# Build your own Raspberry Pi Microscope

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**Since the invention of one of the first microscopes in the 1600's by Antonie van Leeuwenhoek microscopy and imaging have been instrumental in many of the advances in science and scientific research. The teaching of microscopy is often seen as difficult and expensive to do in schools, but microscopy allows one to enter a wonderful and beautiful world beyond the limits of one's own eyesight. The School of Life Sciences Imaging (SLIM) team are all passionate and enthusiastic microscopists and wanted to bring this fascinating microscopic world to schools and the general public. The solution we describe here is a simple yet unique microscope using a Raspberry Pi computer running Linux with a built in camera plus a few nuts and bolts, Perspex and MDF. This model provides a simple and flexible imaging system from scratch using inexpensive components in order to develop their understanding on basic physics, biology and computing.**

The primary aim of the 'Build your own Microscope' outreach project was to inform the primary & secondary students about how imaging is used at the University of Nottingham to conduct research into health and disease. We wanted to engage them and inform them that they too could follow a career in science at a range of levels and qualifications, and to also raise interest in biology, technology and physics through practical exercises. The exercises have led to enhanced teamwork and the production of images, assessed by how well they were completed and the quality and range of images produced. The students were encouraged to experiment and to be creative in the specimens they used and how they imaged them.

The newly developed Raspberry Pi Microscope has been used in a number of other outreach projects including: Pint of Science, May Fest (University of Nottingham open day), Summer School at the University of Nottingham and the Science and Curiosity Fair at Broadway Cinema in Nottingham. The project has generated a great deal of interest from schools, parents and the general public and is continuing to grow. The appeal could possibly be due in part to it being relatively simple to build whilst still producing beautiful images and movies, but also I might add to the enthusiasm and knowledge demonstrated by the SLIM team.

## The Project in Action at Primary and Secondary Schools

The SLIM team have visited several schools in the past year to run practical sessions on the Raspberry Pi Microscope. Target groups for the project were Primary years 5/6 and Secondary years 9/10, these were deemed to be the optimal age groups during the planning stage. The students are given an introduction to microscopy and the lesson aims before building the microscope system in small groups (assisted through demonstrations and full written instructions). Upon completion of the microscope the students are given a range of biological samples such as cumin seeds, sand, flying ants and pond water to look at with the microscopes and capture/save those images using simple Linux commands on the Raspberry Pi computer. They are also encouraged to be creative in how they acquire the images and to image samples from the environment around them (Figure 1).

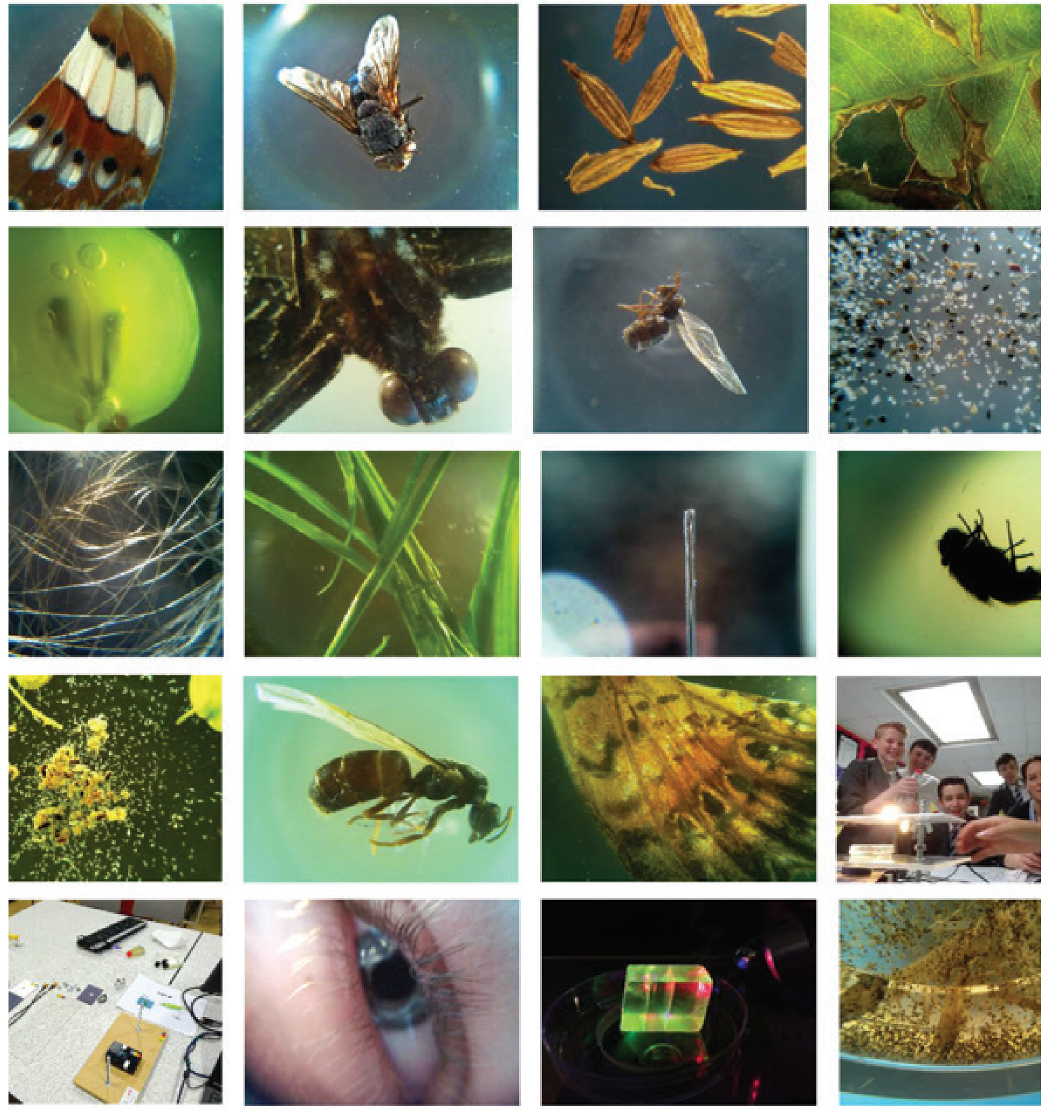

*Figure 1. Images captured during the outreach activities. From left to right, first row: butterfly wing, blue bottle fly, cumin seeds, leaf, second row: grape, butterfly head, flying ant, sand, third row: hair, grass, needle, blue bottle fly, fourth row: pond water, flying ant, butterfly wing, Selston school, fifth row: Raspberry Pi components at Rushcliffe Academy before the activity, eye, crystal illuminated with laser pointers and pond water.*

## Imaging Small Objects

Objects such as fungal, bacterial and yeast colonies, small insects or seeds are difficult to image with classic macro-photography tools but can be imaged or followed in real- time with the Raspberry Pi Microscope. The flexibility of the illumination allows one to create 3D effect illumination, transmitted or dark field illumination so that surface structural features for example on the butterfly wing or a fly can be visualised. Additionally the inverted setup of the stage helps to image large objects/Petri dishes which would not fit under a classical upright microscope. This system is an inexpensive alternative to a stereomicroscope with a camera. A selection of the samples and images acquired with our Raspberry Pi Microscope are shown in Figure 1.

## Setup and Configuration of the Raspberry Pi Microscope

The inspiration came from Kenji Yoshino's idea of building a simple microscope using a smartphone (www.makezine.com/projects/smartphone-microscope). Initially the SLIM team used that setup at May Fest, an open day organised by the University of Nottingham for the general public, but later developed and re-designed it to construct an innovative microscope using a raspberry pi with a built in camera module for image capture (Figures 2 & 3).

All components required to build the Raspberry Pi Microscope can be easily purchased online at www.raspberrypi.org.

### List of components

1. Micro SD card - 8GB pre-loaded with an image of the operating system so can unpack and install.
2. Raspberry Pi camera module
3. Raspberry Pi 2 8GB Desktop Starter Kit
4. Circuit board
5. Monitor, keyboard, mouse
6. HDMI cable to connect Raspberry Pi to the monitor
7. Ethernet cable if internet access is required
8. 2 USB powered reading LED lamps (IKEA)
9. Macro lens with attachment
10. Power supply for the Raspberry Pi (requires ~2000mA (2A), if it's less than 1000mA the camera won't work)
11. Spirit level
12. Microscope base and stage (purchased from a local DIY store)

## Useful commands

| Command | Description |
|---|---|
| raspistill –k | To open a live preview |
| raspistill –o file name.jpg | To save an image with a given file name in jpg format |
| raspivid -o name_of_video.h264 -t 10000 | To record a 10 second video |
| omxplayer name_of_video.h264 | To play the video on the Raspberry Pi |
| --framerate<br>-fps | Specify the frames per second to record. At present, the minimum frame rate allowed is 2fps, the maximum is 30fps |
| raspistill –k –awb tungsten | Auto White Balance. Example method - tungsten |
| raspistill –k –br 100 | Setting a brightness level. Any value between -100 to 100 |
| raspistill –k –co 100 | Setting a contrast level. Any value between -100 to 100 |
| raspistill –k –sa 100 | Setting a saturation level. Any value between -100 to 100 |
| raspistill –k –p 'x,y,w,h'<br>Example: raspistill –k –p '50,300,800,600' | To open the live preview in a specific XY position and size on the screen. |
| sudo apt-get update<br>sudo apt-get install gpac<br>y<br>MP4Box -add original_filename.h264 filename.mp4 | Converting Raspberry Pi camera .H264 video files to. MP4 |

## Instructions

1. Insert the circuit board, camera module and micro SD card in the black box supplied with the Raspberry PI.
2. Glue on the lens attachment (ring) directly above the camera lens, on the Raspberry PI box lid. Place the macro lens on the attachment (magnetic).
3. Connect the Raspberry Pi to the monitor using a HDMI cable.
4. Connect the keyboard and mouse to the USB ports on the Raspberry Pi.
5. Plug in the 2 LED lamps to the USB ports on the Raspberry Pi
6. Connect the Ethernet cable to the Ethernet port on the Raspberry Pi if internet access is required.
7. Finally connect the power supply.
8. Switch on the monitor then the power plug for the Raspberry Pi.
9. Raspberry Pi will boot and a window will appear with a list of different operating systems that you can install. Recommended operating system is 'Rasbian', select this operating system and then click on 'install'.
10. Warning message comes up on the screen, click YES.
11. Rasbian will run through its installation process (approx. 10-15 mins).
12. When the install process has completed, open up terminal and issue the following command:
13. $ sudo raspi-config (this will load the Raspberry Pi configuration menu).
14. Enable Raspberry Pi camera module by selecting option 6 (comm 6).
15. Download the camera software 'Pi Vision' onto the Raspberry Pi. Pi Vision is a graphical user interface for the Raspberry Pi camera. It allows you to control the camera functions without using the terminal.
16. Incentive – easy use of the Raspberry Pi camera. It's also an instructional tool which means that any of the functions/tools used within the software, the commands employed for this will be shown to the user – great way to learn/help new users to understand the command structure.
17. To download the Pi Vision software you will either need access to the internet on the Raspberry Pi or you will need to download the installer file from another PC with internet access onto a USB drive and plug this in to the Raspberry Pi to copy across the file/s.
18. Note: there are only 4 USB ports on the Raspberry Pi so in order to plug in the USB stick you will need to disconnect one of the LED lamps from the box.
19. To run the Pi Vision app you need to first set permissions. Right-click on the app, select Properties > Permissions. Tick the check-box called 'Make this file executable'. Users; 'Everybody'.
20. Double click on the Pi Vision app to run. On the start-up page, there is a button called 'Test Camera Preview'. If the camera is set up correctly when you click on this button it should start a camera preview on the screen. Note that this app allows only 5 sec preview. For a preview window to stay open you need to use the Terminal.

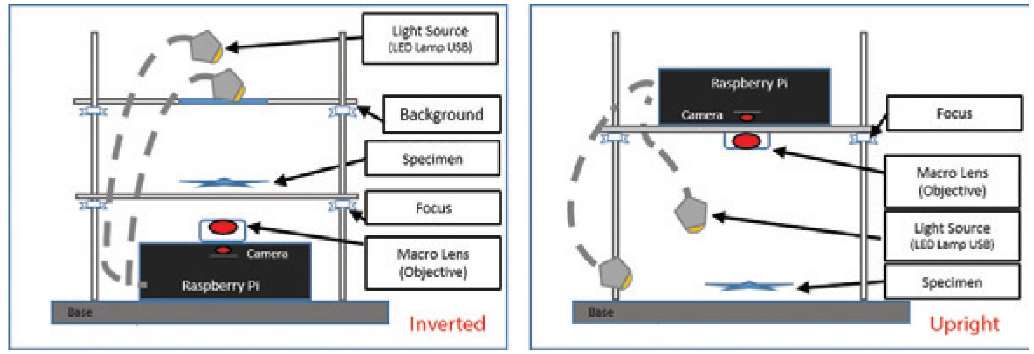


*Figure 2. Labelled diagram of the Raspberry Pi microscope showing the inverted and the upright setups.*

## Conclusion

We have developed an easy to build computer based inverted microscope, using Raspberry Pi with camera module and phone camera macro attachment lens. We have incorporated a flexible illumination – background system, and built it on

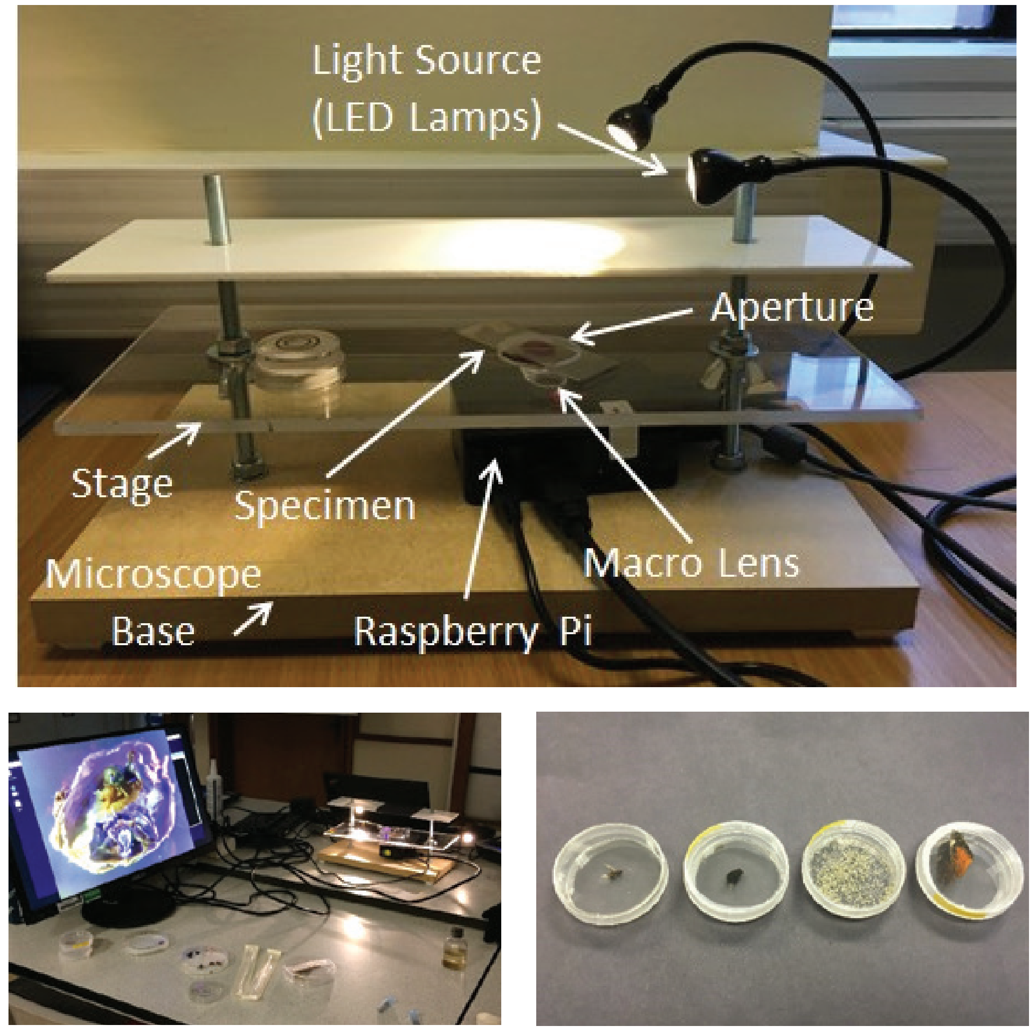


*Figure 3. Assembled Raspberry Pi microscope and samples used in schools.*

a wooden base, in an inverted fashion. The system can be built as an upright microscope as well. The Raspberry Pi Microscope was successfully used in outreach activities, within primary and secondary schools. Using the Raspberry Pi's terminal with the appropriate commands images, videos or even time lapse experiments can be recorded. The microscope has a magnification of 30x, and can produce 5MP images, and FULL HD movies.

This basic system that we have developed can be further modified to include more advanced components. Our future plans are to experiment with the following:

- Increase the magnification using stronger macro attachment lens.
- Add polarisation filters to visualise crystals or minerals
- Incorporate Laser pointers with collimator lenses to create epifluorescence and use long pass fluorescent filters
- Re-design the stage to achieve a fine focusing system
- Construct a more compact/portable version of the microscope to make it more streamlined by re-designing the sample holder and incorporating a touchscreen display.

## Acknowledgements

Thank you to the students of the following schools for the images used in this report: The Nottingham University Academy of Science and Technology, Selston High School, and Whitegate Primary School.

The project was funded by the University of Nottingham Small Grants Scheme Award.

SLIM

School of Life Sciences Imaging

The School of Life Sciences Imaging (SLIM) team are a full time core facility supporting a large imaging facility within Life Sciences at the University of Nottingham. All members are dedicated microscopists and specialists in a wide range of disciplines with a combined experience totalling more than one hundred years. The team support instruments, preparation, analysis and research ranging from wide field, deconvolution, confocal, TIRF, super resolution through to electron microscopy.

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