Contents

Overview

SPIRO, Smart Plate Imaging Robot, is a very simple system that comprises only a handful of electronics components (Fig.1A) and has 3D-printable structural parts (Fig.1B). It is designed for automated time-lapse imaging of samples growing on vertically positioned Petri plates, e.g. plant seeds and seedlings, calli, bacterial colonies, fungi, moss.

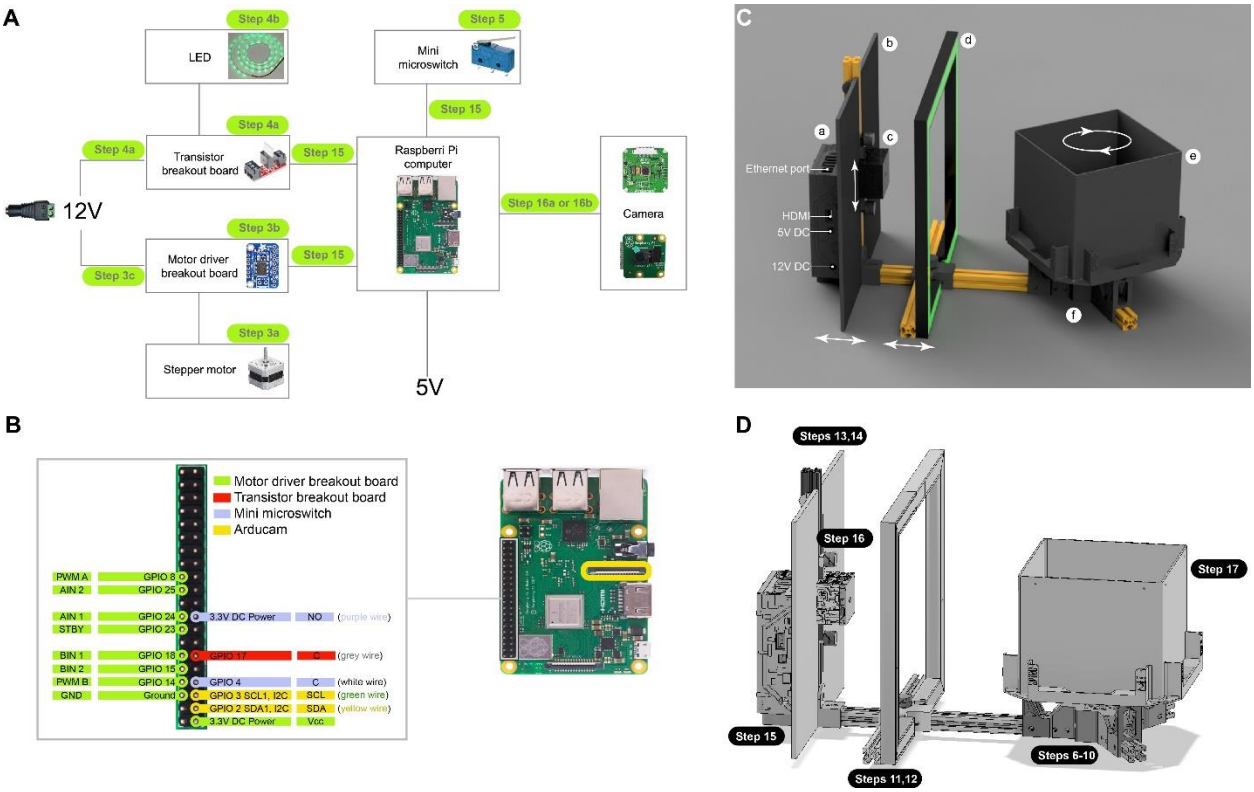

Figure 1. SPIRO Electronics components.

(A) Wiring scheme of SPIRO. SPIRO can be equipped either with an ArduCAM camera with motorized focus (step 16a) or a Raspberry Pi camera with manual focus (step16b). (B) Pinout scheme of the SPIRO. ArduCAM with motorized focus is powered via the CSI camera port on the Raspberry Pi PCB board (yellow frame) and controlled by two GPIO pins. In case of the Raspberry Pi camera v2 with mechanical focus, the camera is connected only to the CSI port. (C) Overview of the SPIRO structure: a, borgs nest harboring the electronics; b, vertical rail with the light screen, position can be adjusted along the horizontal rail; c, camera house, position can be adjusted along the vertical rail; d, LED frame with diffusors, position can be adjusted along the horizontal rail; e, rotating stage to hold Petri plates; f, motor hub harboring stepper motor and connecting the horizontal rails. (D) Overview of steps to assemble the structural parts of SPIRO.

SPIRO is driven by a Raspberry Pi computer powered by 5V DC power supply and operated remotely via WiFi or Ethernet connection using web-based user interface. Raspberry Pi controls the rest of the electronics: camera, endstop, stepper motor and LEDs. SPIRO can be equipped

either with the ArduCAM IMX 219 with a motorized focus or alternatively a Raspberry Pi camera v2 with a manual focus. A mechanical endstop, in this case a mini microswitch, ensures that the rotating stage holding Petri plates is positioned straight in front of the camera lens. LEDs are powered by a 12V power supply unit and connected to the Raspberry Pi computer via a transistor allowing turning the LEDs on and off. The stepper motor rotates the stage with plates and is controlled by the Raspberry Pi computer via the motor driver breakout board and powered by the 12V power supply unit. The SPIRO program is installed on a micro SD card mounted on the Raspberry Pi computer.

SPIRO was designed to be feasible to build without any previous experience in 3D printing, use of Raspberry Pi or soldering. It is assembled in 17 main steps described below. The time required for assembly (starting from the step 3) can range from several hours to several days depending on the user's skills in wielding a screwdriver.

1. Purchase components from the Table S1

Table S1. List of components to be purchased

2. Print structural parts of SPIRO

The printable structural parts of SPIRO are combined into 13 sets. According to our experience, printing all sets takes approximately seven days and requires about 1.5 kg of matt black PLA plastic and 100 g of semi-transparent PLA plastic.

All components were printed using Prusa i3 MK2S printer and additionally tested using Prusa i3 MK3. It is possible to find publicly available printers in centers like Makerspace or use online services to order 3D prints (3dhubs or similar).

We have thoroughly verified and optimized printing settings for each set of parts. It is highly recommended to follow the printing instructions provided in the table to achieve the best possible quality.

Table S2. Structural parts of SPIRO for 3D printing

3. Wire the stepper motor

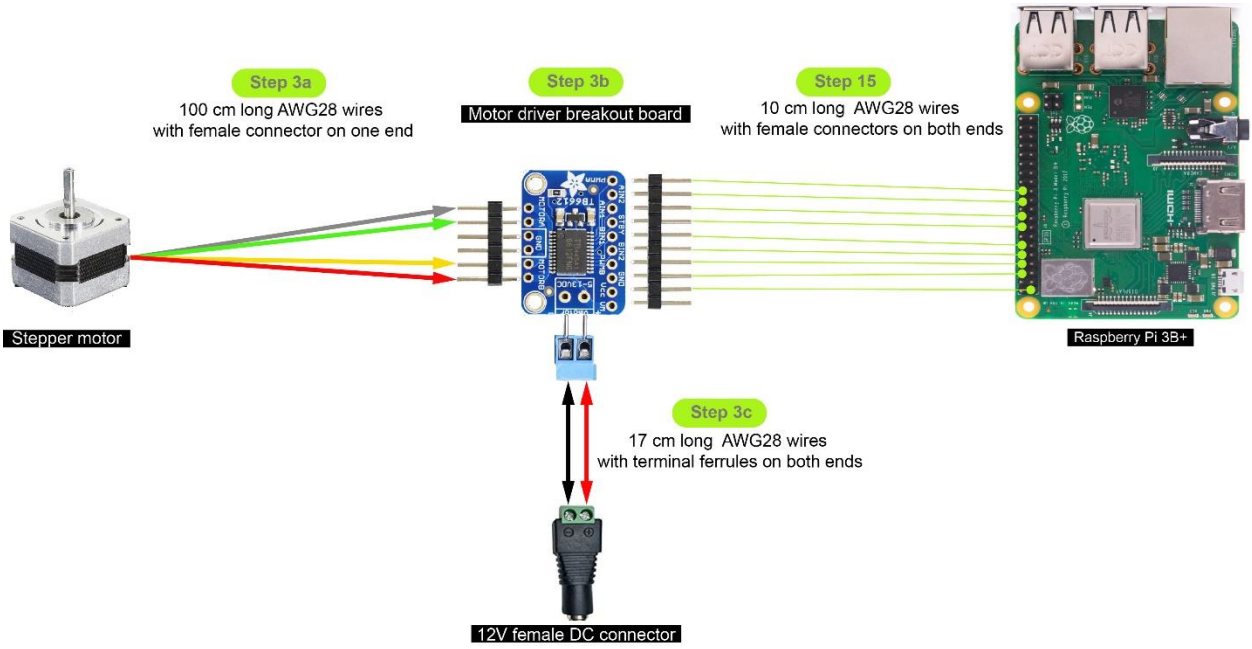

Figure 2. Wiring the stepper motor.

This step has three sub-septs: 3a, soldering four wires to the motor to have the total length 100 cm and to add female terminal connectors. 3b, soldering components of the motor driver breakout board: the pin-arrays (b) and the two-pin screw terminal (c) should be soldered to the board (a). Note the orientation of the parts in the description below. 3c, wiring the 12V DC female connector to the screw terminal on the motor driver breakout board. Connecting the wires from the motor to the driver and from the driver to the Raspberry Pi computer is done later (step 15).

3a. Solder stepper motor wires

Each of the four wires of the motor should be 100 cm long and end with a female terminal connector.

- Please keep the color coding of the wires already attached to the motor: grey, green, yellow, red (Fig. 2).
- Total length of each wire = wire already connected to the stepper motor + AWG 28 cable + jumper cable with one female connector = 100 cm.
- Measure the length of the wires already attached to the motor.
- Cut off one connector from the jumper cable to leave only one female connector attached
- Cut the AWG28 cables to the length required to have in total 100 cm length for each wire.
- Follow instructions in the video 3a. Stepper motor wires for the wire connection/insulation.

Components	# in the Table S1
NEMA 17 stepper motor	4
AWG28 color cables	15
AWG 28 jumper cables with a female terminal connector	11
Heat-shrink tube 1-2mm in diameter	13

Tools	# in the Table S1
Soldering iron + solder	48
Lighter	-
Scissors	-
Wire stripper	46

3b. Solder the motor driver breakout board

- Solder the pins to the board to have long pins facing the labeled side of the board.
- Solder the two-pin screw terminal to the Vmotor holes. Make sure that the terminal and the long pins are on the same side of the board and that the metal ports of the terminal are facing away from the board (Fig. 3B).

Components	# in the Table S1
Motor driver breakout board kit	3
Two-pin screw terminal 3.5 mm pitch	10

Tools	# in the Table S1
Soldering iron + solder	48

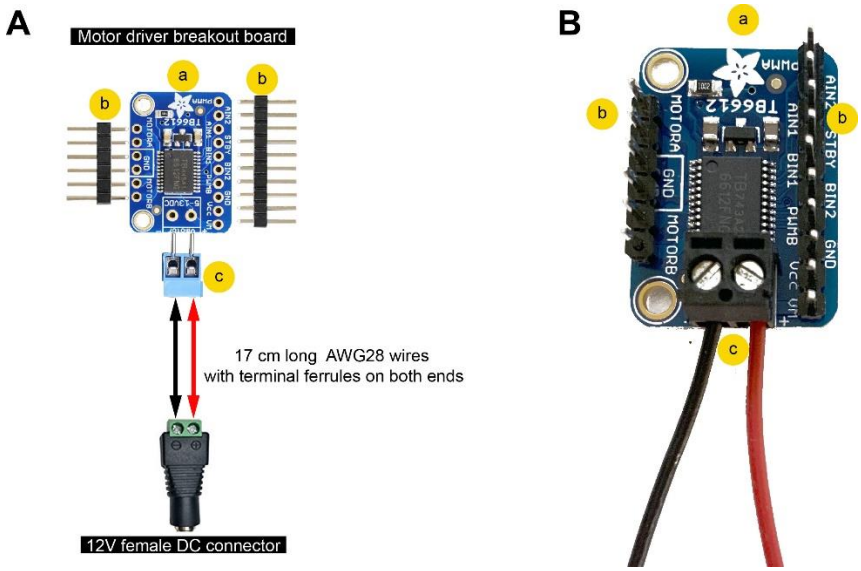

Figure 3. Soldering the motor driver breakout board components
(A) Components to be soldered: a, PCB; b, pins; c, two-pin screw terminal. (B) Soldered driver with power wires connected to the screw terminal.

3c. Wire the motor driver to the DC connector

- Use two 17 cm long 28 AWG wires (black and red)
- Secure terminal ferrules on both ends of each wire. For instructions see the video Securing electric wire ferrules
- Connect the "+ " screw ports of the motor driver and the DC connector with the red wire and " –" ports with the black wire.
- Tighten the screws to secure wires in place.
- Please note that there will be another pair of wires going into the ports of the DC connector to power the SparkFun MOSFET power control kit (Fig. 5D).

Components	# in the Table S1
AWG28 color cables	15
Electric wire ferrules 0,5 mm^2 (not insulated)	14
Heat-shrink tube 2mm in diameter	13

Tools	# in the Table S1
Lighter	-
Scissors	-
Wire stripper or strong teeth	46
Ferrule crimper or very strong teeth	47

4. LED wiring

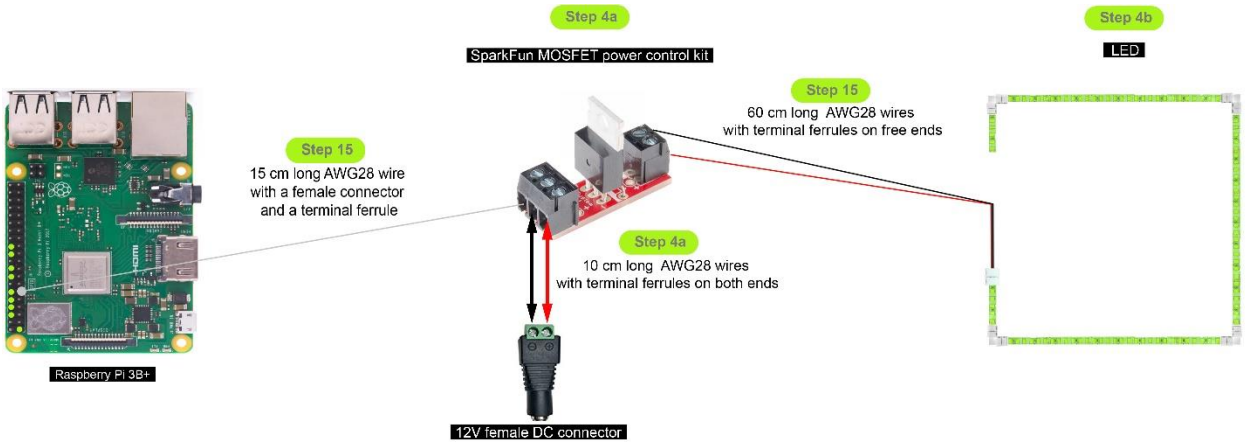

Figure 4. LED wiring.

These steps will include soldering the transistor that will be used to control the LED (SparkFun MOSFET power control kit, step 4a) and connecting the transistor to the 12V DC power supply. LED strip is assembled into a square using 90° corner connectors (step 4b) and a terminal LED connector. LED is attached to the SparkFun MSOFET power control kit and to the Raspberry Pi later during SPIRO assembly (step 15).

4a. Assemble the SparkFun MOSFET power control kit

- Solder the resistor, transistor and both screw terminals to the SparkFun MOSFET power control kit (4a. Figure 1 A-C).
- Connect the three-pin screw terminal to the 12V DC connector:
  - Use two 10 cm long 28 AWG wires (black and red).
  - Secure terminal ferrules on both ends of each wire. For instructions see the video Securing electric wire ferrules.
  - Use the red wire to connect the "+ "port of the three-pin screw terminal of the SparkFun kit to the "+" port of the DC connector.
  - Use the black wire to connect the "-"port of the three-pin screw terminal of the SparkFun kit to the "-" port of the DC connector.
  - Tighten the screws to secure wires in place.
- Use a 15 cm long grey jumper cable with the female terminal pin connector. Secure a terminal ferrule on the free end of the wire. For instructions see the video Securing electric wire ferrules.
- Place the ferrule protected end of this wire into the "C" port of the three-pin screw terminal.

Components	# in the Table S1
SparkFun MOSFET power control kit	7
AWG28 color cables	15
Electric wire ferrules 0,5 mm^2 (not insulated)	14
Heat-shrink tube 2mm in diameter	13

Tools	# in the Table S1
Soldering iron + solder	48
Lighter	-
Scissors	-
Wire stripper	46
Ferrule crimper	47

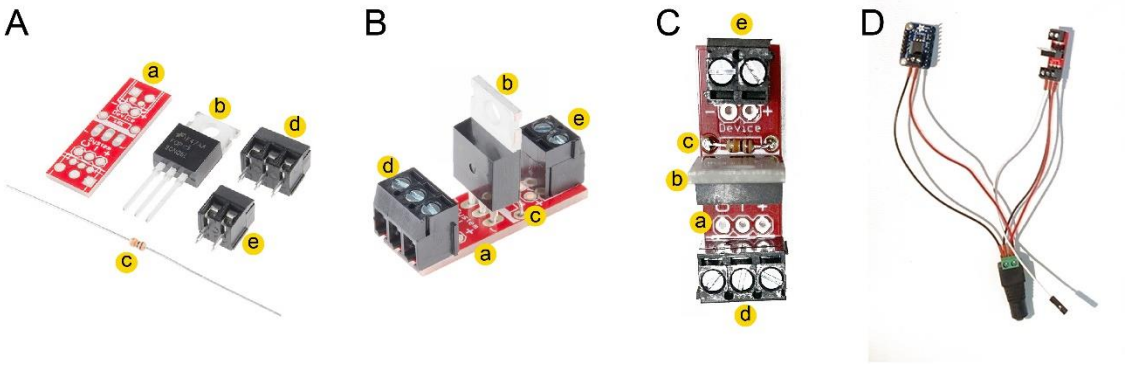

Figure 5. Assembling the SparkFun MOSFET power control kit
(A) Components to be soldered: a, PCB; b, transistor; c, resistor, d, three-pin screw terminal; e, two-pin screw terminal (the photo is modified from SparkFun.com). (B) The side view of the soldered kit. Please note the orientation of the transistor (b) and the screw terminals (d and e). (C) Top view of the soldered kit, note the orientation of the transistor (b) and the resistor (c). (D) SparkFun MOSFET power control kit and motor driver wired to the 12V female DC connector.

4b. Solder wires to the LED terminal connector and assemble the LED strip

- Cut the LED strip into three 25cm long segments (these will be left, top and right parts of the LED square) and two 5 cm long segments (these will be bottom left and bottom right parts of the LED square). Connect the segments using the corner connectors. Make sure the "+" contacts on the corners are connected to the "+" contacts on the LED strip.
- Extend the two wires already attached to the LED terminal connector to have the total length 50cm.
- Crimp a ferrule on the free end of each wire and secure it with the heatshrink tube. For instructions see the video Securing electric wire ferrules.
- Bind both wires together with a coiled cable protection. Cover the 40 cm length starting from the connector. Leave the last 10 cm free of cover.
- Attach the terminal connector to the right bottom strip of the LED square. For instructions see the video LED strip assembly.

Components	# in the Table S1
8 mm green LED strip	8
8 mm LED strip corner connectors	9
8 mm LED strip terminal connector	9
AWG28 color cables	15
Electric wire ferrules 0,5 mm^2 (not insulated)	14
Heat-shrink tube 2mm in diameter	13
Coiled Cable Protection	22

Tools	# in the Table S1
Soldering iron + solder	48
Lighter	-
Scissors	-
Wire stripper or strong teeth	46
Ferrule crimper or very strong teeth	47

5. Solder the mini microswitch wires

- Solder two 110 cm long AWG28 wires to the mini microswitch contacts:
  - The purple wire should be wired to the contact called “NO”.
  - The grey wire should be wired to the contact called “C”.
- Each wire should end with the female pin connector.
- Follow instructions in the video 3a. Stepper motor wires for the wire connection/insulation.

Components	# in the Table S1
Mini microswitch	23
AWG 28 color cables	15
AWG 28 jumper cables with a female terminal connector	11
Heat-shrink tube 2 mm in diameter	13

Tools	# in the Table S1
Soldering iron + solder	48
Lighter	-
Scissors	-
Wire stripper	46

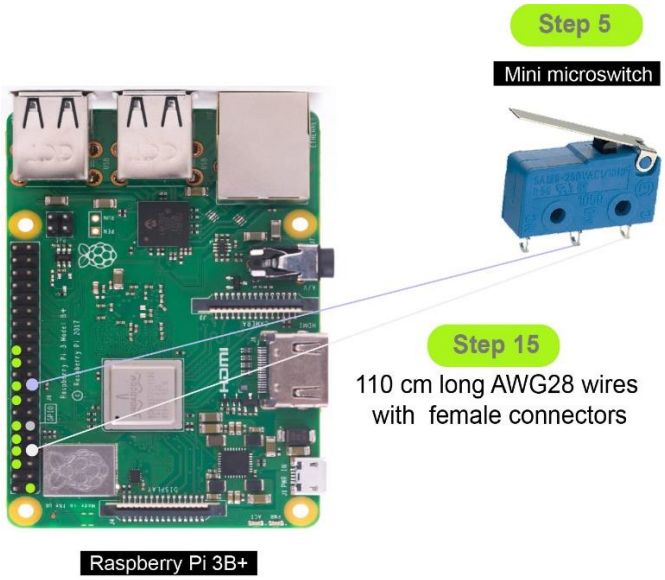

Figure 6. Wiring the mechanical endstop.
The mini microswitch is powered by the 3.3V pin of the Raspberry Pi computer (purple wire) and controlled via its GPIO pin (grey wire).

6. Mount the motor hub

Follow instructions in the video 6. Mounting the motor hub

Components	# in the Table S1
The motor hub assembled in the step 6	-
4x M3 12 mm long	30
	# in the Table S2
Motor hub	Set 1 component 1

Tools	# in the Table S1
Allen key for M3	49

7. Mount the motor hub on the aluminium profiles

Follow instructions in the video 7. Mounting the motor hub on the aluminium profiles

Components	# in the Table S1
The stepper motor wired in the step 1	-
1x T2020 black aluminum profile 40 cm long	16
2x T2020 black aluminum profile 8 cm long	16
12x M5 x 8 mm screw, button head, hex socket, black	34
12x M5 T-nuts for T2020 aluminium profile	40

Tools	# in the Table S1
Allen key for M5	50

8. Mount bearings on the bearing guides

Follow instructions in the video 8. Mounting the bearings

Components	# in the Table S1
3x bearings	18
6x M5 washer	42
3x M5 hexagonal nut	41
3x M5 x 16 mm screw, button head, hex socket, black	37
	# in the Table S2
3x bearing guides	Set 1 components 2 and 3

Tools	# in the Table S1
Allen key for M5	50

9. Mount the mini microswitch on the bearing guide

Follow instructions in the video 9. Mounting the mini microswitch

Components	# in the Table S1
The mini microswitch soldered in the step 5	-
2x M2.5 x 12 mm, flat head countersunk, black	27
2x M2.5 hexagonal nut	29
The bearing guide assembled in the step 8	-
	# in the Table S2
Mini microswitch house	Set 1 component 4

Tools	# in the Table S1
Screwdriver for M2.5	49

10. Mount bearing guides on the aluminum profiles and install the slit cover

Follow instructions in the video 10a. Mounting bearing guides and video 10b. Aluminum profile slot cover

Components	# in the Table S1
Bearing guides assembled in the steps 8 and 9	-
9x M5 x 8 mm screw, button head, hex socket, black	34
9x M5 T-nuts for T2020 aluminium profile	40
2020 Aluminium Profile Slot Cover black, ca 1 m	17

Tools	# in the Table S1
Allen key for M5	50

11. Mount the aluminum rail for the LED frame

Follow instructions in the video 11. Mounting aluminium rail for LED

Components	# in the Table S1
2x Aluminium profile T2020, black, 14 cm long	16
M5 x 16mm bolt, hex head	37
6x M5 8 mm, buttonhead, black	34
3x M5 T-nuts	40
2x M5 slide-in bracket for T2020 aluminium profile	42
	# in the Table S2
Holder for the LED frame rail	Set 1 component 7
1x bottom for a thumb screw	Set 1 component 8
1x cap for a thumb screw	Set 1 component 9

Tools	# in the Table S1
Allen key for M5	50

12. Mount the LED frame

Follow instructions in the video 12. Assembling of the LED illumination:

- Attach the LED strip to the LED frame
- Mount the frame on its aluminum rail

Components	# in the Table S1
LED strip assembled in the step 4b	-
4x M5 12 mm, flat head countersunk	36
4x M5 T-nuts	40
Super glue	52
	# in the Table S2
LED frame right half	Set 7
LED frame left half	Set 8
Diffusor left part (L)	Set 9 component 1
Diffusor bottom left part (BL)	Set 9 component 2
Diffusor bottom right part (BR)	Set 9 component 3
Diffusor top part (T)	Set 10
Diffusor right part (R)	Set 11

Tools	# in the Table S1
Allen key for M5	50

13. Mount the vertical rail

Follow instructions in the video 13. Mounting the vertical rail

Components	# in the Table S1
2x Aluminium profile T2020, black, 30 cm long	16
1x M5 16mm bolt, hex head	39
1x M5 8 mm screw, button head, hex socket, black	34
1x M5 slide-in bracket for T2020 aluminium profile	42
	# in the Table S2
Holder for vertical rail	Set 1 component 6
1x bottom for a thumb screw	Set 1 component 8
1x cap for a thumb screw	Set 1 component 9

Tools	# in the Table S1
Allen key for M5	50

14. Mount the light screen

Follow instructions in the video 14. Mounting the light screen

Components	# in the Table S1
5x M5 11-12 mm screw, button head, hex socket, black	35
5x M5 T-nuts	40
	# in the Table S2
Left part of the light screen	Set 6
Right part of the light screen	Set 5

Tools	# in the Table S1
Allen key for M5	50

15. Assemble and mount the birds nest

Follow instructions in the video 15. Assembling and mounting of the birds nest
The pinout scheme for all components is available on the Fig. 1B. Additionally, connections for individual components are illustrated on the Fig. 2, 4 and 6.

Components	# in the Table S1
1x Raspberry Pi 3B+	1
Motor driver + SparkFun power control kit + DC connector wired in steps 3 and 4	-
2 x M2.5 12 mm, flat head countersunk	27
2 x M2.5 12 mm, button head	26
4x M2.5 hex nuts	29
4x M3 12 mm, button head	30
4x M3 20 mm, flat head countersunk	31
8x M3 hex nuts	32
1x M5 x 11-12mm screw, button head black	35
2x M5 T-nuts	40
	# in the Table S2
1x Birds nest	Set 2 component 1
1x Lid for the birds nest	Set 2 component 2
1x DC connector lid	Set 2 component 3
1x SparkFun holder	Set 2 component 4
1x M5 5 mm tall nut (optional)	

Tools	# in the Table S1
Screwdriver for M2.5	49
Allen keys for M3 and M5	50
Forceps	53

16. Mount and connect the camera

SPIRO supports Raspberry Pi camera v2 that requires manual adjustment of the focus or ArduCAM IMX219 with motorized focus. The image quality does not significantly differ between the cameras. Raspberry Pi camera v2 is significantly cheaper than the ArduCAM, however we recommend using the latter for much more convenient operation of the robot.

16a. Mount and connect the ArduCAM with motorized focus

- Prepare two 60 cm long AWG28 wires with female connectors on both ends:
  - Use one yellow and one green wire, the color-coding is important for further assembly
  - Cut the AWG28 cables and jumper cables with female connectors to have the final total 60 cm for each wire
  - Follow instructions in the video 3a. Stepper motor wires for the wire connection/insulation.
- Follow instructions in the video 16b. Mounting and connecting the ArduCAM IMX219

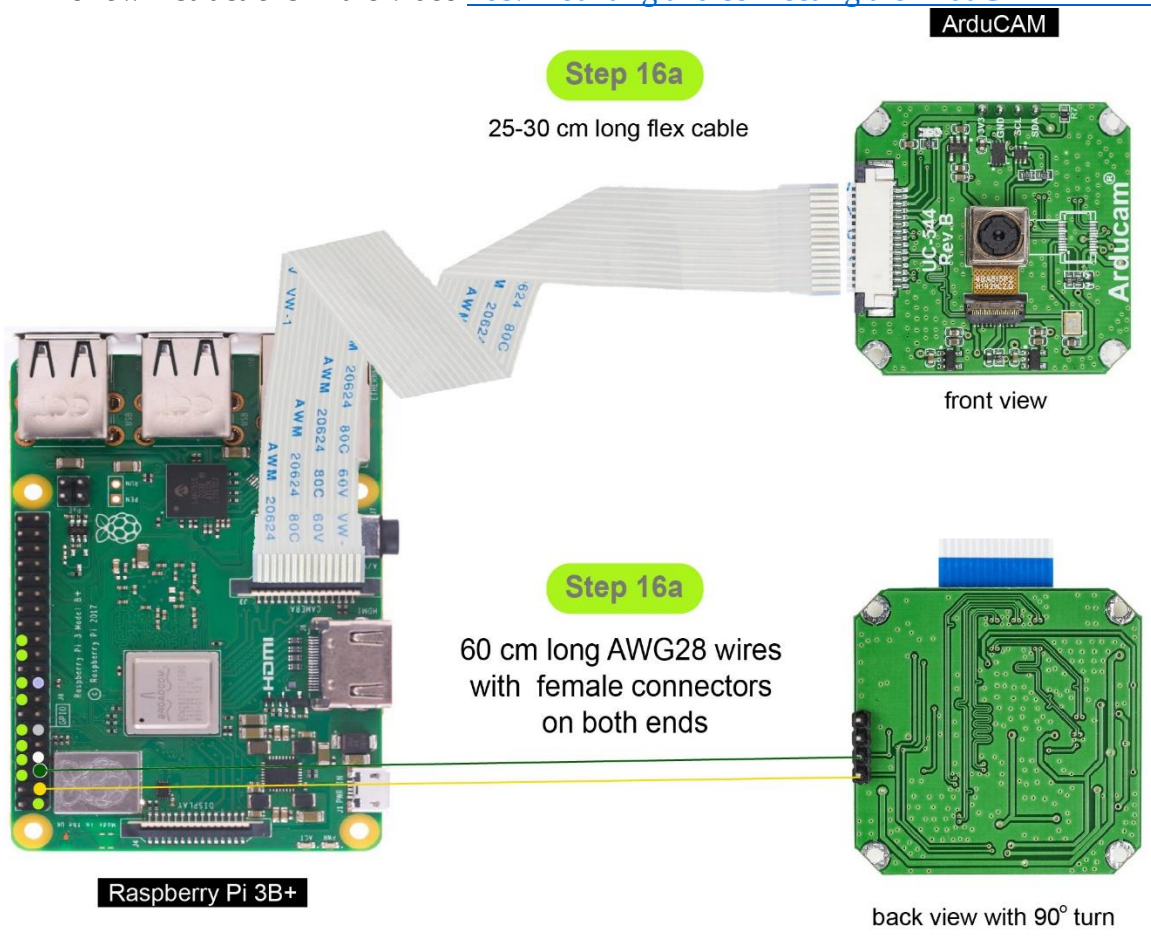

Figure 7. Connecting the ArudCAM with motorized focus.

The ArduCAM is connected to CSI port on the Raspberry Pi computer via white flex cable and to the two GPIO pins: SDA (yellow wire) and SCL (green wire). Please note that the metal surfaces on the flex cable should be facing the metal pins in the ports on the Raspberry Pi computer and on the camera PCB.

Components	# in the Table S1
1x ArduCAM with motorized focus	20b
1x Flex cable, ca 25 cm long	21
4x M2 x 20mm, flat head countersunk	24
4x M2 hex nuts	25
2x M5 x 16mm bolt, hex head	39
2x M5 T-nuts	40
AWG 28 color cables	15
AWG 28 jumper cables with a female terminal connector	11
	# in the Table S2
1x Camera house for ArduCAM camera	Set 3a component 1
1x Lid for the camera house	Set 3a component 2
2x bottom for a thumb screw	Set 3a component 3
2x cap for a thumb screw	Set 3a component 4
1x Stabilizer for the camera	Set 3a component 5

Tools	# in the Table S1
Screwdriver for M2.5	49
Allen key for M3	50

16b (alternative to 16a). Mount and connect the Raspberry Pi camera with manual focus

Follow instructions in the video 16. Mounting and connecting the camera

Components	# in the Table S1
1x Raspberry Pi Camera v2 8 MP	20a
1x Flex cable, ca 25 cm long	21
4x M2.5 x 8mm, flat head countersunk	28
4x M2.5 hex nuts	29
2x M5 x 16mm bolt, hex head	39
2x M5 T-nuts	40
	# in the Table S2
1x Camera house for pi camera	Set 3b component 1
1x Lid for the camera house	Set 3b component 2
2x bottom for a thumb screw	Set 3b component 3
2x cap for a thumb screw	Set 3b component 4
1x Stabilizer for the camera	Set 3b component 5

Tools	# in the Table S1
Screwdriver for M2.5	49
Allen key for M3	50

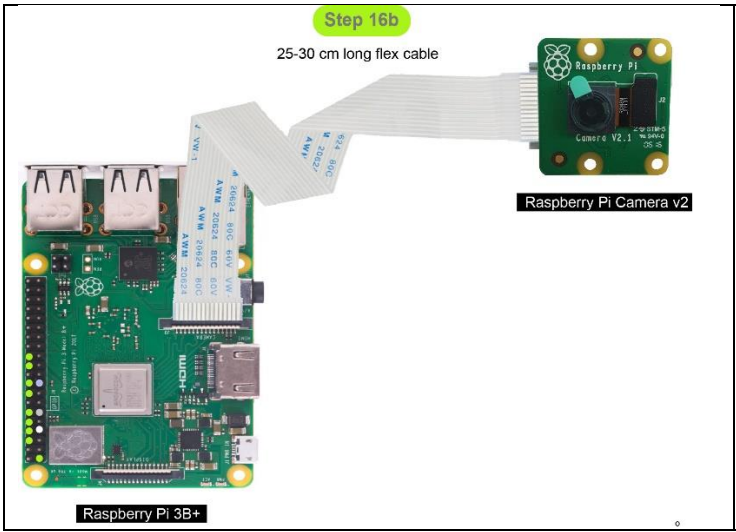

Figure 8. Connecting the Raspberry Pi camera v2 with manual focus (alternative to the ArduCAM).
The Raspberry Pi camera v2 is connected to CSI port on the Raspberry Pi computer via white flex cable. Please note that the metal surfaces on the flex cable should be facing the metal pins in the ports on the Raspberry Pi computer and on the camera PCB.

17. Assemble and mount the cube

Follow instructions in the video 17. Assembling and mounting of the cube
While mounting the coupling, please make sure that more than half of it is covering the motor shaft. It is of utmost importance to fix the screws on the coupling as tight as possible.

Components	# in the Table S1
1x Rigid shaft coupling M5 to M5	19
2x M2.5 x 8mm, flat head countersunk	28
2x M2.5 hex nuts	29
1x M5 x 20 mm bolt, hex head	38
	# in the Table S2
1x Cube	Set 4
1x Mini microswitch pin (tiny dick)	Set 1 component 5

Tools	# in the Table S1
Screwdriver for M2.5	49

18. Software installation

For installation, please follow the instructions provided in the github repository for SPIRO software.

Components	# in the Table S1
1x micro SD card class X, 32 Gb or more	12
1x Ethernet cable	54

Tools	
A computer with micro SD card reader	
A monitor with an HDMI cable	
Access to two internet ports open for SSH connection	