Mousecam – a head-mounted camera system for freely moving mice

Step-by-step building instructions

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Last updated: July 13, 2018

1 Description

This document contains step-by-step building instructions for the head-mounted camera system described in:

> Meyer AF*, Poort J*, O'Keefe J, Sahani M, Linden JF. *An ultralight head-mounted camera system integrates detailed behavioral monitoring with multichannel electrophysiology in freely moving mice*. (in revision; see also bioRxiv, `https://doi.org/10.1101/294397`)
> (* These authors contributed equally to this work)

If you are using the camera system in your work please cite the above paper.

Remarks: If you are looking for a different variant of the design or want to contribute modified and/or new designs, you can find all files in the mousecam github repository. Please use the *issue tracker* to report problems with building the camera system and create *pull requests* for improved/new designs.

Software: This guide describes the construction of the head-mounted camera system hardware. Running the system, synchronizing it with neural recordings, and extracting pupil position and other variables requires software. Examples include:

- Custom camera software for the Raspberry Pi (RPi), which also integrates with the open-ephys plugin-GUI. As this software uses zeromq (with bindings for many programming languages) for communication between the recording computer and the RPi, it can easily be extended/adapted to other systems.
- A Python package with functions to do pupil tracking, body tracking, image registration, and estimation of head orientation from accelerometer data.
- Code (including open-ephys plugin) for controlling common inertia measurement unit (IMU) sensors and synchronizing movement data with neural recordings is available here.
- A Python package for behavioural scoring (including GUI for manual annotation) can be found here.

Detailed installation instructions can be found in the README.md files of the different repositories.

2 Parts required for building the camera system

Part	Supplier/item	Weight(g)	Cost	Comment
Camera sensor	Adafruit 1937	0.51	£33.00	incl. suspended cable
Camera holder	see 3.1	0.27	n/a	
Mirror holder	see 3.1	0.07	n/a	
IR mirror	Qioptiq Calflex-X	0.15	£4.00	cut to 7 mm x 7 mm
21 G steel cannula	Coopers Needle Works	0.04	£0.10	cut to 20 mm
IR LED	Vishay VSMB2943GX01	0.016	£0.74	
Resistor (150–200Ω)	Farnell Multicomp	0.01	£0.17	package 3216
2 x 36 G wire	Alpha Wire 2936	2 x 0.01	£0.10	50 mm
2 x female gold pin	RS Components 481-500	2 x 0.05	£0.90	cut solder pot
Miniature connector	Omnetics A79007-001	0.09	£50.00	cut thru-hole tails
Preci-Dip connector	852-10-008-10-001101	0.14		alternative to A79007-001

Table 1: **Parts required for building the miniature head-mounted camera system.** Weights were measured using a calibrated micro scale (Satorius CPA225D, Germany). Prices for steel cannula, mirror tiles, and wires were estimated without taking the cost of tools (e.g., glass cutter) into account. 3D printed parts were printed using a commercially available printer (Ultimaker 2+, the Netherlands) and PLA material (colorfabb, the Netherlands). Gray rows indicate alternative parts.

3 Construction of the camera system

Warning

Perform these steps at your own risk and take all reasonable safety precautions. Some safety tips are listed but these are not meant to be exhaustive.

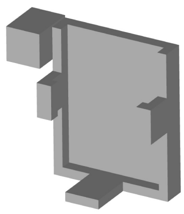
3.1 Custom parts: camera and mirror holders

Required tools and parts:

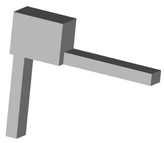
- 3D printer (e.g. Ultimaker 2)
- 3D printing material (e.g. Velleman PLA3B1)
- file, scalpel or other small knife
- camera holder STL file: cam_holder.stl
- mirror holder STL file: mirror_holder.stl

Use the software for your 3D printer (e.g., Cura for Ultimaker) to convert the STL files to a format your printer understands. After printing clean up parts with file or scapel; try to fit camera into holder (fit should be tight); and file side clips until camera fits in holder.
Depending on the printer it might be useful to modify the designs such that minimal filing/cutting is required after printing. The source files (in OpenSCAD format) are available in the mousecam repository in the openscad directory.

Camera holder



Mirror holder



3.2 Assembling of the camera system

Note: construction of the camera system requires some off-the-shelf parts. We provide example parts (supplier/item) as used in the above paper but other parts might work as well.

Required parts and tools:

- Camera and mirror holders (see 3.1)
- 21 G steel cannula (e.g., Coopers Needle Works). We successfully used thin-walled steel cannulas but other cannulas (e.g., a 21 G syringe needle after cutting the tip) will also work.
- Infrared (IR) mirror (e.g., Qioptiq Calflex-X)
- Small IR LED (e.g., Vishay VSMB2943GX01)
- Small resistor, 150–200 Ω (e.g., Farnell Multicomp, package 3216)
- 2 x 30–36 AWG wire (e.g., Alpha Wire 2936); length $\approx$ 5 cm
- Miniature connectors for connecting the camera system to the implant/skull (e.g., Omnetics A79007-001/A79010-001 or 8-pin Mill-Max connectors)

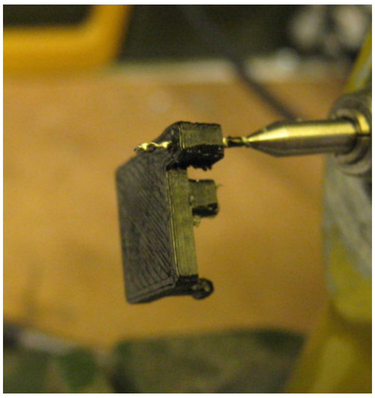
- optional: 2 x female gold pin (e.g., RS Components 481-500)
- Dremel (e.g. Proxxon D-54518) with cutting disc (e.g. wheel no. 409) and 0.8 mm drill bit (DU68.10)
- glass cutter; most glass cutters should work. We successfully used this one.
- 2 combination pliers; if available 1 self-locking hemostat pliers
- A length measuring device (e.g., ruler or caliper)
- A thin and straight solid object, e.g., a metal ruler, for guiding glass cutter

Steps:

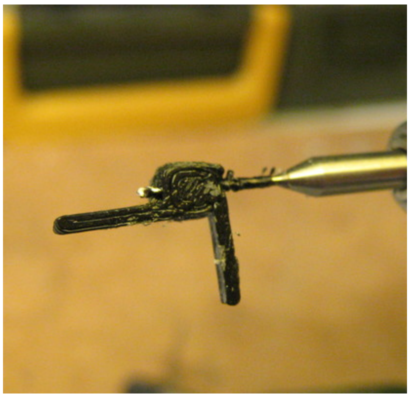
1. Drill hole in the camera holder with Dremel and 0.8 mm drill bit (Figure 1a). Use hemostat or other pliers (not shown in photo) to hold the camera holder while drilling.
2. Drill hole in the mirror holder (holding it with pliers) using Dremel and 0.8 mm drill bit (Figure 1b).
3. Cut cannula (21 G) to $\approx$ 2 cm with cutting disc on Dremel (Figure 1c). Use safety glasses and hold both ends with pliers. Bend with second pliers at one of the ends to give sharp bent tip (Figure 1d). The bent tip will be fixed with a drop of epoxy to the back of the camera holder later on to prevent the mirror holder from rotating around the axis of the cannula.
4. Push cannula from the back of the camera holder through the hole until the back of the camera holder hits the bent tip of the cannula.
5. Bend cannula in the middle ($\approx$ 1 cm) by about $\approx 60^\circ$ using pliers. See Figure 1e for a camera holder with mirror holder and bent cannula.
6. To cut the infrared (IR) mirror (e.g. Qioptiq Calflex-X 25 x 25 mm), first mark desired size (e.g., 7 x 7 mm for a relatively large field-of-view including eye and whiskers) with a removable marker. Score with glass cutter (along a thin solid object, e.g., a metal ruler) along one side of mirror. Break off scored line by holding both sides with pliers and carefully moving one pair up or down (wearing safety glasses). The mirror packing paper, a lens cleaning tissue, or some thin rubber sheet can be used to protect the mirror. Note: breaking glass is tricky and may occasionally result in a jagged edge; repeat until edge is satisfactory. Glue sharp side against mirror holder and cover outside with super glue or epoxy if necessary. It is also possible to use a file to get rid of sharp edges.
7. Glue cut mirror tile to 3D printed mirror holder. A very thin layer of super glue (e.g., Loctite Power Flex Gel) is sufficient to permanently fix the mirror to the mirror holder.
8. Put a very thin layer of super glue onto the cannula and gently push the cannula into the hole in the mirror holder. This will secure the mirror, but will still allow for positioning the mirror later on during calibration (see 5).
9. Attach LED with a tiny drop of super glue to the bottom of the camera holder.
10. Solder a current-limiting resistor to the anode (+) of the LED (unless it is simpler to solder the LED closer to the power source). The value of the resistor depends on the LED and the power source (there are plenty of on-line tools, e.g., this one, to calculate the resistor value). Secure LED and resistor using a thin layer of (transparent) epoxy.

11. Solder two thin wires (30–36 AWG) to the cathode (-) of the LED and the resistor. The length of the wire depends on the distance between the camera holder and the LED power source. For the Intan headstage used in the paper about 5 cm wires were long enough. Moreover, in order to quickly connect/disconnect the wires to/from the power source during experiments it might be useful to use miniature gold pins and sockets. Cut away the solder pots, solder the wires to the pin sockets and secure the wires with a tiny drop of epoxy. Finally, solder the corresponding pins to the power source (e.g., the solder holes of the Intan headstage).

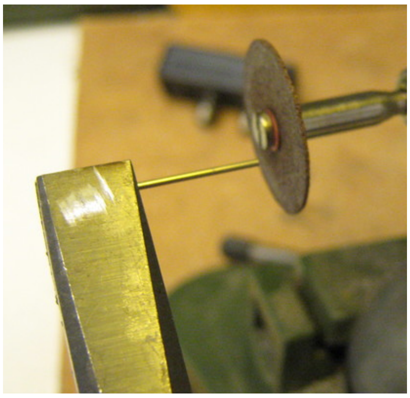
12. Fix connector (e.g., Omnetics A79007-001 after cutting away solder tails) using super glue to the back of the camera holder. See Figure S1 in the paper for an example of a fully assembled camera system with connector.



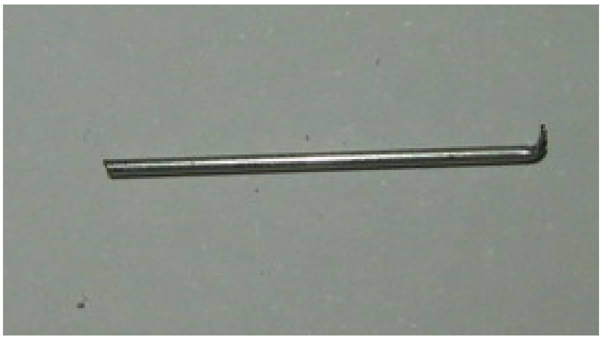
(a) Camera holder



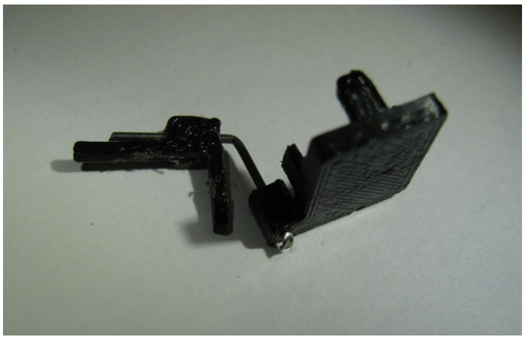
(b) Mirror holder



(c) Cutting of cannula



(d) Cut cannula with bend



(e) Camera and mirror holder with cannula

Figure 1: Building of custom parts.

4 Implantation instructions

See paper for details on surgery. The counterpart of the miniature connector on the camera holder (e.g., Omnetics A79010-001 connector) can be fixed to the implant/microscope or directly onto the skull using strong dental cement (e.g., C&B Superbond, Sun Medical, Japan), so the camera holder can be easily and securely connected to the animal. The position and angle of the connector can be tested during surgery. However, it is possible to make finer adjustments later on by positioning the mirror (see 5). Therefore it is useful to be able to head-fix the mouse after it is fully recovered from surgery (e.g., in a recording set-up).

5 Calibration

The easiest method is to head-fix the mouse and adjust the position of the mirror and the angle of the cannula while monitoring video images using the head-mounted camera. If the mirror holder is not tight enough (i.e. the mirror is slowly moving due to gravity) it is possible to add a very thin layer of super glue around the cannula to increase friction. This allows the mirror to be adjusted but it will stay in the right position. Once the mirror has been adjusted such that the camera shows the desired field of view, carefully take off the camera holder (without touching the mirror), and secure the mirror holder using strong epoxy (e.g., Araldite Steel). Do not glue the mirror holder while the camera system is on the head of the mouse! The LED angle may also need to be adjusted. It is also possible to calibrate the camera in a freely moving mouse, e.g., by restraining the mouse by hand, but this requires experience and is not recommended for those new to the camera system. Another option is to briefly anaesthetize the animal for adjusting the mirror.