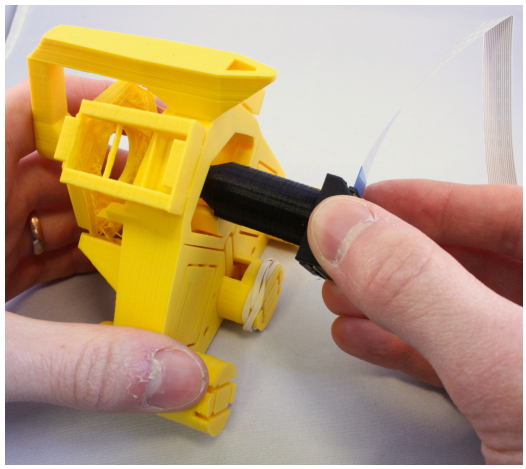
Step 7. Assemble the Raspberry Pi lens and camera into the optics module, as described in the optics module brick.

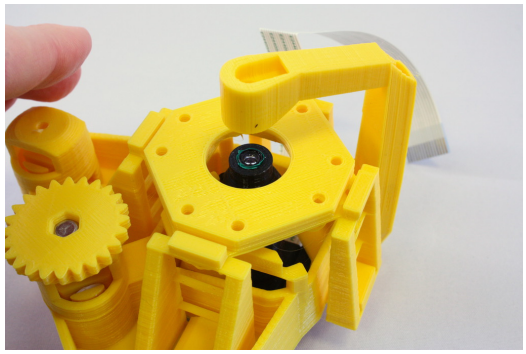


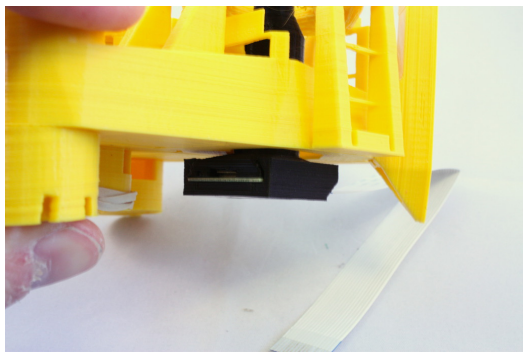
Step 8. Slot the optics module onto the dovetail mount, from the bottom. You may find it easier to fit if you wiggle the module from side to side as it goes in. It may also help to support the dovetail from the top (through the hole in the stage), as it will flex when you push the objective on to it. If you push too hard it is possible to break the flexure mechanism that holds the optics module.


support clip
insert
wiggle

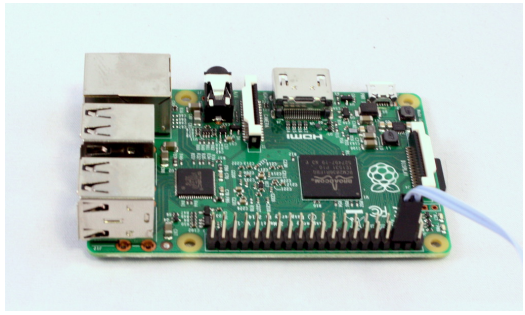




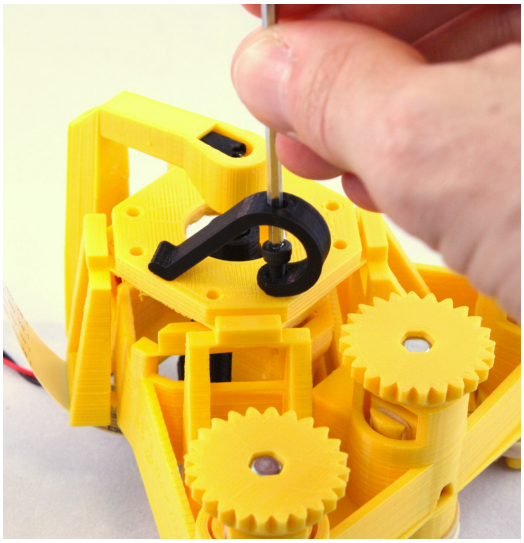


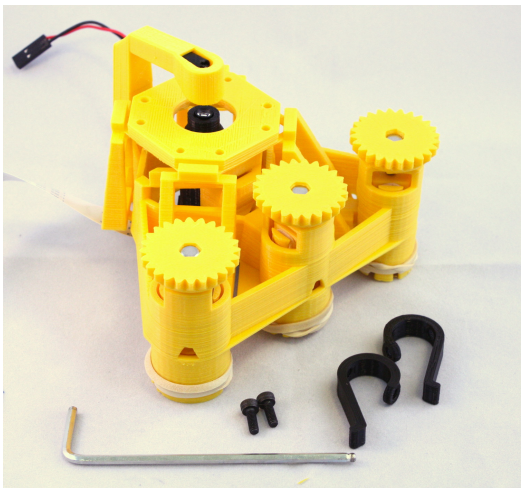


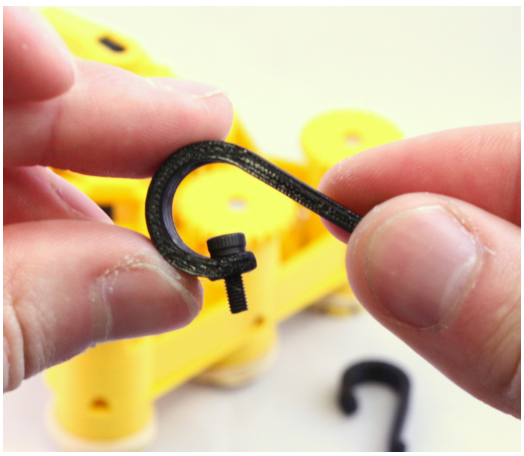
Step 9. Plug the LED cable into the GPIO connector on the Raspberry Pi, to the 0v and 5v lines. These are the second and third pins from the top of the connector, on the outside edge - pins number 4 and 6. Plug in the camera to the camera connector as described in the Raspberry Pi documentation (the connector is next to the Ethernet port, and the contacts on the cable face the port, i.e. they face away from the tab on the plug).

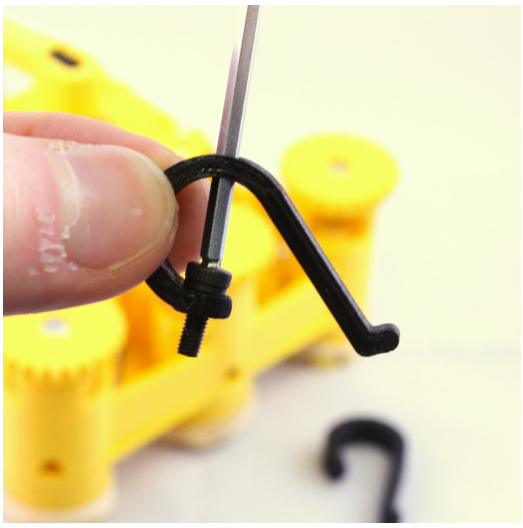


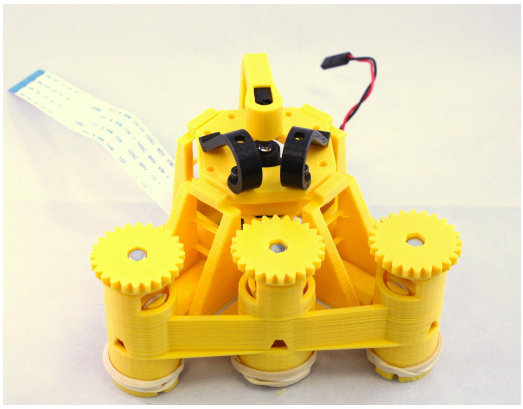
Step 10. After this, there are only the sample clips to go – exactly where you place these will depend on the samples you intend to use, but in any case you simply push the M3 screws into the clips, then screw down into the holes on the stage.

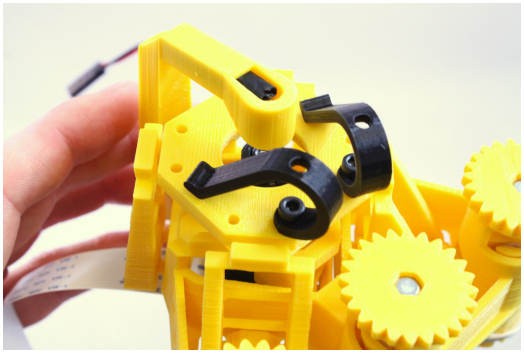


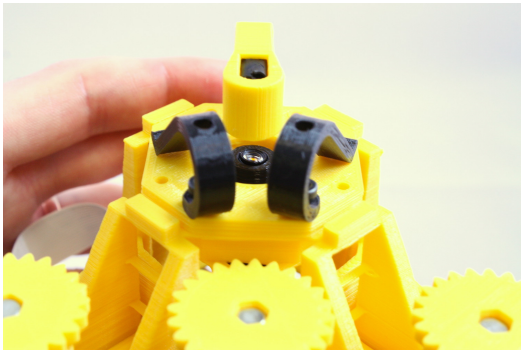




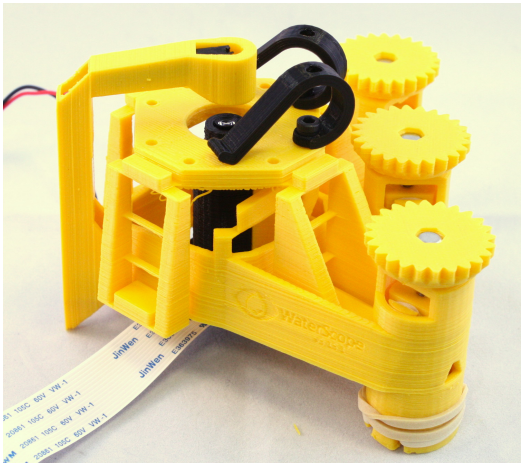


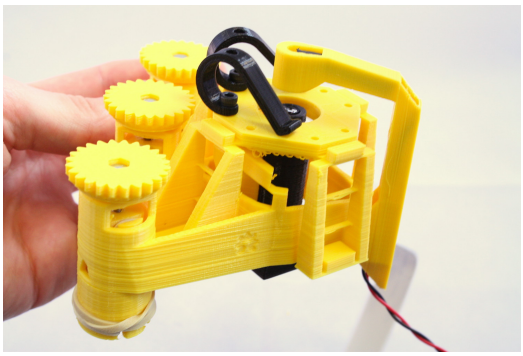


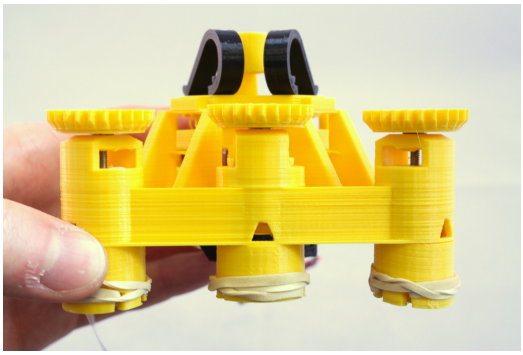




Step 11. Your microscope is now complete – happy observing! You might want to consult https://www.raspberrypi.org/documentation/usage/camera/ or https://www.raspberrypi.org/documentation/usage/camera/raspicam/README.md if you need a hand setting up the camera.







Raspbery Pi Camera Mount/Extension Tube

Abstract: This is a push-fit extension tube that turns a Raspberry Pi camera module into a microscope with a field of view about 400um across and a resolution of around 2um (better than 2um in the case of v2 of the camera module).

Description: This is the optics module for the OpenFlexure Microscope. It holds a Raspberry Pi camera module and lens, but the lens is reversed and placed 40mm from the sensor, allowing it to function as a high-magnification microscope with a resolution of around 2um.

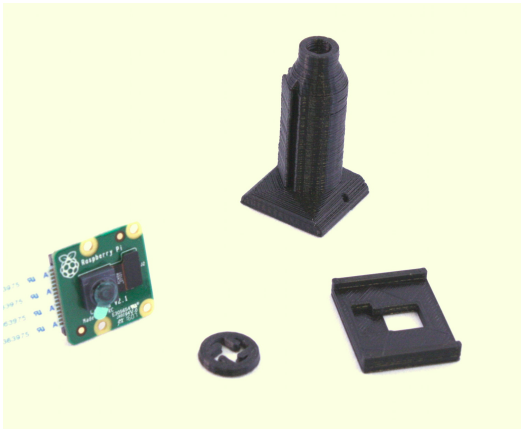
This is a push-fit extension tube that turns a Raspberry Pi camera module into a microscope with a field of view about 400um across and a resolution of around 2um (better than 2um in the case of v2 of the camera module).

Requires:

Mechanical holder: Optics module plastic parts **x 0**
Optics and Sensor: Camera lens removal tools **x 0**
Tools for removing the lens:

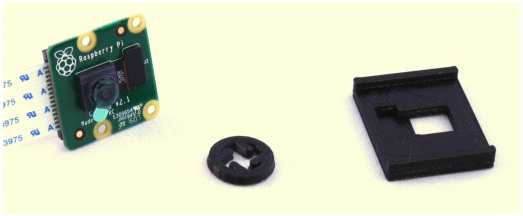
Instruction:

Step 1. First, assemble the necessary tools and parts: the optics module plastic parts (the "objective" and camera board cover), the Raspberry Pi camera module (version 2), the tools for removing the camera lens, optionally two M2 screws to secure the camera. Depending on print quality, you might also need a sharp craft knife or some tape. NB the lens removal tool, board gripper, and optics module are all specific to the camera you're using (v1 or v2 of the Raspberry Pi camera module). This version of the instructions is for version 2 of the camera board, if you have v1 it's a similar process but the older versions of the instructions give more detail. Later production runs of the Raspberry Pi camera module ship with a lens removal tool included, which is better than the printed tool.

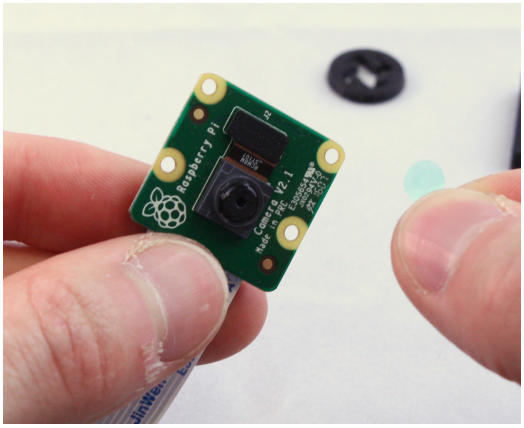


Step 2. WARNING! The camera board is static sensitive. Take the usual anti-static precautions (ideally use an anti-static wristband connected to ground, but at the very least make sure you touch an earthed object, such as a metal pipe, before working on the camera module.

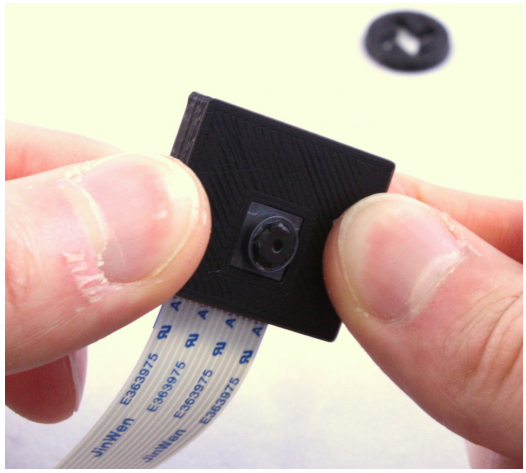
Step 3. We need to remove the lens from the camera. To do this, you need the two plastic tools (the board gripper and the lens remover) as well as the camera module. If you are using a USB camera, the lens is held on by two screws from the back, and can be removed by unscrewing these. SAVE THE SCREWS, as you will need them later!

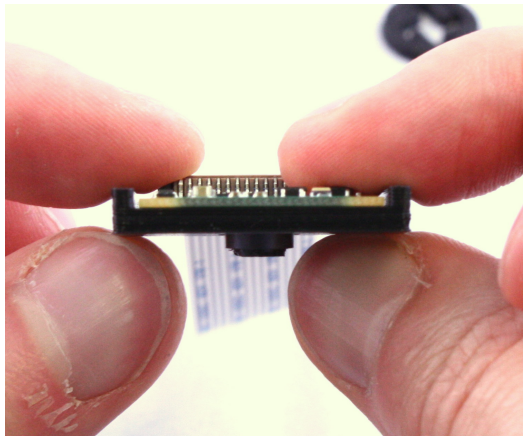


Step 4. Remove the protective film from the camera lens.

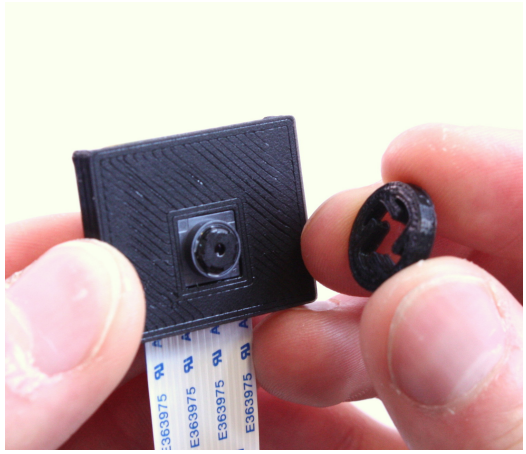


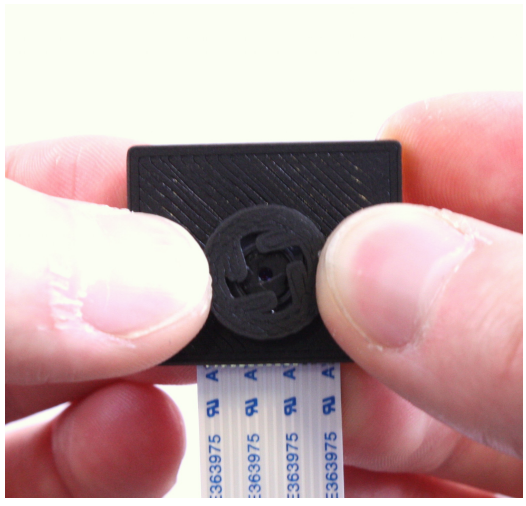
Step 5. There is a small ribbon cable connecting the camera to the PCB that is very easy to break. There is a square plastic jig that fits over the camera and PCB (the "camera board gripper"), which stops the camera twisting and damaging the ribbon cable. Fit this over the camera as shown. Note that the part for v2 of the camera board will sort-of fit v1, but you need to be a little more careful as it's not a perfect fit.





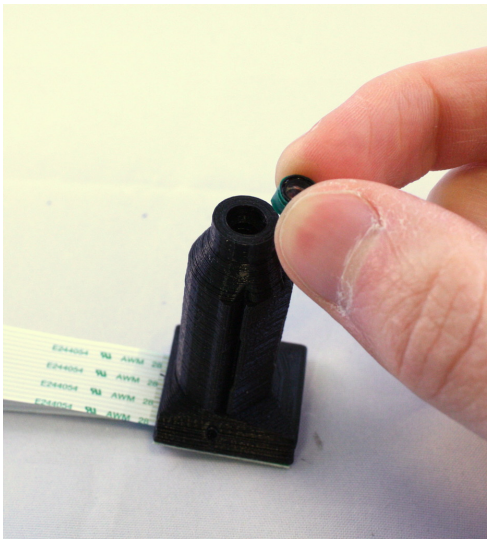
Step 6. Next, unscrew the lens from the camera module. Use the plastic tool to grip the lens module. This is a small circular part with four prongs that fits over the lens of the camera board (version 2 only) as shown. To remove the lens, push the removal tool onto the lens (just the top part, with the little plastic flanges) and turn anticlockwise to remove it. It only works if the prongs are pointing anticlockwise, so make sure it's the right way round. You will may feel a crack as it starts to move - this is normal. It's important to use the board gripper to hold the camera chip in place and prevent damage to the delicate ribbon cable. After you've removed the lens, check that the little black ribbon cable connecting the camera module (square plastic housing) to the PCB is still connected - pop it back in by pushing it with a finger if needed. Once you've removed the lens, be sure to place the camera face down on the desk, or put a piece of tape over the square black lens holder; this will help stop dust settling on the sensor, which is hard to clean.

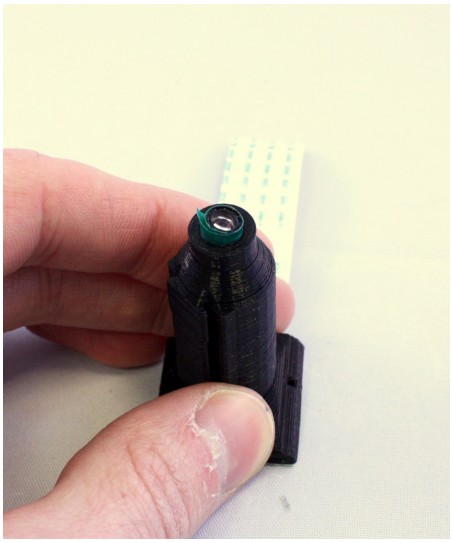


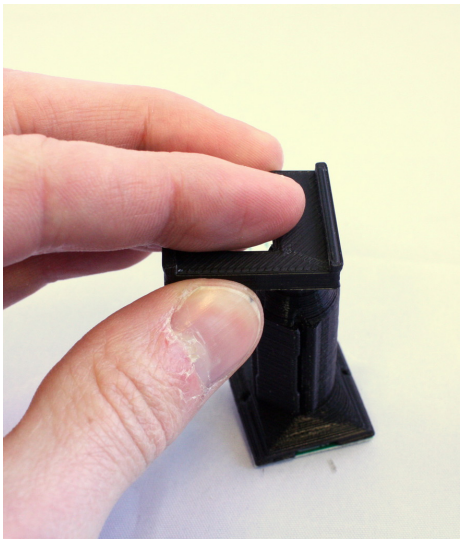


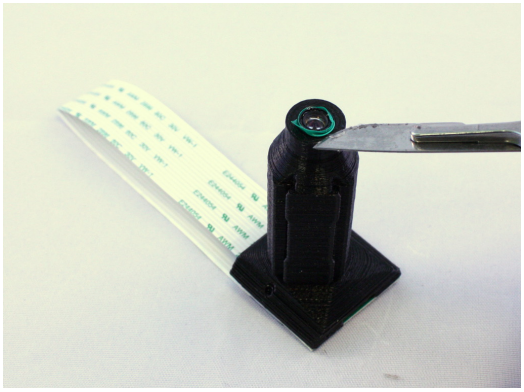
Step 7. Before assembling the parts into the holder, make sure it's free from dust by blowing some air through it, and check there are no strings of plastic in the central hole through the mount.

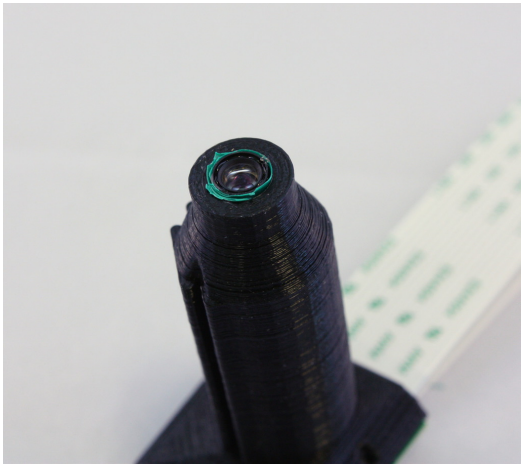
Step 8. Next, put the lens into the holder. This should just push-fit, but may take a small amount of force, or require a layer of tape wrapped around the lens to make it fit tightly (depending on your printer). If it looks like it will require too much force, you might have a different design of camera module and you may need to re-print the part slightly larger (or get a replacement if you bought a kit). If you wrapped tape around the lens, trim off any tape that protrudes above the lens with a scalpel or sharp craft knife.



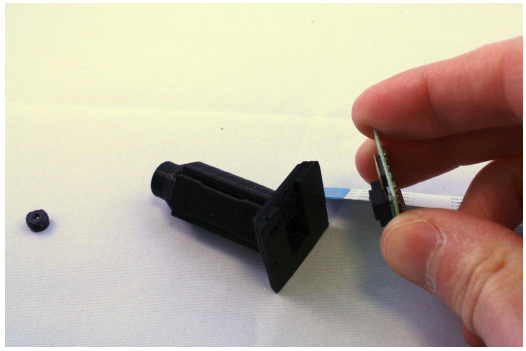


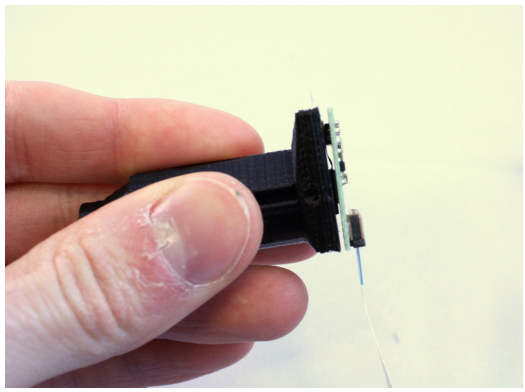


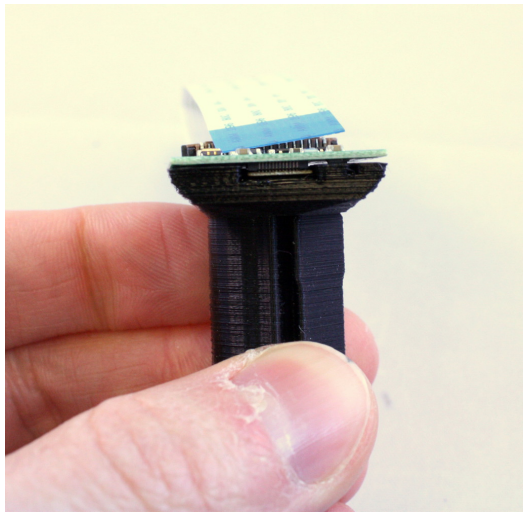




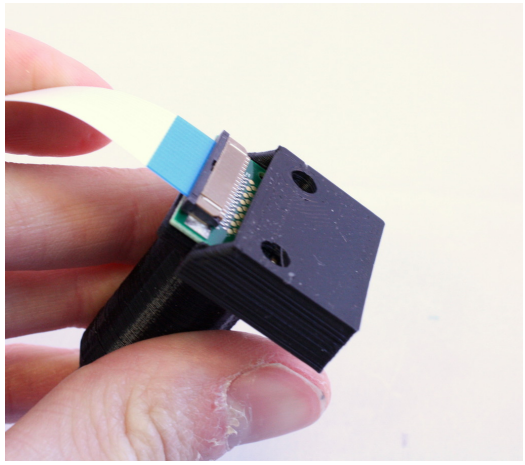
Step 9. Finally, press the camera module onto the bottom of the optics mount, so the camera board sits flush with the bottom of the mount. The newer push-fit is much easier to use, and should fit in with a gentle but firm press from your thumb. It probably won't crack or click into place, but it should be held by the push-fit. Don't worry if it's not gripped very strongly, the cover will hold it in place.

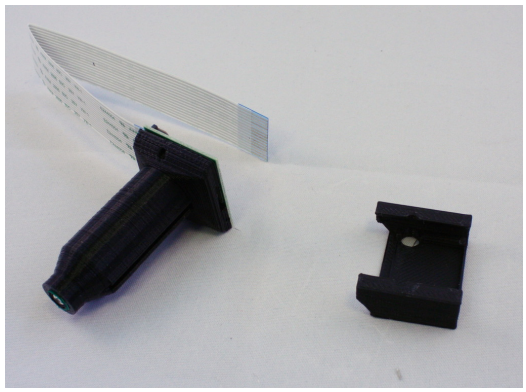


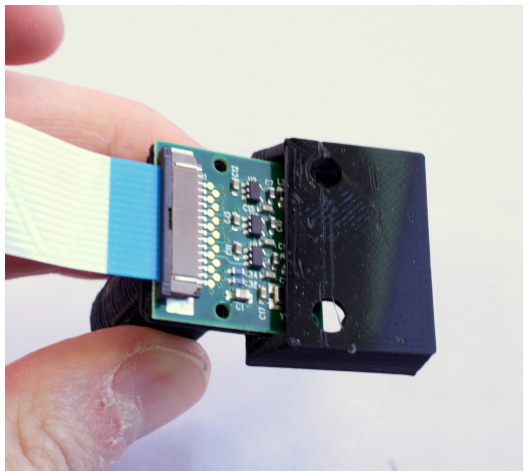


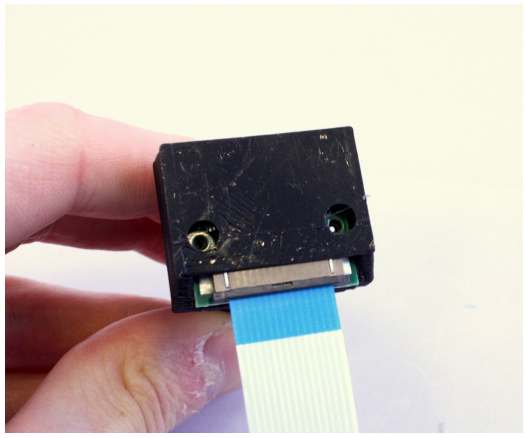


Step 10. Slide the cover over the camera board, starting at the end farthest from the ribbon cable connector. This will stop the camera falling out, and also protects the PCB from short circuits.

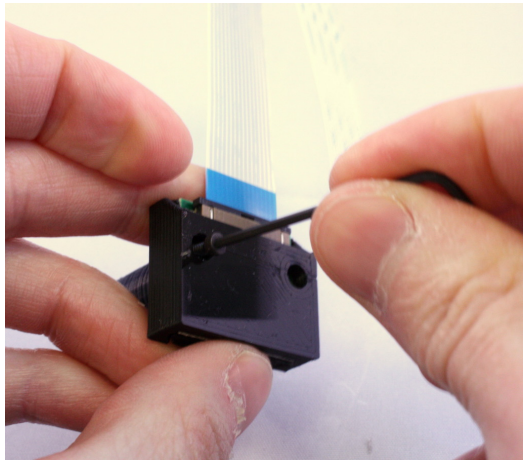








Step 11. Lastly, if you want to make the module more robust, you can insert two M2 screws from the bottom, to lock the cover on and hold the PCB in place. This is useful if the ribbon cable might be pulled accidentally, for example.



High-resolution Optics Module

Abstract: This is a simple tube microscope, using an RMS objective lens and a second lens for tube length correction. It allows the OpenFlexure microscope to take images with higher resolution than those obtained with the webcam lens.

Description: This is the optics module for the OpenFlexure Microscope. It holds a Raspberry Pi camera module and an objective lens. It's compatible with the LS65 or LS75 version of the stage, depending on whether the objective has a 25mm or 35mm parfocal distance.

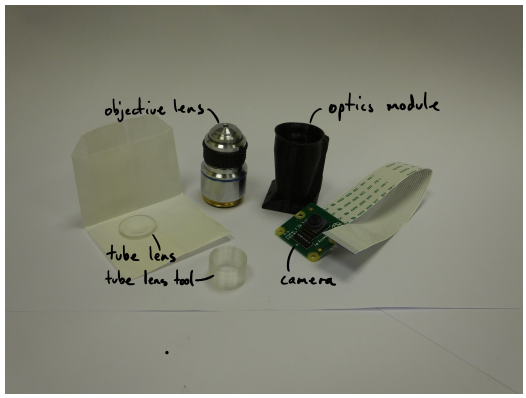
This is a simple tube microscope, using an RMS objective lens and a second lens for tube length correction. It allows the OpenFlexure microscope to take images with higher resolution than those obtained with the webcam lens.

Requires:

Mechanical holder: Optics module plastic parts **x 0**
Optics and Sensor: Camera lens removal tools **x 0**
Tools for removing the lens:

Instruction:

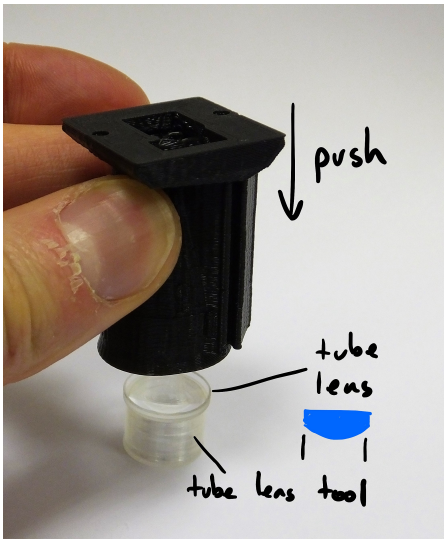
Step 1. First, assemble the necessary tools and parts: the optics module plastic part (and camera board cover if you're using a Pi camera), the camera module, the tools for removing the camera lens, the tool for inserting the tube lens, and optionally two M2 screws to secure the camera (if using Pi camera). NB the lens removal tool, board gripper, and optics module are all specific to the camera you're using.



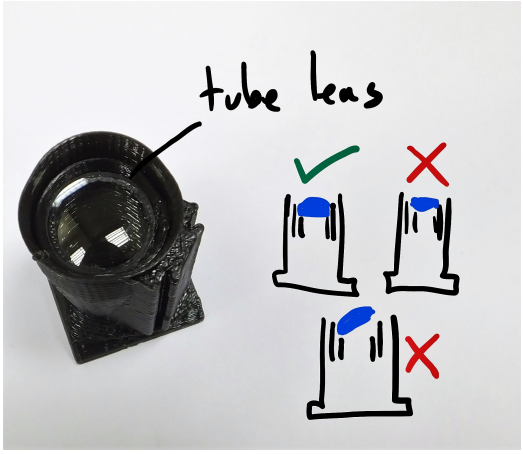
Step 2. WARNING! The camera board is static sensitive. Take the usual anti-static precautions (ideally use an anti-static wristband connected to ground, but at the very least make sure you touch an earthed object, such as a metal pipe, before working on the camera module.

Step 3. Before assembling the parts into the holder, make sure it's free from dust by blowing some air through it, and check there are no strings of plastic in the central hole through the mount.

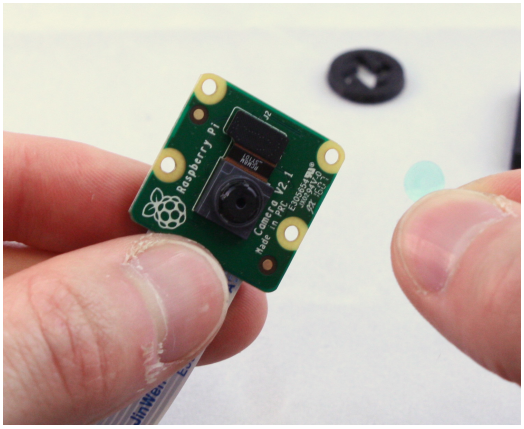
Step 4. First, insert the tube lens into the holder. Place the lens on the insertion tool, curved side down. Take the optics module, and line it up with the lens. Push down, and the lens should pop into place. Take care to keep the optics module straight as you do this.



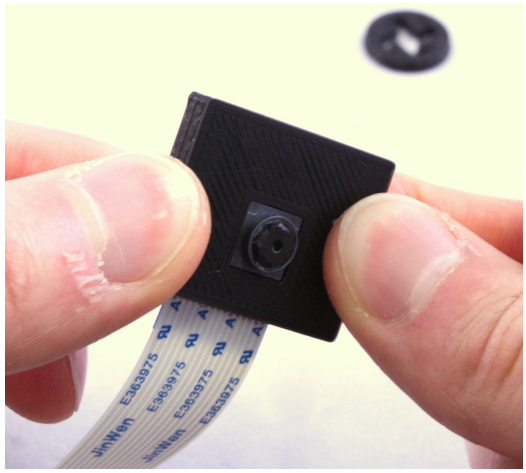
Step 5. If the lens does not sit flat, place the optics module on the insertion tool and push again - it may require some force, and you should hear it click into place.

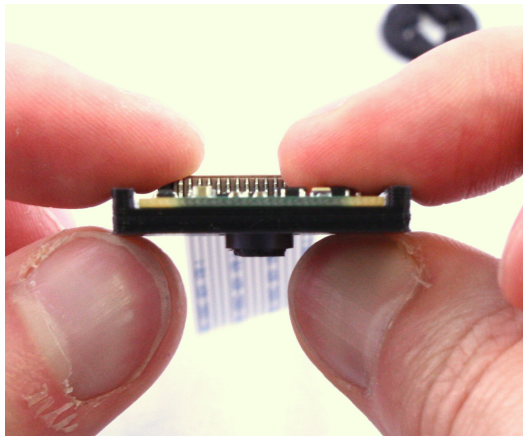


Step 6. Remove the protective film from the camera lens.

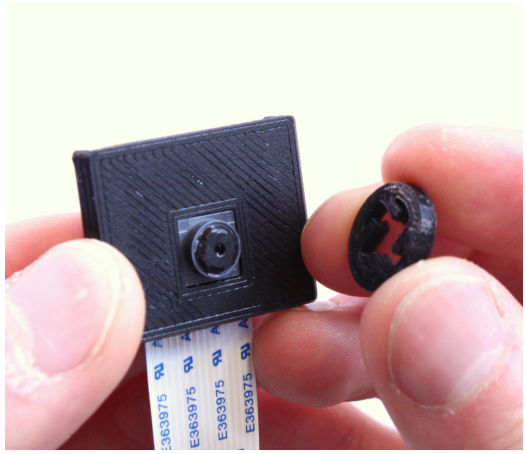


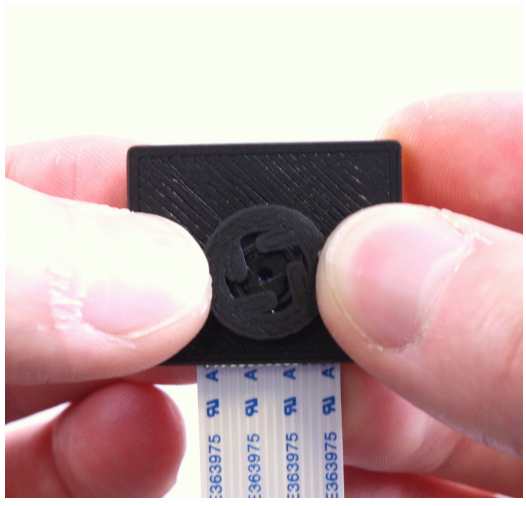
Step 7. There is a small ribbon cable connecting the camera to the PCB that is very easy to break. There is a square plastic jig that fits over the camera and PCB (the "camera board gripper"), which stops the camera twisting and damaging the ribbon cable. Fit this over the camera as shown. Note that the part for v2 of the camera board will sort-of fit v1, but you need to be a little more careful as it's not a perfect fit. For USB webcams, the lens can simply be unscrewed from the back of the PCB with a small screwdriver.



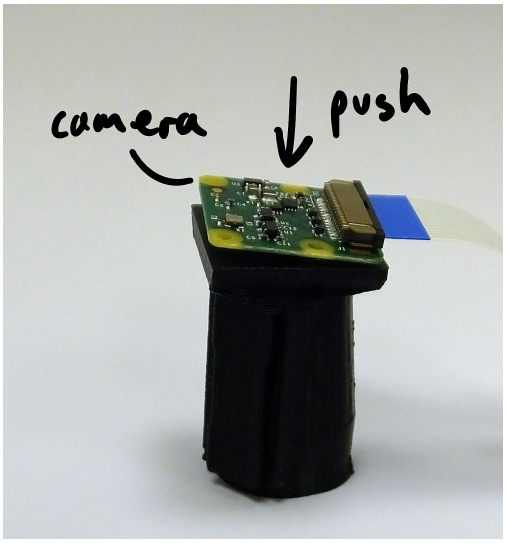


Step 8. Next, unscrew the lens from the camera module. Use the plastic tool to grip the lens module. This is a small circular part with four prongs that fits over the lens of the camera board (version 2 only) as shown. To remove the lens, push the removal tool onto the lens (just the top part, with the little plastic flanges) and turn anticlockwise to remove it. It only works if the prongs are pointing anticlockwise, so make sure it's the right way round. You will may feel a crack as it starts to move - this is normal. It's important to use the board gripper to hold the camera chip in place and prevent damage to the delicate ribbon cable. After you've removed the lens, check that the little black ribbon cable connecting the camera module (square plastic housing) to the PCB is still connected - pop it back in by pushing it with a finger if needed. If you are using a USB camera, the lens is held on by two screws from the back, and can be removed by unscrewing these. SAVE THE SCREWS, as you will need them later! Once you've removed the lens, either cover the sensor (without touching it) or fit the camera to the optics module immediately, to avoid dust buildup on the sensor..

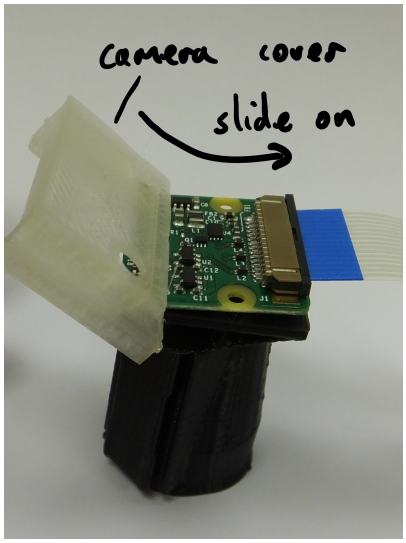




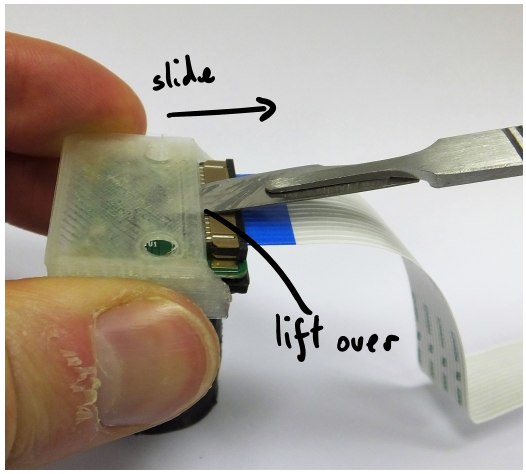
Step 9. Press the camera module onto the bottom of the optics mount, so the camera board sits flush with the bottom of the mount - it should fit in with a gentle but firm press from your thumb. It probably won't crack or click into place, but it should be held by the push-fit. Don't worry if it's not gripped very strongly, the cover will hold it in place. If you're using the USB version, the board simply screws onto the optics module using the screws that held the lens on.



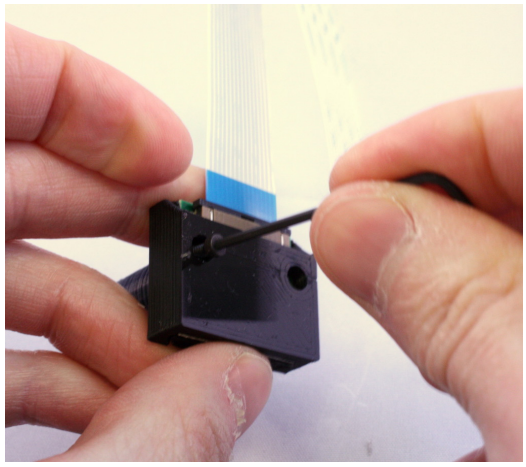
Step 10. Slide the cover over the camera module. It can help to tilt the cover as you start to fit it on.



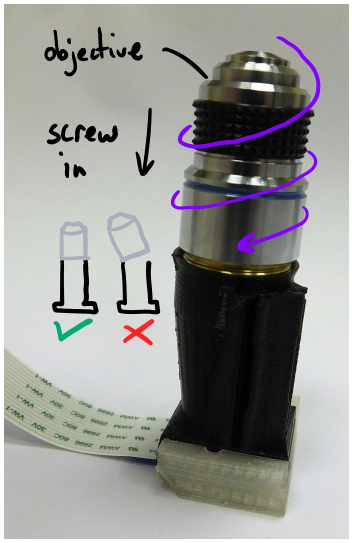
Step 11. The cover is a deliberately tight fit. If it's too tight to fit over the ribbon cable connector, you can ease it over with a craft knife, fingernail, or piece of card.



Step 12. Lastly, if you want to make the module more robust, you can insert two M2 screws from the bottom, to lock the cover on and hold the PCB in place. This is useful if the ribbon cable might be pulled accidentally, for example.



Step 13. Finally, screw the objective into the tapered opening at the top of the module. Take care to keep it aligned with the axis of the module - when it is screwed down, you don't want a gap anywhere between the top of the plastic and the bottom of the objective "shoulder". This may be a tight fit - sometimes clamping the optics module in a vice is helpful.



Actuator assembly

Abstract: An actuator, based on an M3 screw, brass nut, and elastic bands, that can precisely and repeatably move a plastic flexure mechanism.

Description: This assembly is used to actuate each of the three axes of the OpenFlexure Microscope stage. It consists of a plastic gear that fits onto an M3 screw, which then pulls up on a brass nut. Elastic bands pull down on the nut, tensioning the system. This confers two benefits: firstly, it allows us to actuate the flexure mechanism both up and down - doubling the travel - and secondly, it eliminates much of the backlash from the system.

An actuator, based on an M3 screw, brass nut, and elastic bands, that can precisely and repeatably move a plastic flexure mechanism.

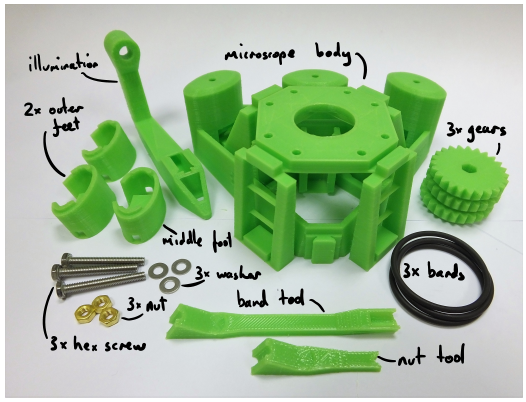
License: CERN Open Hardware License

Requires:

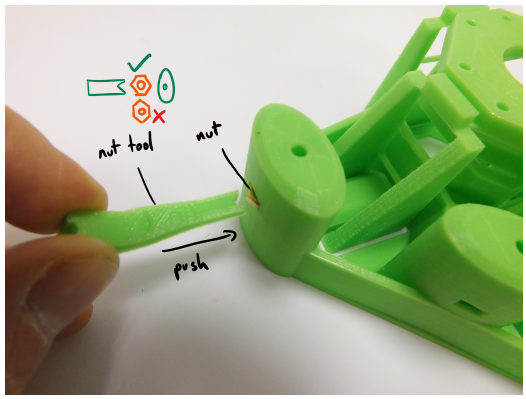
Lead screw: 25mm M3 Hexagon-head screw, Qty:3 **x 0**
Nut for lead screw: M3 Nuts (preferably brass), Qty: 3 or 4 **x 0**
Washer: M3 Washer, Qty: 3 or 4 **x 0**
Return spring: Viton O ring, 30mm inner diameter, 2mm cross section, Qty: 3 **x 0**
Actuating gear/thumbwheel: Camera lens removal tools **x 0**

Instruction:

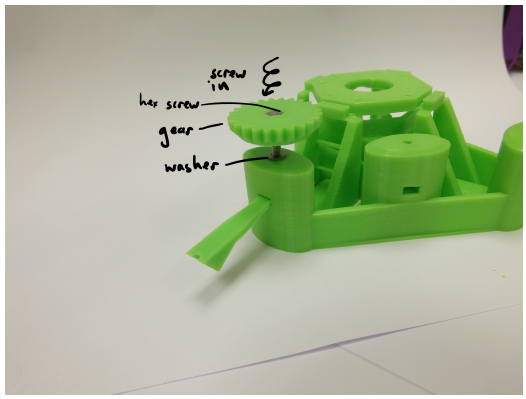
Step 1. There are three of these actuators on the microscope: these steps should be followed for each one in turn. Note the quantities in the parts list are for one actuator, and they don't include the microscope body. The image for this steps shows everything you will need to assemble the three actuators (NB the illumination arm is not yet needed).



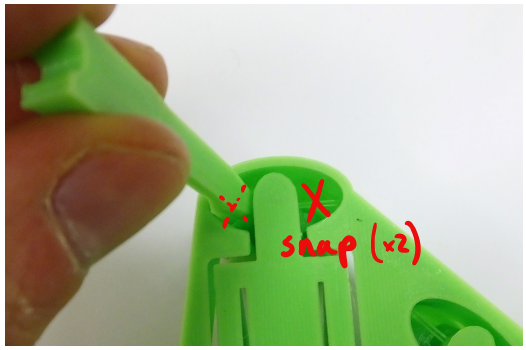
Step 2. We need to place a nut inside each actuator. Insert it from the side, through the slot in the actuator column, and push it into place with the tool. Take care to insert the nut corner-first (i.e. with flat sides parallel to the tool), otherwise it will jam.



Step 3. Next, put one of the hex-head screws into the gear, and screw into the nut that is now inside the actuator. Use a washer between the gear and the microscope body.

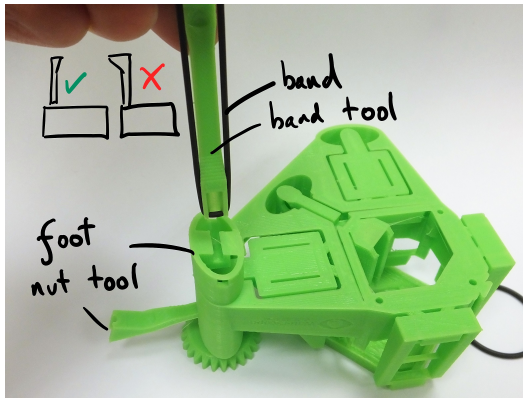


Step 4. Turn the microscope over and, using the elastic band tool or a craft knife, snap the two thin plastic supports as shown.

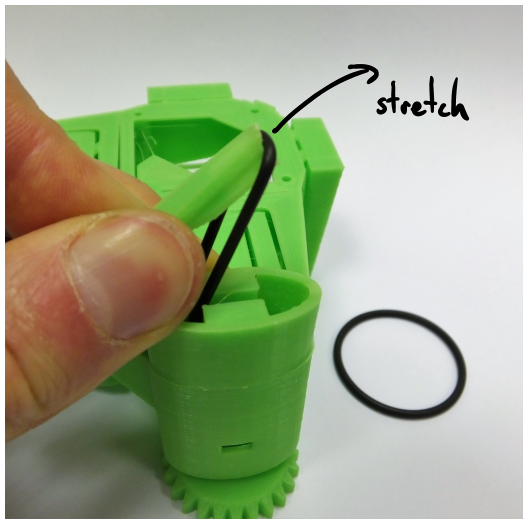


Step 5. Fit the foot to the bottom of the microscope. NB the two tilted feet must go on the outside of the microscope, and the gap in the foot points towards the optics module.

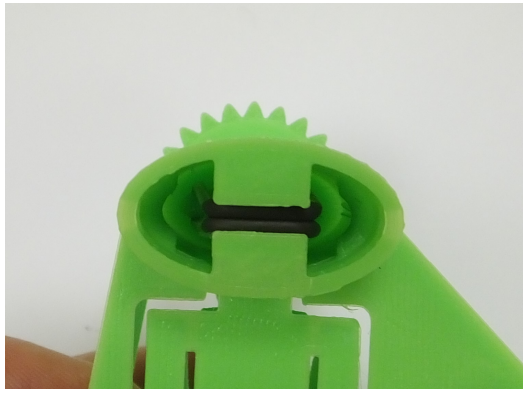
Step 6. Hook one of the Viton (or rubber) bands over the elastic band tool, and insert it through the foot. Push in until it clicks into place on the hook. If you are using #32 rubber bands, you should probably double up the band so it's properly stretched, otherwise it will be too long. NB the band tool will only work one way round; the flat side should be towards the outside of the foot, the handle points inwards.



Step 7. Hook the tool through the free end of the band, and stretch it up, before inserting that end of the band into the other side of the actuator. If possible, lift the band up so it doesn't catch on the foot while you do this - otherwise it's possible to overstretch and tear the band.



Step 8. You should now have the band pulling both sides of the actuator down as shown. If you used a long elastic band, you can break the thin layer at the bottom of the foot on either side, to pull the band out and wrap it around the foot to tighten it. This is not necessary for the Viton bands, or if you're using doubled-over #32 bands.



Step 9. Congratulations, you've assembled the actuator! There are three to do, so you may now need to go back and make the next one.

Illumination Arm (fixed)

Abstract: A holder for an LED to take images in transmitted light.

Description: The illumination arm holds an LED above the sample, for simple transmission images. The adjustable version with a condenser lens will get higher resolution and brightness.

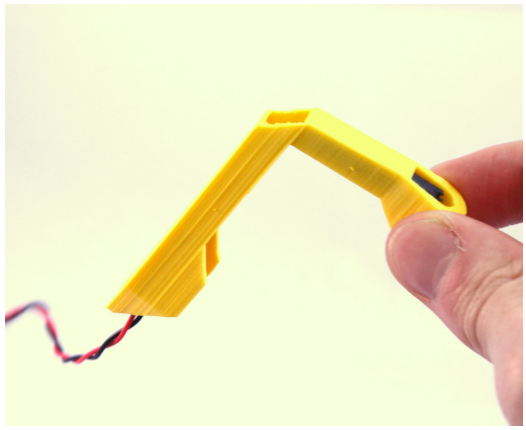
A holder for an LED to take images in transmitted light.

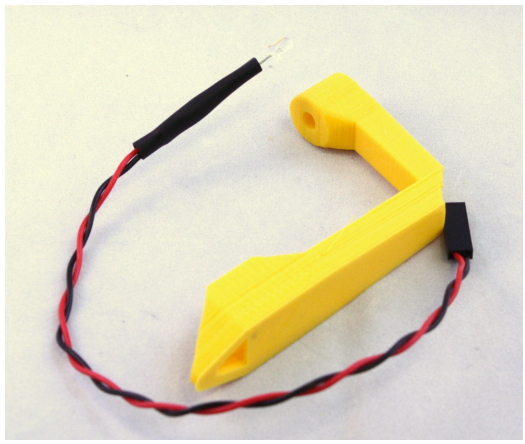
Requires:

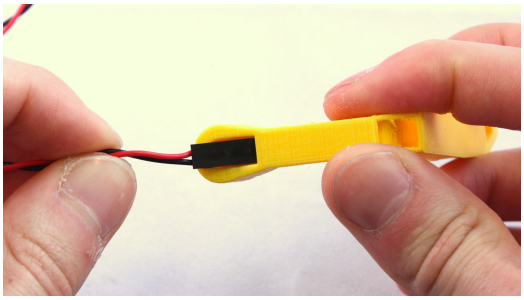
Illumination: Gear/thumbscrew, Qty: 3 **x 0,** Jumper wires with female header pin connectors **x 0,** Illumination arm and rear foot **x 0**

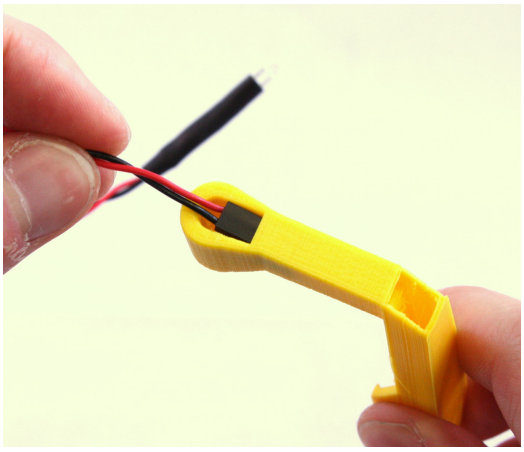
Instruction:

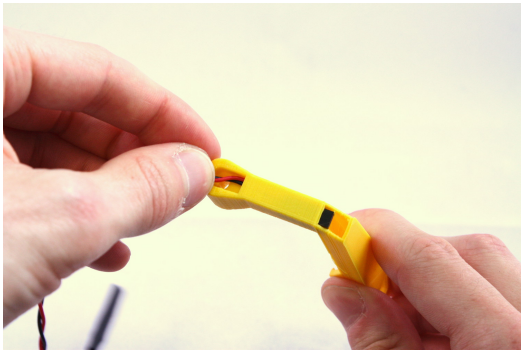
Step 1. Assemble the illumination: Bend the LED so it's pointing at right angles to the cable, then thread the wire for the LED through the illumination arm and push the LED into its hole. It's usually easiest to start at the LED end and feed the connector into the mount (it might require a little force). If you have a pre-made LED wire with a connector on the end, threading it through is all that's needed - if you just have the components you will need to connect them together in series first, and solder or crimp them. Some of the pre-made LED wires are thicker than expected, so they take some force to pull into the arm - but they will go in with some perseverance! You can stick a piece of white tape or sticky label over the LED (i.e. between the LED and the stage) to act as a diffuser, this helps to blur out out-of-focus artefacts, such as dirt on the wrong side of your microscope slide.

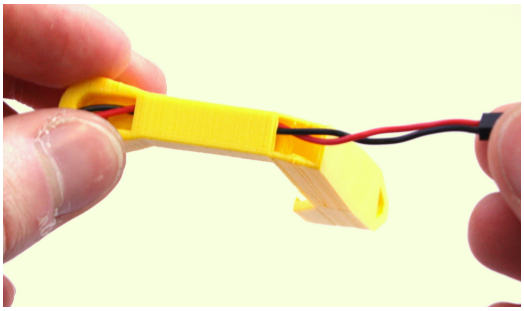


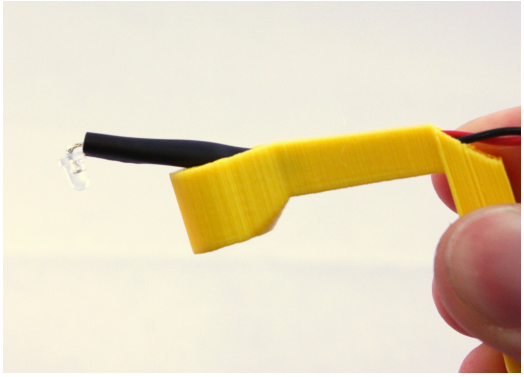


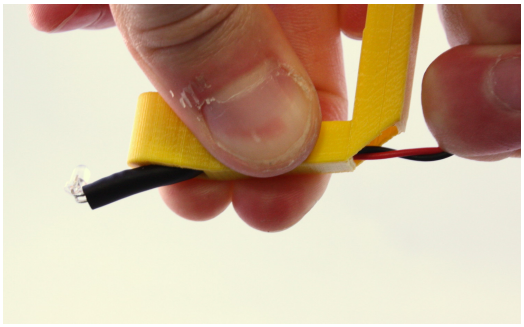


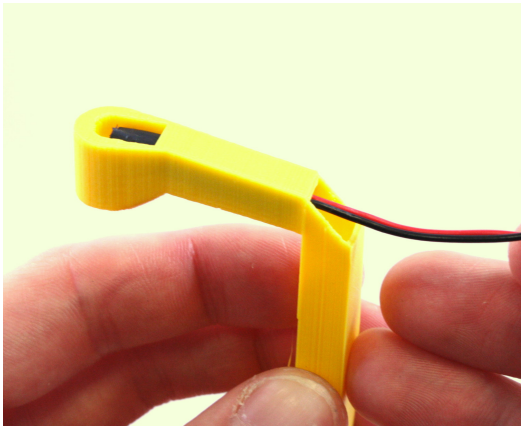


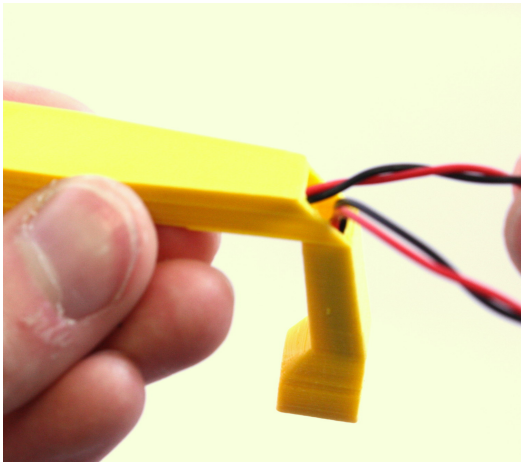


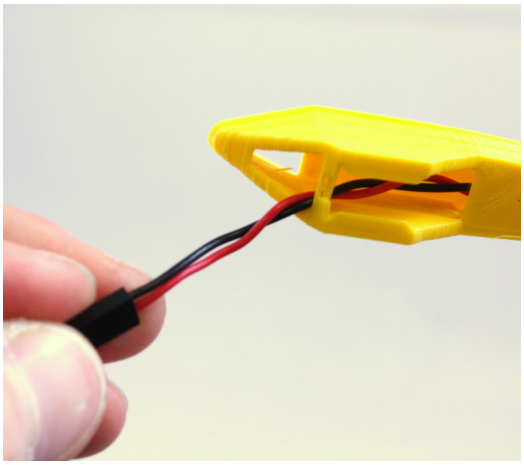




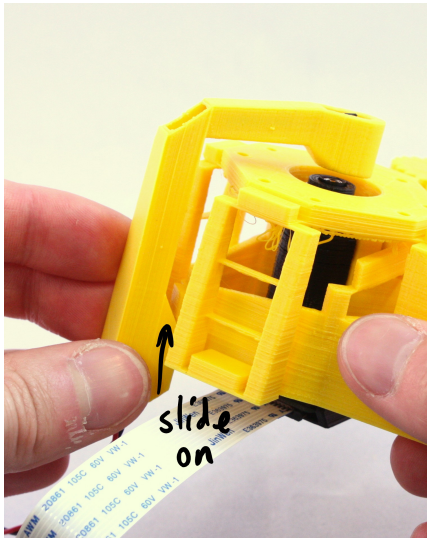


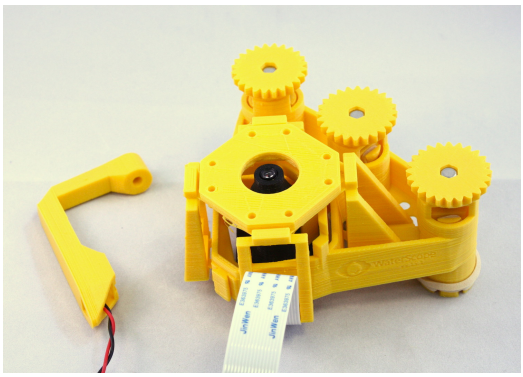


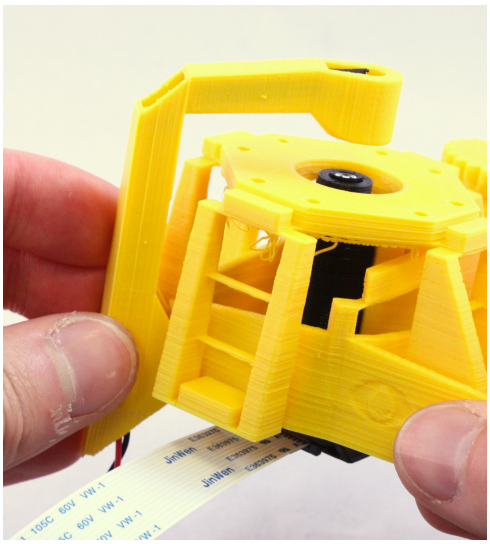




Step 2. Slot the illumination arm on to the dovetail mount for it at the back of the microscope. Wiggling it slightly makes it easier to push on. It should be pushed on from the bottom, and on version 5.15.1 and later, there should be a stop to prevent it sliding up and off.







Illumination Arm with Condenser

Abstract: A holder for an LED and lens to take images in transmitted light.

Description: The illumination arm holds an LED above the sample, with a condenser lens. It will get higher resolution and brightness. There is a screw holding the two parts together, which goes through a slot to allow simple, slip plate style adjustment of the condenser alignment.

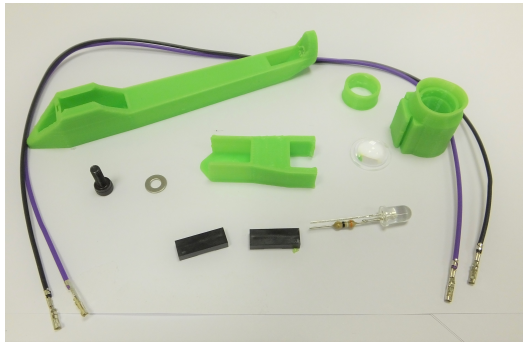
A holder for an LED and lens to take images in transmitted light.

Requires:

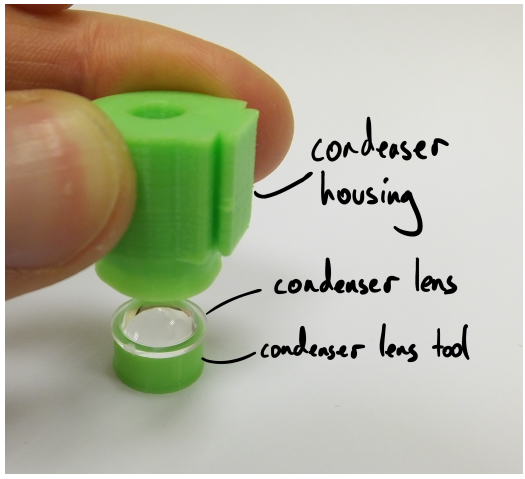
Illumination: Gear/thumbscrew, Qty: 3 **x 0,** Jumper wires with female header pin connectors **x 0,** Illumination arm and rear foot **x 0,** M3 Nuts (preferably brass), Qty: 3 or 4 **x 0,** M3 Washer, Qty: 3 or 4 **x 0,** 8mm M3 screws, Qty: 2 or 3 **x 0**

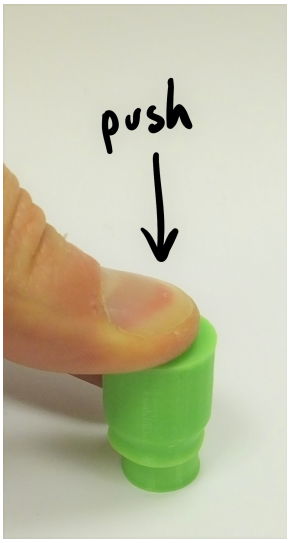
Instruction:

Step 1. To build the condenser, you will need the two parts of the mounting arm, an M3 screw and washer, the cable, LED, and lens, and the condenser housing. You will also need the printed lens insertion tool to put the lens into the holder.

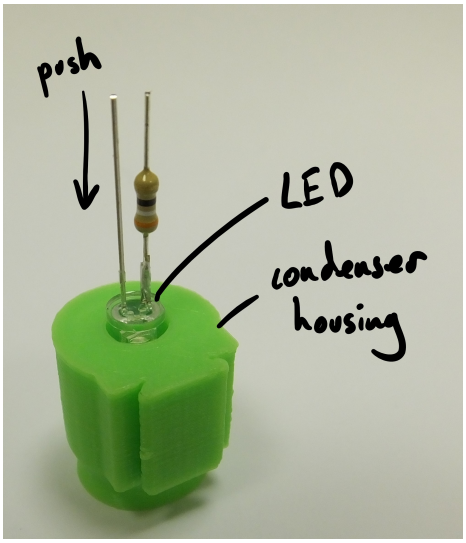


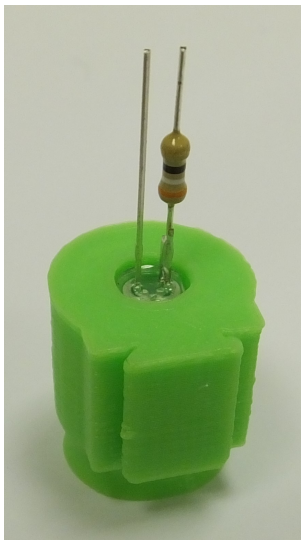
Step 2. Place the condenser lens on the insertion tool (flat side down), and push the condenser housing down onto it. Take care to keep it vertical. You may need to push fairly hard. As with the tube lens in the optics module, check it's flat and push again if necessary.



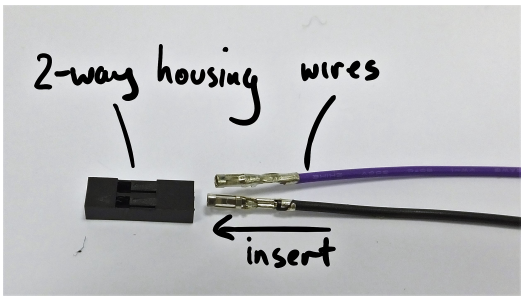


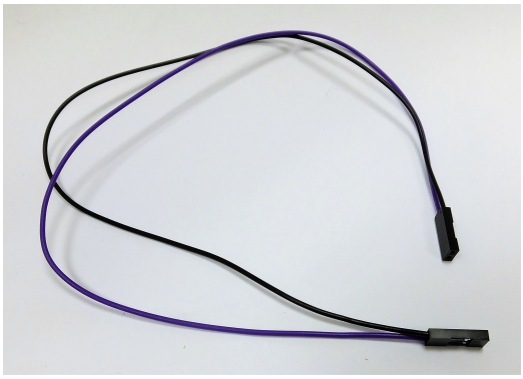
Step 3. Insert the LED into the condenser housing. It should push-fit and stay in place. It can be glued if it doesn't stay in.





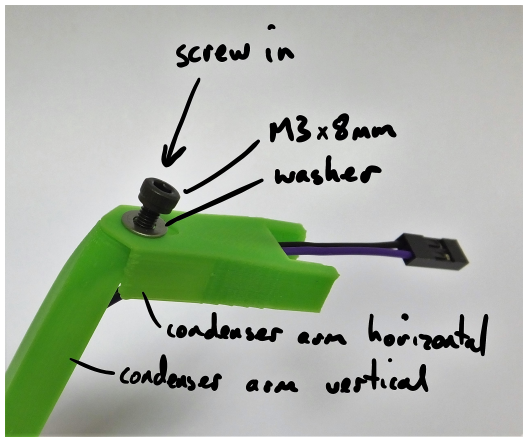
Step 4. Assemble the cable for the LED. If using pre-crimped cables, as supplied with our kit, fit the 2-way header to either end. Don't worry about polarity, it's easy and harmless to simply rotate the connector 180 degrees if you need to.



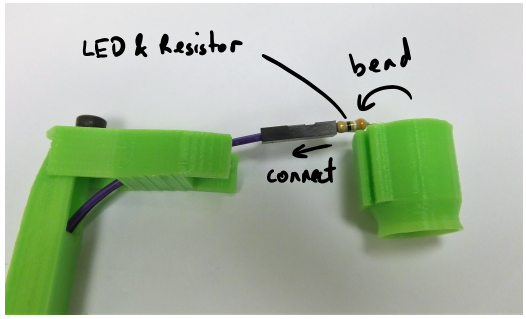


Step 5. Thread the cable through the mounting arm as shown. It's much easier to do this before assembling the arm.

Step 6. Screw the horizontal part of the mounting arm onto the vertical part. The hole should be about the right size for an M3 screw to self-tap.

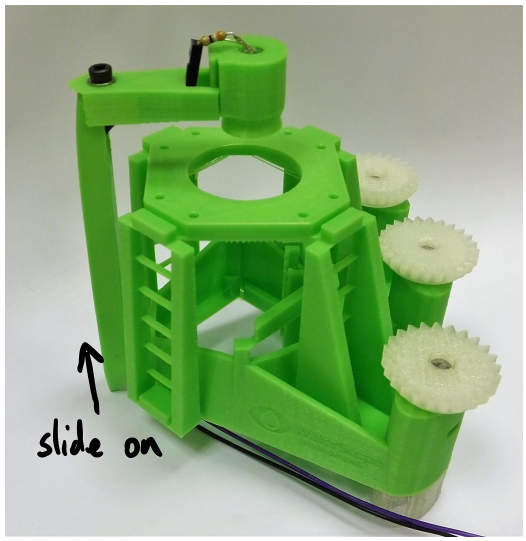


Step 7. Connect the LED to the cable by pushing the legs into the 2-way housing.



Step 8. Slide the condenser housing onto the dovetail clip at the end of the arm. Wiggling it from side to side might help if it's stiff.

Step 9. Fit the illumination arm to the microscope by sliding it onto the dovetail from underneath. The thin linker between the two sides of the clip may snap - this is not a problem, it's there only for support during printing..



Part: M3 Nuts (preferably brass), Qty: 3 or 4

Description: M3 Nuts (preferably brass), Qty: 3 or 4

Supplier: Anglian Fasteners Limited

Supplier catalog #: 11355

URL: www.anglianfasteners.co.uk

Instruction:

Step 1. These nuts form part of the actuator. Brass ones will have less friction and result in smoother motion, though it's possible they will wear out more quickly. An extra one is required by the adjustable illumination arm, which needn't be brass.

Part: 25mm M3 Hexagon-head screw, Qty:3

Description: 25mm M3 Hexagon-head screw, Qty:3

Supplier: Anglian Fasteners Limited

Supplier catalog #: 6663

URL: www.anglianfasteners.co.uk

Instruction:

Step 1. These screws are used as the lead screws for the stage; stainless steel is probably best. If hexagon-head screws are not available, a good substitute is to screw a nut tightly against the head of the screw, so the screw can still be turned by the thumbwheel or gear.

Part: M3 Washer, Qty: 3 or 4

Description: M3 Washer, Qty: 3 or 4

Supplier: Anglian Fasteners Limited

Supplier catalog #: 7118

URL: www.anglianfasteners.co.uk

Instruction:

Step 1. The washers fit between the gears and the microscope. An extra one is required by the adjustable illumination arm.

Part: 8mm M3 screws, Qty: 2 or 3

Description: 8mm M3 screws, Qty: 2 or 3

Supplier: Anglian Fasteners Limited

Supplier catalog #: 14315

URL: www.anglianfasteners.co.uk

Instruction:

Step 1. These screws attach the sample clips. A further screw is used in the illumination arm, if you have an adjustable one.

Part: White LED, 5mm diameter, 15 degree beam angle

Description: White LED, 5mm diameter, 15 degree beam angle

Supplier: Farnell Element14

Supplier catalog #: 1716696

Manufacturer catalog #: OVL-3321

Instruction:

Step 1. The white LED is for illumination. Exact specifications are unimportant, but this is the one I use. 5mm diameter is what I've designed for, but there's no reason you couldn't tweak the illumination arm to use a 3mm LED.

Part: 60 Ohm resistor

Description: 60 Ohm resistor

Supplier: Farnell Element14

Supplier catalog #: 1565328

Manufacturer catalog #: MFR3-68RFC

Instruction:

Step 1. This resistor allows the LED to be run from a 5V GPIO pin on the Raspberry Pi. If you use a different LED, you may need a different resistor. Note the maximum current you can draw from the Pi is not huge.

Part: Jumper wires with female header pin connectors

Description: Jumper wires with female header pin connectors

Instruction:

Step 1. You need wires to connect the LED to the 5V power supply from the Raspberry Pi. If you've bought a kit, it will be supplied with a ready-made lead that has the LED at one end and the header connector at the other end. My preferred DIY option is two cores from a ribbon cable, soldered to the LED and resistor at one end and with a crimped-on connector at the other. If you want a no-soldering solution, four female-female jumpers allow you to connect everything (using a cut-off leg of the resistor to join two of them together).

Part: Viton O ring, 30mm inner diameter, 2mm cross section, Qty: 3

Description: Viton O ring, 30mm inner diameter, 2mm cross section, Qty: 3

Instruction:

Step 1. The O-rings function as springs, to provide a return force on the nut that is pulled upwards by the screw. I use Viton O-rings, 30mm ID, as they provide about the right force. You can substitute for number 32 elastic bands, which are about 3mm wide and about 150mm in circumference (i.e. 75mm long when measured as a loop). If you use these, you should fold them in half, so you have a band that's effectively 75mm in circumference. Buying a band that size is a bit difficult, but if you can get one, great!

Part: Raspberry Pi

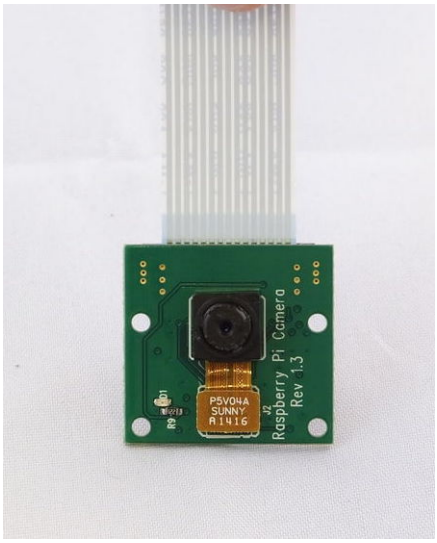
Description: Raspberry Pi

Instruction:

Step 1. Any model will do! If you buy a kit, it may or may not come with a Pi. NB if you buy a Pi Zero, only the Zero+ has a camera connector, and even that needs a special lead. Of course, if you're using a camera that's not the Raspberry Pi camera module, you can use whatever USB-compatible device you like.

Part: Camera Module

Description: Camera Module



Supplier: Raspberry Pi

Manufacturer catalog #: Camera Module v2

Instruction:

Step 1. NB I've pictured v1.3 of the camera board here; the microscope is designed to work with v2 of the board, although older versions of the optics module exist that work with v1. You can also use a webcam, and there are versions of the optics module available to use the Logitech C270 and a USB webcam supplied by WaterScope.

Part: Microscope Body

Description: Microscope Body

File: main_body_SS.stl

File: main_body_SS-M.stl

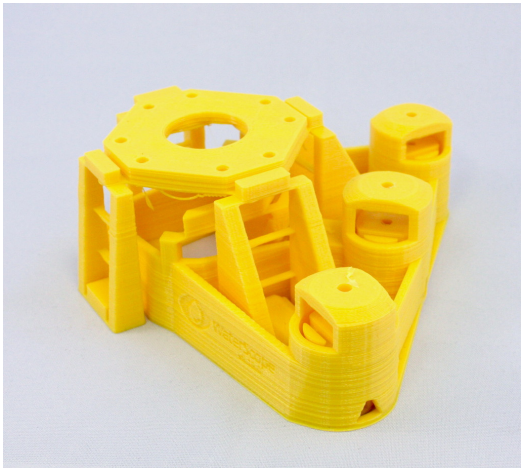
File: main_body_LS65.stl

File: main_body_LS65-M.stl

Material usage: 0.1 KG

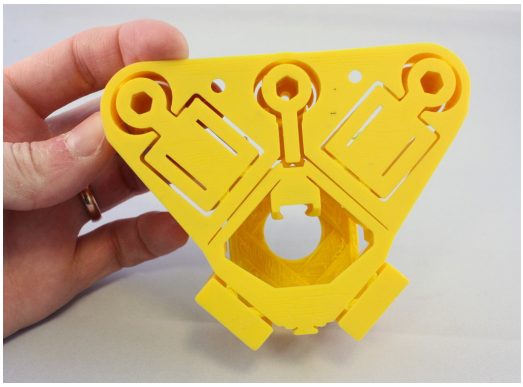
Instruction:

Step 1. This should be printed without support material. On smaller/less well calibrated machines, I print this part on its own and then print the rest of the parts in a second print. Which version of the body you need depends on two things: firstly, whether you want to use a large optics module (versions with LS65 in the name) or a small one (versions with SS), and secondly whether you want attachment lugs for motors (files with -M in the name). All the files start with `body_`.You need the SS version if you're using a Raspberry Pi camera or a Logitech C270 camera, together with the lens that came on the camera. If you're using a microscope objective, or the USB camera with M12 lens, you need the LS65 version. The microscope body takes around 8 hours on a RepRapPro Ormerod (and many other low-end printers) or about 5 hours on Ultimaker, MakerBot, and the like.



Step 2. After printing, you should run a 3mm drill bit through the 3mm holes in each actuator, to ensure the screws can rotate freely. If you don't have a drill, an M3 screw should do...

Step 3. If the bottom layer has oozed out too much, or if you used a brim (not reccommended) you might need to clean up the bottom so it looks like this - it's important that the moving parts aren't stuck to the body with a thin layer of plastic (this most often happens around the struts connecting the objective clip to the rest of the microscope).



Step 4. You may need to use needle-nose pliers to pull strings of plastic from the underside of the microscope stage or the underside of the caps of the actuator columns. If your printer is correctly calibrated there shouldn't be much, and I often get away without any - but some printers (particularly if using ABS) are prone to a bit of "spaghetti" under the stage.

Part: Microscope feet, Qty: 3

Description: Microscope feet, Qty: 3

File: feet.stl

Material usage: 0.01 KG

Instruction:

Step 1. You need two tilted feet and one untilted foot, as provided in feet.stl.

Part: Optics module plastic parts

Description: Optics module plastic parts

File: optics_picam2_pilens.stl

File: optics_picam2_rms.stl

File: picam_cover.stl

File: optics_usbcam_M12.stl

File: optics_usbcam_rms.stl

File: optics_c270_ownlens.stl

File: optics_c270_rms.stl

Material usage: 0.01 KG

Instruction:

Step 1. There are several versions of the optics module, depending on your camera (Raspberry Pi Camera v2, Logitech C270, or WaterScope USB camera) and on whether you will use the lens from the camera (pilens, M12, ownlens) or an RMS objective and 40mm tube lens. Make sure you pick the right STL file for your camera module! There is a cover that fits over the Raspberry Pi camera module, and holds it firmly onto the optics module.

Step 2. The optics module needs to print with some fine detail, so the dovetail meshes nicely with the stage. A good way to ensure this is to print it at the same time as other parts - either print more than one optics module at a time, or print it at the same time as the microscope body. This slows down the time for each layer, and means the plastic can cool more completely before the layer on top is deposited, resulting in a higher-quality part. The optics module is best printed in black to cut down on stray light inside the tube - though it will still work in other colours.

Part: Camera lens removal tools

Description: Camera lens removal tools

File: picam2_lens_remover.stl

File: picam2_board_gripper.stl

File: picam1_board_gripper.stl

Material usage: 0.01 KG

Instruction:

Step 1. These tools make it much easier to remove the lens from a Raspberry Pi camera module. See the documentation for the Raspberry Pi Camera Mount/Extension Tube for instructions. These tools are for version 2 of the camera board. The board gripper for v1 is included for convenience - you'll need a small pair of pliers (I like mini combination pliers) to unscrew the lens if you have v1 of the board. v2 of the Raspberry Pi camera module now comes with a lens removal tool, which is better than the printed one - but the board gripper is still useful.

Part: Gear/thumbscrew, Qty: 3

Description: Gear/thumbscrew, Qty: 3

File: large_gear.stl

Material usage: 0.01 KG

Instruction:

Step 1. These gears are used to control the leadscrews that move the stage. You can replace them with more comfortable thumbscrews if desired, or use stepper motors to drive them automatically. You need three gears. NB the gears are designed to print with the circular face down, this avoids marring of the teeth and helps it stick to the bed better.

Part: Optics (optional)

Description: Optics (optional)

Instruction:

Step 1. If you are not simply using the lens that came with your camera, you will need an RMS microscope objective. The LS65 version of the microscope body is compatible with 25mm parfocal length objectives; if you have a longer 35mm parfocal length objective you'll need to either print a taller LS75 body, or fit a 10mm spacer to raise the sample up higher. If you are using an RMS objective, you'll also need to use a tube lens; 16mm diameter, 40mm focal length (e.g. [Comar 40 PQ 16] (http://www.comaroptics.com/components/lenses/simple-convex-lenses/quality-planoconvex-lenses#row-40_pq_16))

Part: Condenser Lens (optional)

Description: Condenser Lens (optional)

Instruction:

Step 1. If you want to use a condenser lens, so far I've based the design around a 12mm diameter lens, with a focal length of about 12mm. WaterScope can supply these, contact them for more details.

Part: Illumination arm and rear foot

Description: Illumination arm and rear foot

File: illumination_and_rear_foot_standard_stage.stl

Material usage: 0.01 KG

Instruction:

Step 1. The illumination arm fits on to the microscope using a dovetail, and includes the rear foot. If using the non-adjustable version, this prints best with other parts of a similar height, e.g. other illumination arms, the optics module, or the microscope body. The adjustable versions print flat, so they shouldn't be a problem. The condenser lens optics will also work without a lens, though the image won't be as bright. The illumination arm is available in 4 versions: they all start with `illumination_and_back_foot_` and then you can choose either adjustable arm with a bare LED, or bare LED plus tape (`adj`) or one that uses a condenser lens (`condenser`). It's important to match the type of microscope you're using (LS65 or SS). If you are using a riser to make space for a larger objective (if you've got a 35mm parfocal length objective) you'll need the LS75 version.

Part: Sample Clip, Qty:2

Description: Sample Clip, Qty:2

File: sample_clip.stl

Material usage: 0.002 KG

Instruction:

Step 1. These are optional, but they are useful for holding slides on the stage. Usually, I use two of these for a normal microscope slide, screwed onto the top of the stage.

Part: Microscope leg test object

Description: Microscope leg test object

File: just_leg_test.stl

Material usage: 0.01 KG

Instruction:

Step 1. This test piece checks your printer can bridge between the tops of the legs without failing. If it passes this test, you're probably fine to print the rest of the microscope.

Authors

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Total bill of materials for this project

Part	Quantity	Supplier	Supplier part number	URL
Optics module plastic parts	2			
Camera lens removal tools	4			
Gear/thumbscrew, Qty: 3	2			
Jumper wires with female header pin connectors	2			
Illumination arm and rear foot	2			
M3 Nuts (preferably brass), Qty: 3 or 4	2	Anglian Fasteners Limited	11355	www.anglianfasteners.co.uk
M3 Washer, Qty: 3 or 4	2	Anglian Fasteners Limited	7118	www.anglianfasteners.co.uk
8mm M3 screws, Qty: 2 or 3	3	Anglian Fasteners Limited	14315	www.anglianfasteners.co.uk
25mm M3 Hexagon-head screw, Qty:3	1	Anglian Fasteners Limited	6663	www.anglianfasteners.co.uk
Viton O ring, 30mm inner diameter, 2mm cross section, Qty: 3	1			
Microscope Body	1			
Raspberry Pi	1			
Microscope leg test object	1			