Assembly Information

CENTRIFUGE

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T1. Tools

The hardware tools used while building the CENTRIFUGE can be viewed in Table S1 as well as in Figure S1. Besides the 3D printer these are all basic highly available and common tools.

Table S1: Hardware Tools

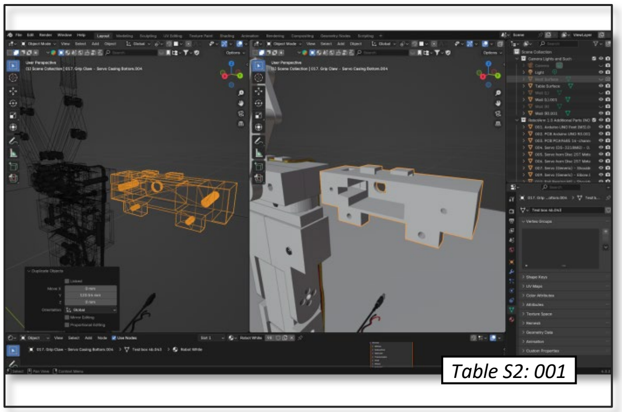
No	Item Name	Comment
001	BambuLab X1 Carbon 3D Printer	Or any other 3D printer that gets the job done
002	Allen Keys	
003	Screw Drivers	
004	Pliers	
005	Wire Stripper	
006	Caliper	
007	Cutter	Mainly for 3D parts
008	Polishing tool	Optional (for 3D parts)
009	Drill	Optional (for 3D parts)

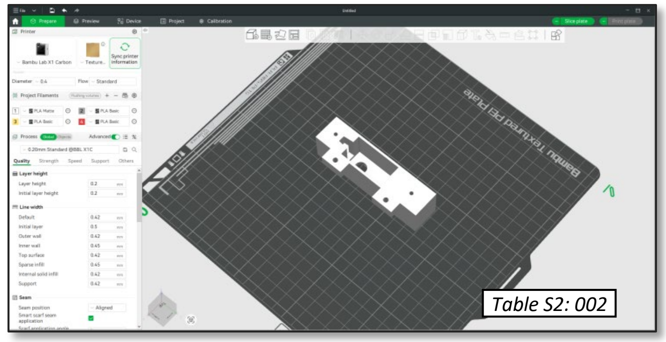
Figure S1: Example Images of the Hardware Tools 001-009

The Software tools used as seen in Table S2 and also in Figure S2 are all freeware and easy to download online.

Table S2: Software Tools

No	Item Name	Comment	Price
001	Blender 4	For editing STL files	Free
002	BambuLab Studio	Or any other 3D printer app (For 3D printing)	Free
003	ArduinoIDE	For editing, compiling and transfer Firmware	Free
004	CENTRIFUGE Firmware	For Controlling Arduino	Free





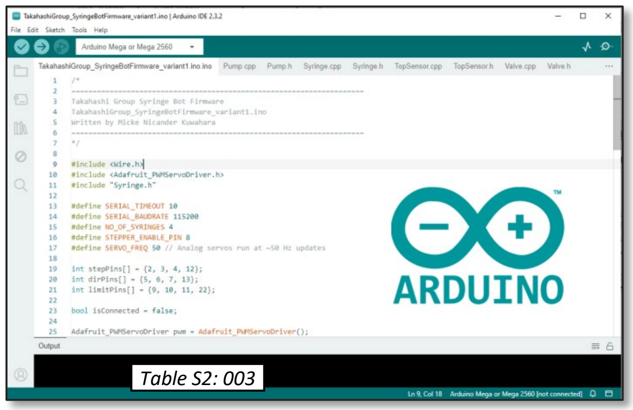


Table S2: 004

Figure S2: Images of the Software Tools 001-003

T2. Get the Mechanical Hardware and the Electronics in order

The non-plastic, non-printable parts used for CENTRIFUGE was basically nuts and bolts, Ball Bearings, a few wires and of course the Arduino controller boards and the DC-motor with its driver board. In the tables below (Table S3) all parts used that need to be purchased can be found together with an approximate price (in USD, 2026). In Figure S3 one can see rendered reference images of the parts for purchasing support.

Table S3: Parts that needs to be purchased

No	Item Name	Amount	Comment	Unit Price (ca)	Total Price
01	2020 Extrusion (300mm)	4	To use as Centrifuge frame for stabilizing centrifuge when running	$1,90	$7,60
02	Corner Gusset Plate	4	To connect the 4 2020 extrusion bars	$4,00	$16,00
03	Bolts M3 x 8	20	To fasten the 4 Metal frame corner connector to the 2020 extrusions	$0,07	$1,40
04	20-Series Square Nut M3	20	To fasten the 4 Metal frame corner connector to the 2020 extrusions	$0,12	$2,40

05	Bolts M4 x 8	8	To fasten the 4 Box Corner Stands to the extrusions	$0,07	$0,56
06	20-Series Square Nut M3	8	To fasten the 4 Box Corner Stands to the extrusions	$0,12	$0,96
07	Bolts M4 x 8	4	To secure the Flange Hub to the Centrifuge Test Tube Holder	$0,07	$0,28
08	Nut M4	4	To secure the Flange Hub to the Centrifuge Test Tube Holder	$0,06	$0,24
09	Flange Shaft Fitting Metal Hub	1	To secure the Centrifuge Test Tube Holder to the Shaft	$4,50	$4,50
10	Flange Secure Bolt	2	To secure the Centrifuge Test Tube Holder to the Shaft (Included with the Flange)	-	-
11	Bolts M2.5 x 6	1	To fasten the Hull Sensor in place below (1.5mm) the spinning magnet	$0,05	$0,05
12	Nut M2.5	1	To fasten the Hull Sensor in place below (1.5mm) the spinning magnet	$0,05	$0,05
13	Magnet (Tiny)	2	Fastened under the Test Tube Holder to allow the Hall sensor count the RPM	$0,02	$0,04
14	Nut M2	~2	To counter weight the magnets on the Test Tube Holder	$0,05	$0,10
15	Shaft M8 (Steel) 160mm	1	The spinning shaft connected to the motor and the Test tube Holder	$1,80	$1,80
16	Coupling M5 to M8	1	To connect the motor to the shaft	$5,20	$5,20
17	One Way Bearing Clutch (id:8mm;od:22mm;w:7mm)	1	Connected closest to the motor to allow for free spinning when motor stops	$10,00	$10,00
18	Ball Bearing (id:8mm;od:22mm;w:7mm)	2	Lower and Upper Ball bearing for stabilization of the shaft	$0,40	$0,80
19	Bolts M2 x 5	8	To fasten the boards to the bottom of the box	$0,05	$0,40
					$52.38 ¥8125
E01	4-Digit 7-Segment Display	1	Displays 4 digit numbers (0000-9999) or text for Speed state and current RPM	$1,60	$1,60
E02	Breadboard (Normal Size)	1	Shared VCC and GND Central Board	$1,50	$1,50
E03	Breadboard (Small Size)	1	Button Holder	$1,00	$1,00
E04	BTS7960 motor driver	1	Motor Driver Circuit Board to control Power distribution to the DC-Motor	$10,00	$10,00
E05	Buttons (ON/OFF) and (RPM STEP)	2	Classic 4-Pin Buttons for controlling Speed state and On/Off	$0,32	$0,64
E06	DC Motor 775 10000RPM 12V/24V 5-10A	1	A powerful High Speed DC-Motor (15000-20000 RPM at No-Load)	$13,90	$13,90
E07	Hall Sensor (KS0020)	1	Sensor that reacts to passing magnetic pulses in order to count RPM	$3,44	$3,44
E08	Low Pass Filter Capacitor	1	Used to make the Hall sensor less sensitive to DC-Motor magnetic field (Sensor Pin to GND)	$0,02	$0,02
E09	Arduino UNO R3 PCB	1	The main controller of all electronic parts, running the firmware	$15,00	$15,00
E10	Arduino UNO power adapter	1	To feed power to the Arduino from the socket	$7,50	$7,50
E11	Arduino UNO USB	1	To upload Firmware from PC to Board	$3,25	$3,25
E12	*Power Supply Unit (up to 24V)*	*1*	*To power the DC-Motor*	*$55,00*	*$55,00*
E13	Wires	23	Any electric wires that solves the connects properly (Various lengths)	$0,09	$2,00
				$59,85 (w. PSU $114.85) ¥9200 (w. PSU $17700)	
			TOTAL:	**$112,23 (w. PSU $167.23) ¥17325 (w. PSU $25825)**	

The main parts in this list are of course the Arduino UNO R3 controller board, the BTS7960 motor driver, and the 775 DC-motor itself, together with whatever is needed to connect all. All non-printable parts are chosen for their easy accessibility worldwide, and their fully possibility to replace or change without any major headaches, as well as fairly low cost.

The power supply (E12) can be of any kind as long as it can provide up to 24V and 5-10A, to make sure the Centrifuge can run smoothly and powerful enough without struggle.

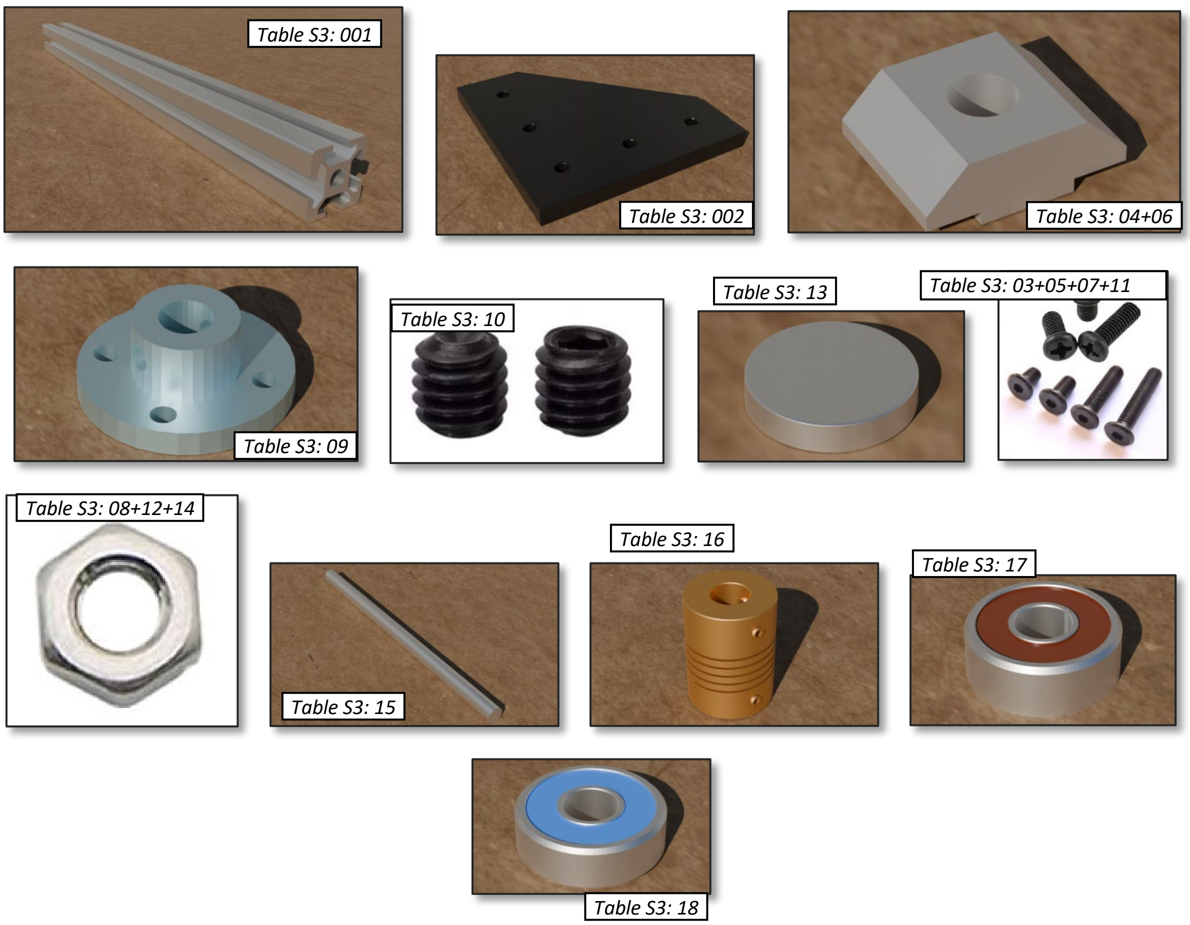


Figure S3: The non-printable, purchased Mechanical Hardware parts used for building CENTRIFUG. The images are just references, the exact look may differ.

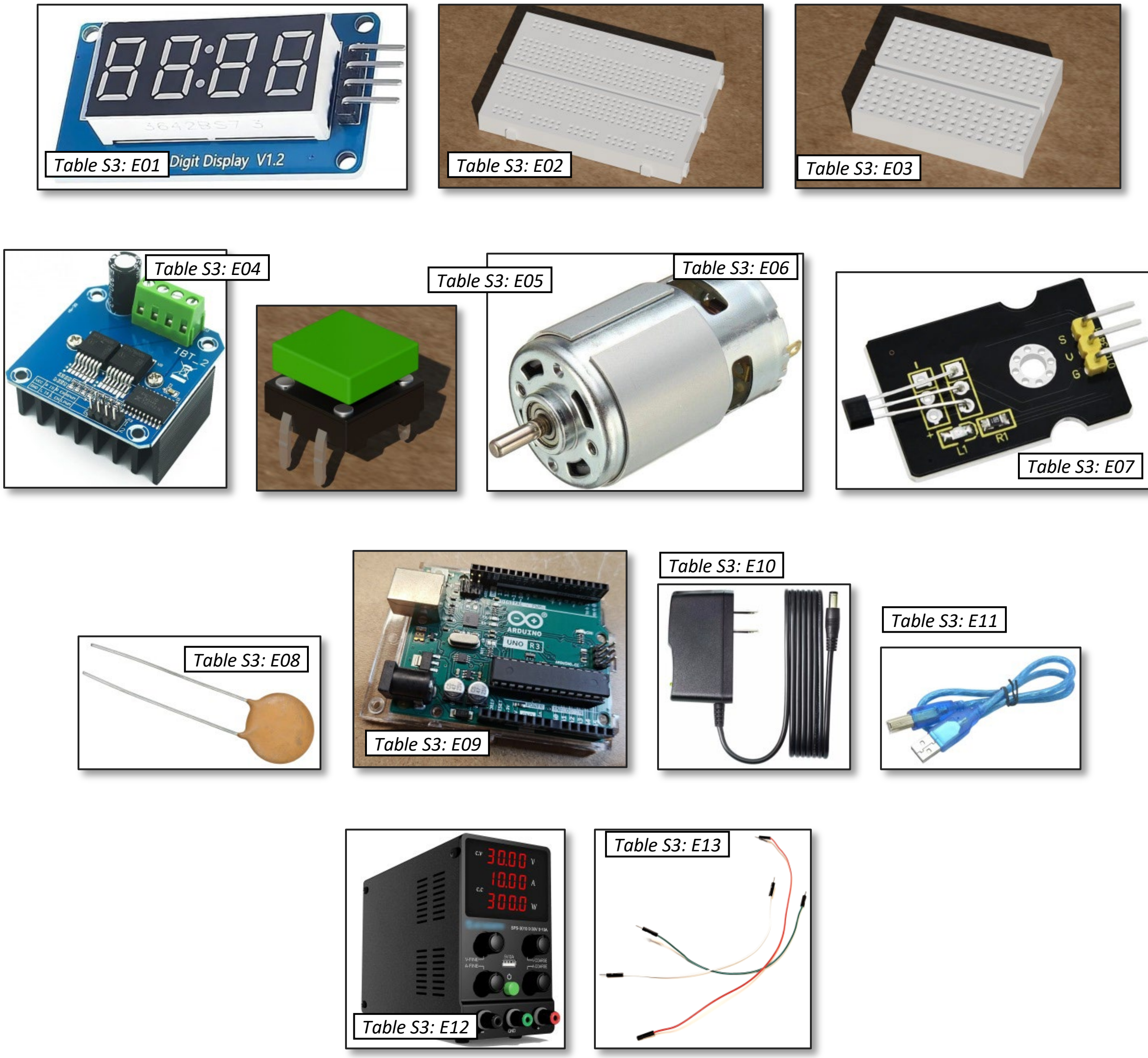


Figure S4 (Cont.): The non-printable, purchased Electronic parts used for building CENTRIFUGE. The images are just references, the exact look may differ

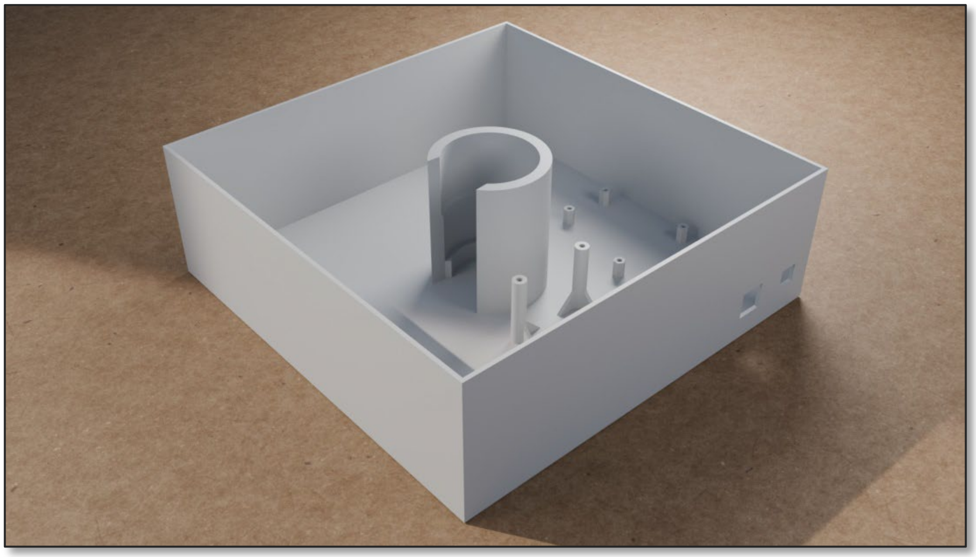
T3. Getting the 3D-printed parts in order

All the 3D parts needed for CENTRIFUGE are listed in the table below (Table S4) and can also be seen in
Figure S5.

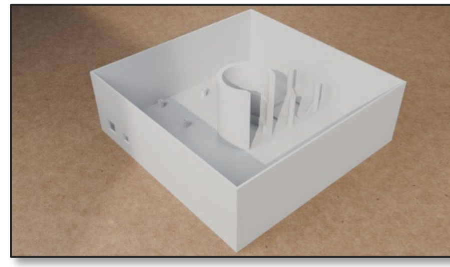
Table S4: All 3D-printed parts

No	STL File Name	Amount	Comment	Printing Time (ca)	Filament Amount (ca)	Cost (ca)
01	Centrifuge Box - lv01 (Bottom) v.1	1	Motor & Arduino Holder	7h 6min	299 g	$4,50
02	*Centrifuge Box - lv01 (Bottom) v.2*	*0-1*	*Motor & Arduino Holder MIRRORED from v1*	*7h 6min*	*299 g*	*$4,50*
03	Centrifuge Box - lv02	1	Frame to hold Buttons and Display	3h 21min	110 g	$1,65
04	Centrifuge Box - lv03	1	Frame Wall (Plain Simple)	1h 42min	53 g	$0,80
05	Centrifuge Box - lv04 (top)	1	Frame Wall (Plain Simple)	4h 43min	174 g	$2,60
06	Centrifuge Box - lv03 Ball Bearing House Cross	1	To hold the One Way Clutch Ball Bearing	1h 48min	63 g	$0,95
07	Centrifuge Box - lv04 Ball Bearing House Cross	1	To hold the lower Ball Bearing stabilizer	1h 48min	60 g	$0,90
08	Centrifuge Box - Top Ball Bearing House Cross v.1	0-1	To hold the Upper Ball Bearing stabilizer (No hall sensor support) (Only Used if v.2 is not used)	1h 11min	31 g	$0,45
09	Centrifuge Box - Top Ball Bearing House Cross v.2	1	To hold the Upper Ball Bearing stabilizer (KS0020 hall sensor support)	1h 49min	40 g	$0,60
10	*Centrifuge Test Tube Holder - No Holes*	*0*	*Template to use if custom tube sizes are needed*	-	-	-
11	Centrifuge Test Tube Holder - With Holes	1	4 Tube Holes for d:29mm, l: 116mm tubes	3h 00min	118 g	$1,75
12	Centrifuge Box - Lid	1	Top Cover to protect user if something goes wrong	8h 58min	357 g	$5,40
13	Support Piece for Digit Display and Button Board	1	Helper parts to hold and support the button and display parts ((needs to be glued))	0h 22min	5 g	$0,08
14	Box Corner Stand	4	To be attached to metal frame and fit the Centrifuge box	4h 09min	106 g	$1,59
15	TPU Rubber Feet	4	Controls the natural shaking and movement of the centrifuge (Use TPU filament)	0h 31min	7 g	$0,10
16	Feet Extension	4	Gives more stability to the centrifuge (Adding Anti-slip tape is recommended)	0h 29min	12 g	$0,18
		22		**39h 46min**	**1404 g**	**$21.10**
			TOTAL COST: (Everything, All Parts (excl. tools))		**$133,33 (w. PSU $188.33) ¥20625 (w. PSU $29125)**	

01



02 (Mirrored from 01)



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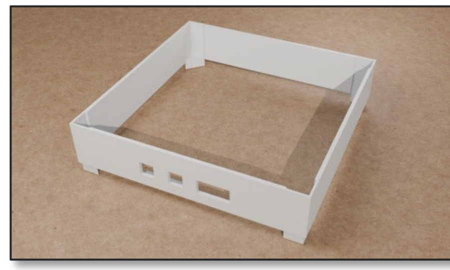

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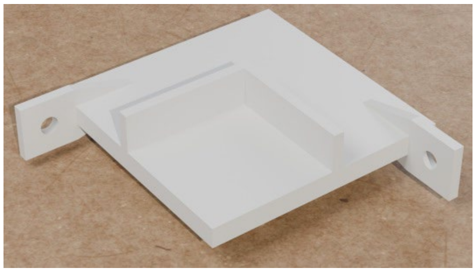

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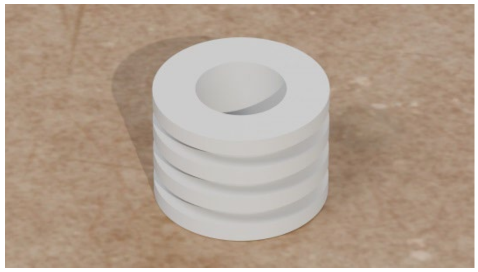

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Figure S5: All the 3D-printed parts needed and used for CENTRIFUGE

The dimensions are all set in millimeter in the STL-files. If for some reason any object is scaled or altered, then naturally, any parts that are connected, most likely, have to be edited as well.

The STL-files are available on GitHub at the following address: https://github.com/Materials-Informatics-Group/Centrifuge/tree/main/3D-Parts

In most cases the default STL files available for download will work as is and no editing is needed. The CENTRIFUGE development team mainly did all editing inside either Blender or Bambu Lab Software, but any software that can manage STL-files should suffice. The original CENTRIFUGE device was printed with Bambu Lab X1 Carbon, using PLA Basic filament, but for increased strength Polycarbonate filament (PC) should do a good job.
The size of some parts are maximized for the with Bambu Lab X1 Carbon printer, but might be aligned wrong when loaded and need to be slightly moved.
If one uses a printer that is smaller and therefore is forced to scale down the parts, it is recommended that it is done in a tool that allows the thickness of the walls to stay intact, in order to maintain the safety of the box protection.
If the user intends to increase the maximum RPM, it is highly recommended to use PC filament and also increase the thickness of the box walls, in case something goes wrong at those high speeds.

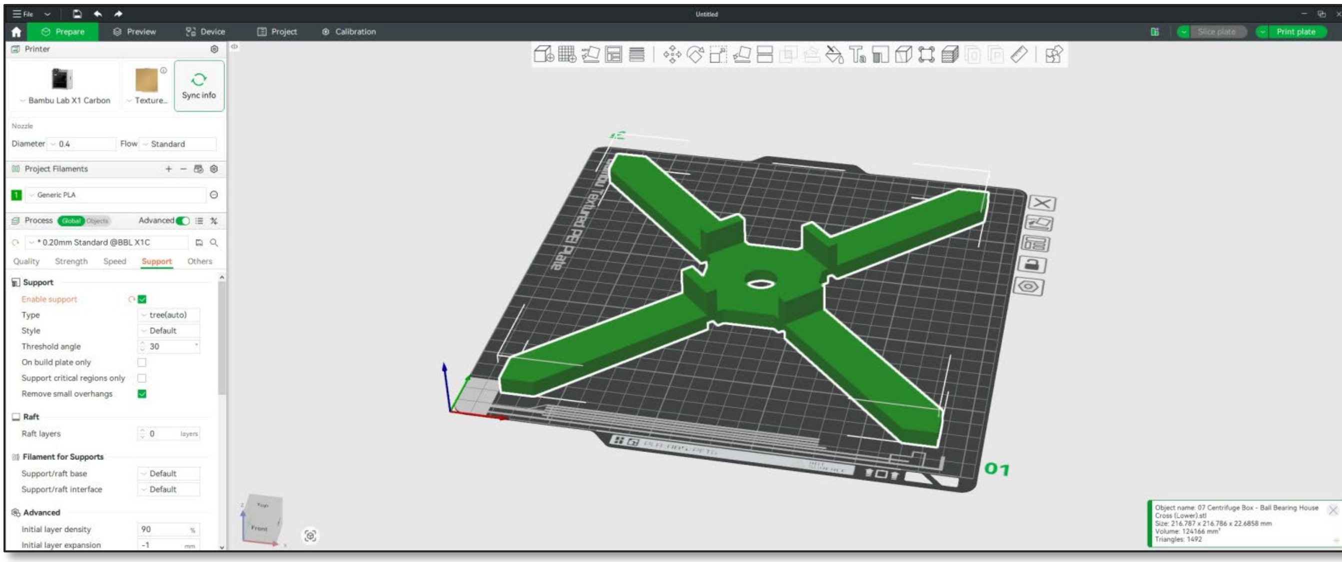

Figure S6: Bambu Lab Studio for slicing the 3D parts and send to the printer.

All prints were made with 0.4mm nozzle and with the layer height of standard 0.2mm.

As previously mentioned Blender 4 was used for all STL-file editing, by importing the STL file into Blender, do the editing and changes and then export back as STL. In Figure S7 one can see how the Blender interface basically looks like in edit mode, but for detailed instructions and knowledge it is recommend that one reads the Blender manual and perhaps do one or two tutorials.

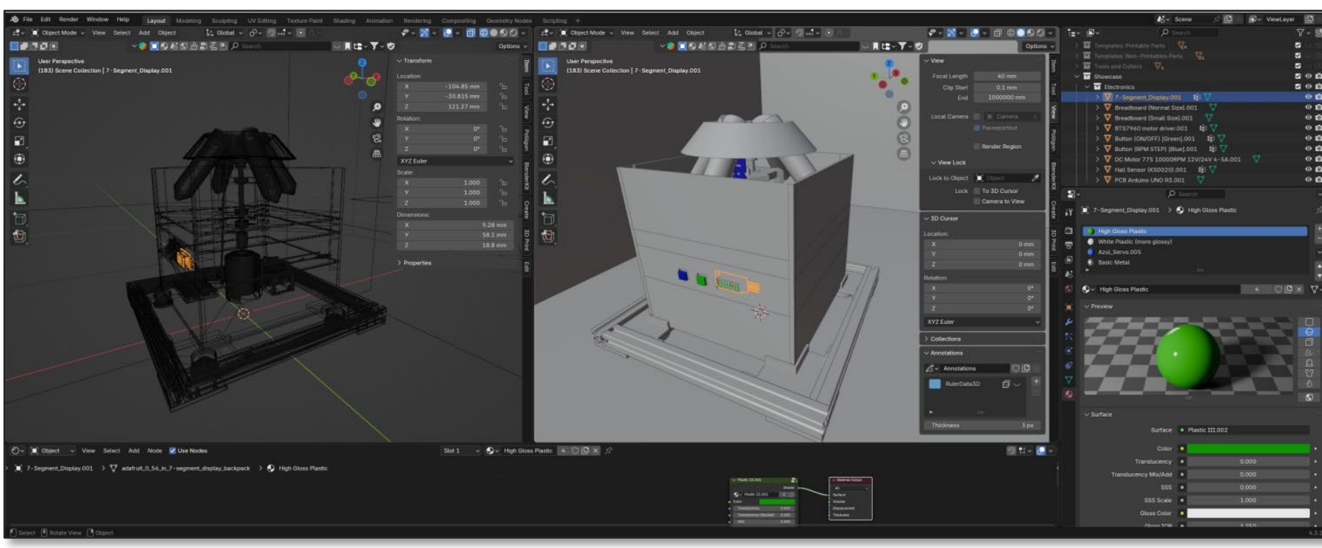

Figure S7: Editing a 3D object inside Blender is fairly easy once one get the hang of it.

After printing the CENTRIFUGE device, one should have a set of 3D parts similar to Figure S8.

What decides whether a part is ready to go as is or needs editing is of course the size and shapes of the purchased parts such as the DC motor, and/or the bolts and nuts one uses. If one makes any changes there, then the 3D parts needs to change too. Which is totally fine as this paper tries to convey.

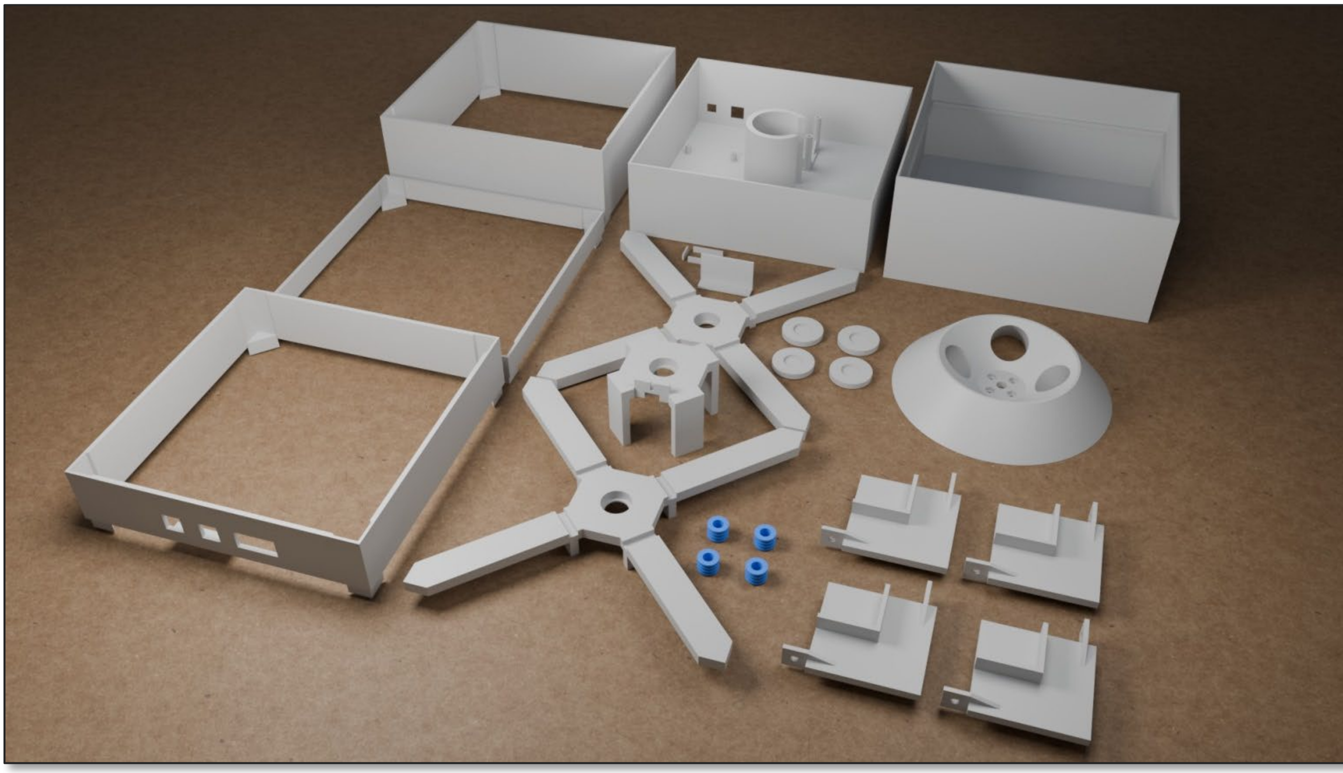

Figure S8: A set of 3D printed parts for one CENTRIFUGE device.

T4. Regarding the 775 DC Motor

The CENTRIFUGE uses only one high speed, high-torque, brushed DC Motor of the 775 type, for 12V-24V and popular for DIY, robotics, and small power tools, featuring speeds from 250 to 20,000 RPM.

Figure S9: A 775 DC Motor used in the CENTRIFUGE.

We soldered the wires to the motor, even though we avoided all other types of soldering for easy changes and maintenance, but for the motor it felt like a safer way to do things..

The firmware is written with safety in mind and is a big part of how the speed of the motor is controlled. For any changes to that please learn more about the motor and Arduino codes.

T5. Micro Controller Boards

In the table below (Table S5) one can see what boards were used for CENTRIFUGE in order to control all the parts.

Table S5: The microcontroller boards used by CENTRIFUGE

No	Item Name
09	Arduino UNO R3
04	BTS7960 motor driver
01	4-Digit 7-Segment Display

The Arduino Uno R3 (Figure S10) was a good versatile and simple board for everything we needed as well as might need for future customization, so that was selected early, but one can use other compatible Arduino boards as well.

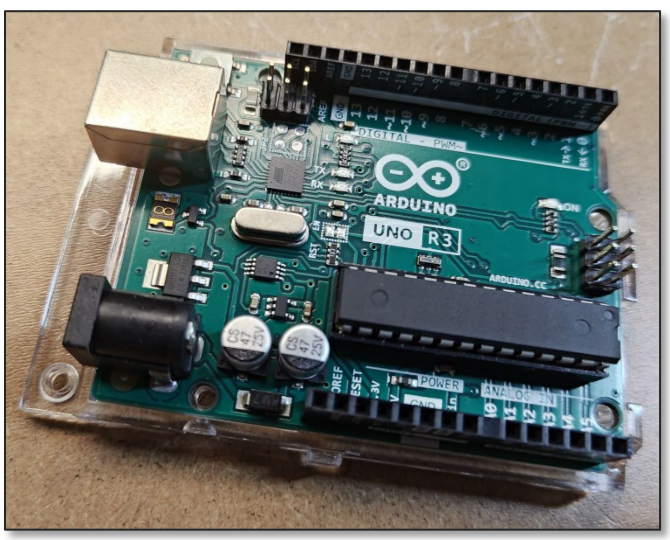

Figure S10: Arduino UNO R3 with all its pins and connectors.

The IBT-2 motor driver module, based on the BTS7960 high-current half-bridge chips, serves as the power interface between the Arduino controller and the 775 DC motor. It enables bidirectional motor control using PWM signals while handling significantly higher currents than the Arduino can provide directly. The module isolates the low-voltage logic control from the high-current motor supply, ensuring stable and safe operation. With separate enable and PWM inputs for each half-bridge, the IBT-2 allows precise speed regulation and reliable startup behavior, making it well suited for applications such as this centrifuge, where controlled acceleration and consistent RPM performance are essential.

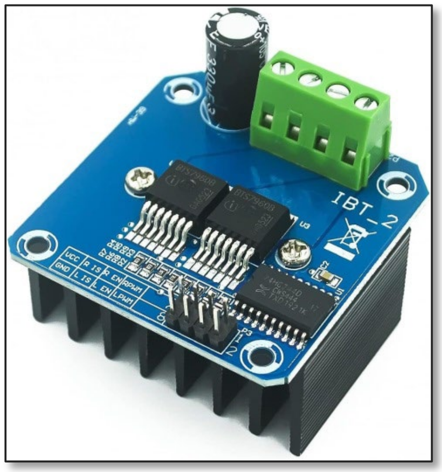

Figure S11: IBT-2 motor driver module (BTS7960), providing high-current bidirectional PWM control between the Arduino and the DC motor.

The 4-digit 7-segment LED display module, based on the TM1637 driver IC, provides a simple and efficient interface for real-time numerical feedback from the centrifuge system. Using a two-wire communication protocol (CLK and DIO), the display minimizes required I/O pins while allowing clear presentation of RPM values and system states. The integrated driver handles multiplexing and brightness control internally, reducing processing load on the Arduino. Its compact form factor and high-contrast segmented output make it well suited for laboratory equipment where immediate readability and reliable operation are essential.

Figure S12: 4-digit TM1637-based 7-segment LED display module for real-time RPM and status indication.

T6. Power and wiring

Most other section explain the specific details regarding the power source and the wiring, but it is of importance to pay attention to follow those instructions correctly as well as making sure all safety regulations are followed. If not very familiar with electricity, it is recommended to make sure one uses power supplies that are easily used and installed by anyone and does not need much of tinkering such as a variable regulated power supply commonly available in most lab environments. And whenever plugging in wires, always make sure that the wires never cross or goes in the wrong direction, to avoid damage to parts or equipment. The 775 DC motor needs between 12-24 Volts depending on individual specifications, and about 5-10A of current.

Figure S13: Probably the best type of power source for non-electricians.

Figure S14: Be careful to make sure wires are correctly connected.

T7. Initial Testing and Becoming Familiar with the Key Parts

In the schematics and images seen in Figure S15 – Figure S17 one should be able to read the complete setup for all electronic parts, both for testing individual parts as well as the finished full assemble. One can use the code for the final CENTRIFUGE Firmware for testing since it is prepared for sending individual serial commands test all parts of the system. For detailed pin connection information please refer to the data sheet for each board.

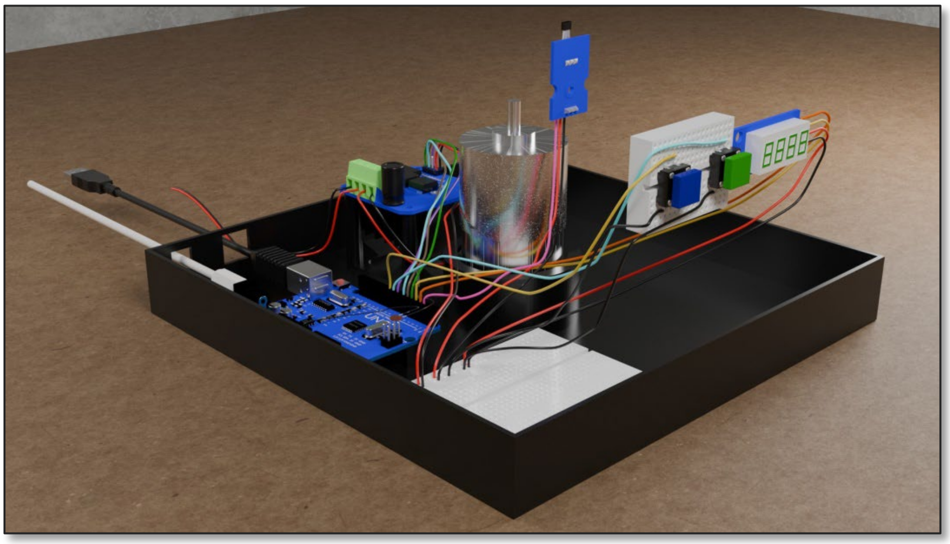

Figure S15: The Arduino Uno and the IBT-2 board connected to each other as well as to the motor, the buttons, the display and the hall sensor.

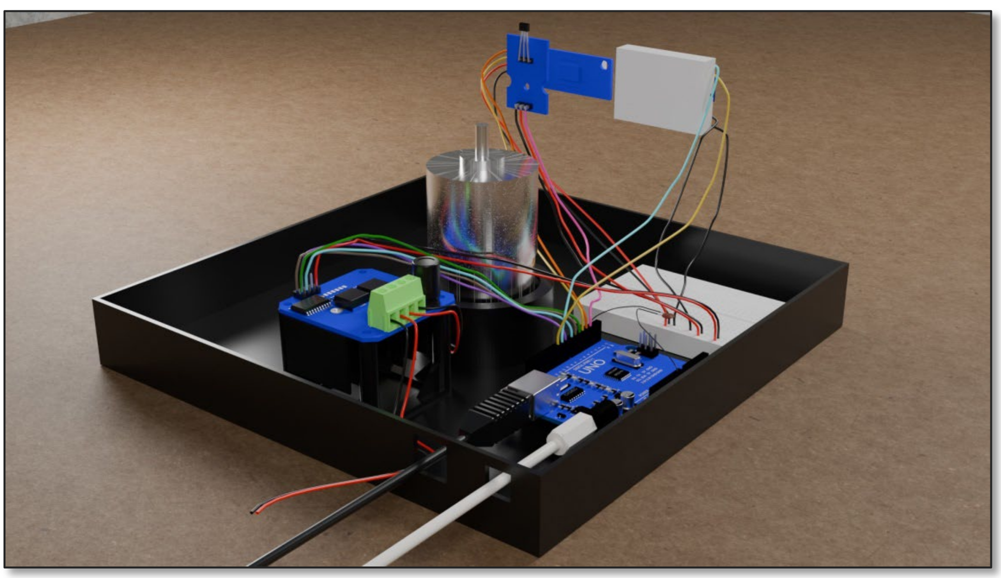

Figure S16: The Arduino Uno and the IBT-2 board connected to each other as well as to the motor, the buttons, the display and the hall sensor (additional angle).

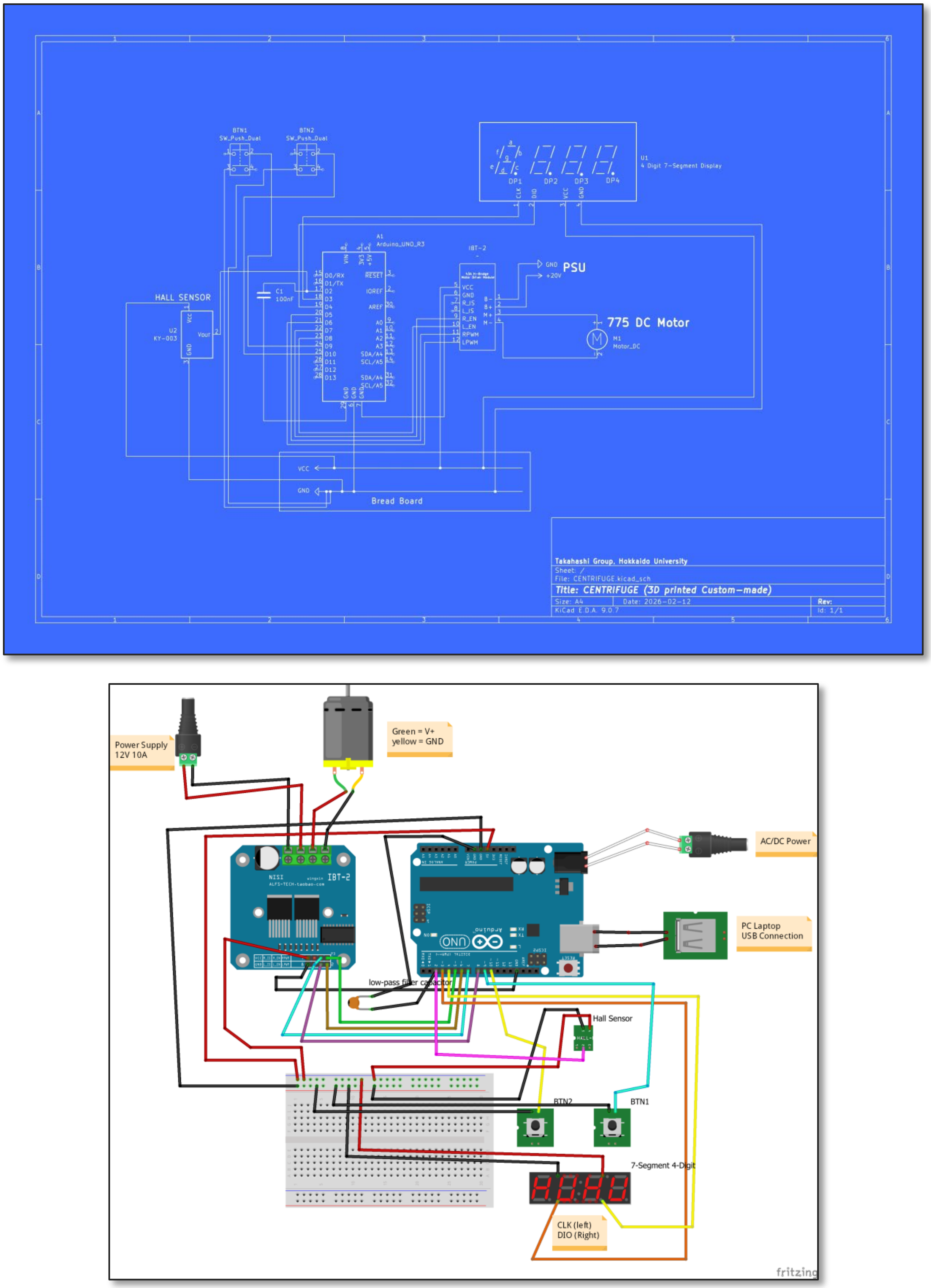

Figure S17: A more schematic view of the CENTRIFUGE setup.

Using ArduinoIDE for the Arduino board, and the C++ firmware code made for CENTRIFUGE, one can simply test each part one by one to make sure they work before final assembly.
Pay attention to that when one uses the IBT-2 board, then one need to install the libraries for that as explained in the T9 code section.

When the firmware is uploaded and the ~20V 10A power to the motor is connected one can test the motor by sending serial commands via the serial monitor in ArduinoIDE. Which commands are available can be seen in the code and explained further in this document. But a simple test command would be “R”. for toggle between ‘Run’ and ‘Stop’ and the number 0-4 to set the speed.
If the centrifuge accelerates smoothly and the displayed RPM stabilizes close to the expected target values for each state, then the motor control and feedback configuration are functioning correctly. If the speed overshoots significantly, oscillates, or does not reach the intended RPM, the PWM control parameters and target RPM values defined in the firmware should be reviewed and adjusted. Particular attention should be given to the base PWM start level, ramp behavior, and any calibration constants related to the Hall sensor. It is recommended to first test the motor at low speed (safe mode) and verify stable RPM readings before operating at higher speeds, ensuring that mechanical balance and sensor alignment are correct.

With above tests one can confirm that all hardware are working and can be finally assembled into the centrifuge box for real use.

T8. Fully Assembling the CENTRIFUGE Device

All the parts have been listed and illustrated in the former sections of this document, so please return there if a reminder of individual parts is needed.

Below we assemble each part one by one with any additional important detailed information where such is needed. The images themselves should mainly tell all that is needed to know though.

In most cases M3 and M4 bolts are used, but if that does not fit or is obviously too small or too big, then some other size might do the trick. In each step a list of parts used for that step is included using id numbers inside a set of italic square brackets *[]*, pointing to the table and item involved.

STEP 1: *[S3: 01-06, S4: 14-16]* Building the Base Frame.

Figure S18: All the parts included in the assembly of the frame base.

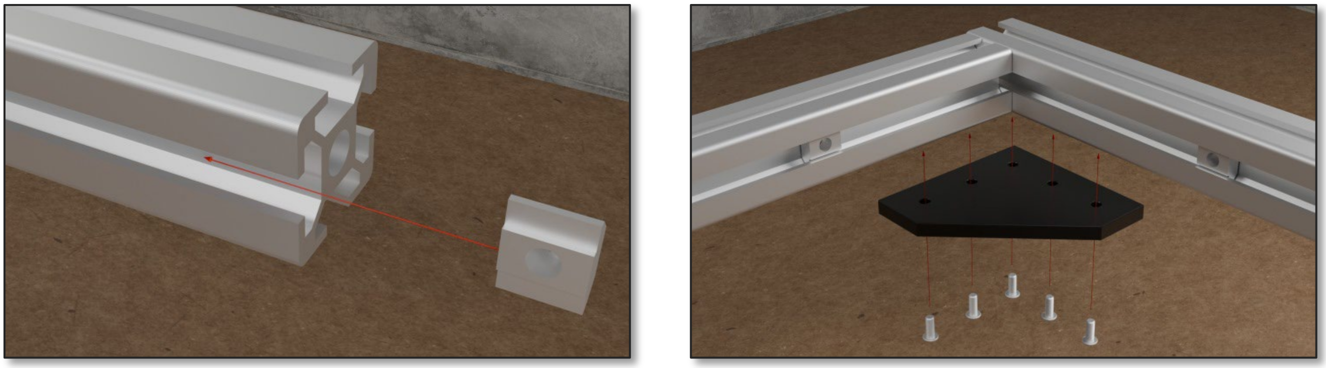

Figure S19: Sliding in the square nuts where they are needed and fasten the parts with the bolts.

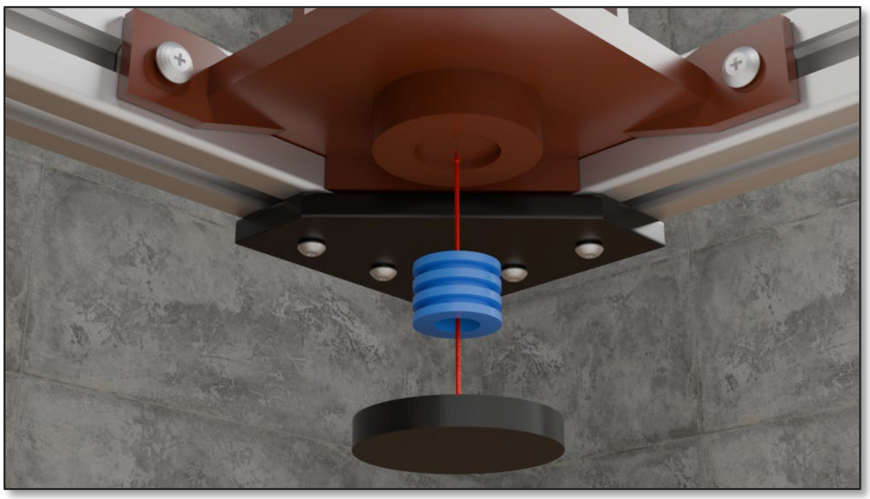

Figure S20: Glue the feet to the base corners.

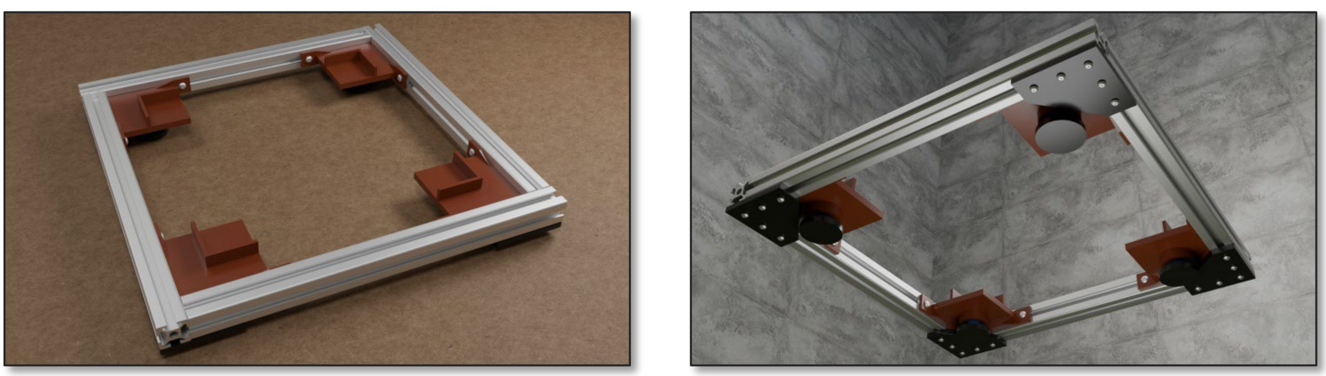

Figure S21: With all parts secured and assembled, seen from two angles.

STEP 2: *[S3:19, E01-E11, S4:01]* Add and fasten all the boards and the motor to the CENTRIFUGE Box bottom. Use some thick dampening rubber tape inside the motor holder if you have it, for softer movements of the box as well as more quiet when running the Centrifuge. Finally connect all the wires and cables. For more schematic details of the wire connections see Figure S17.

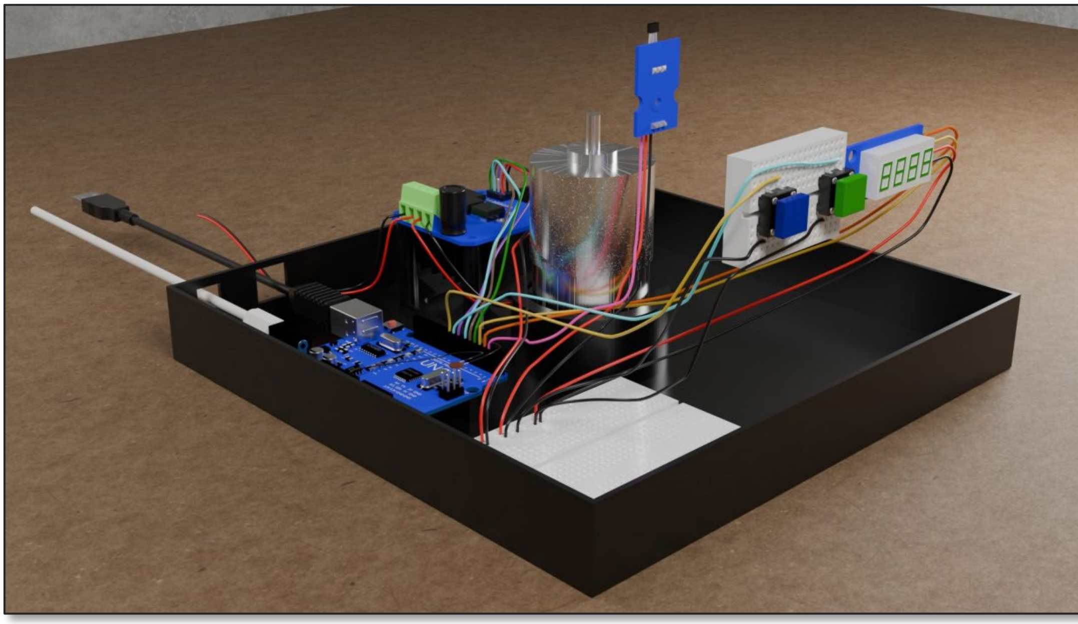

Figure S22: All the wires connected where they need to be.

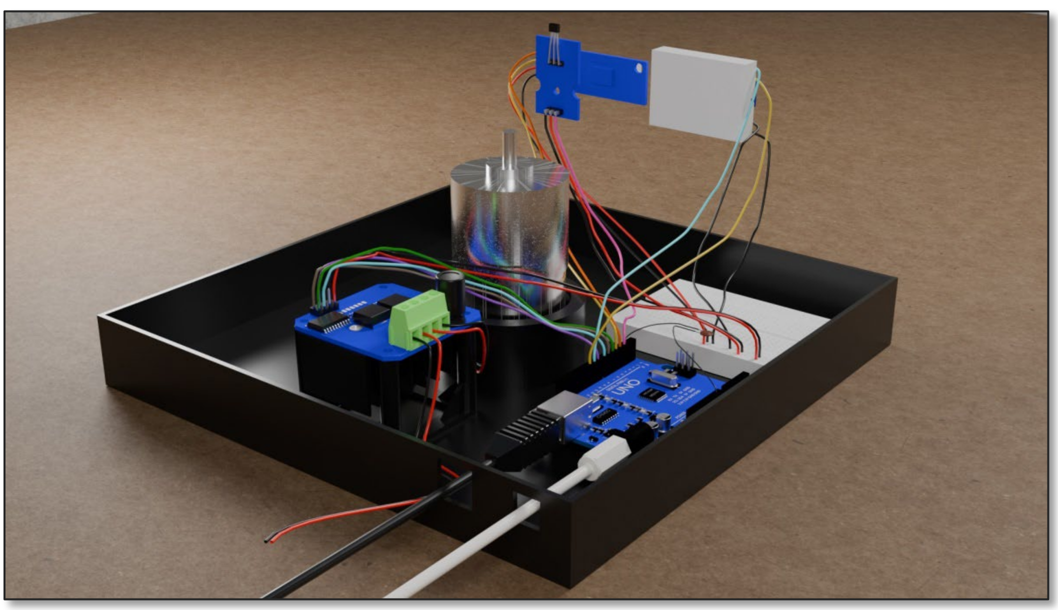

Figure S23: All the wires connected where they need to be from another angle.

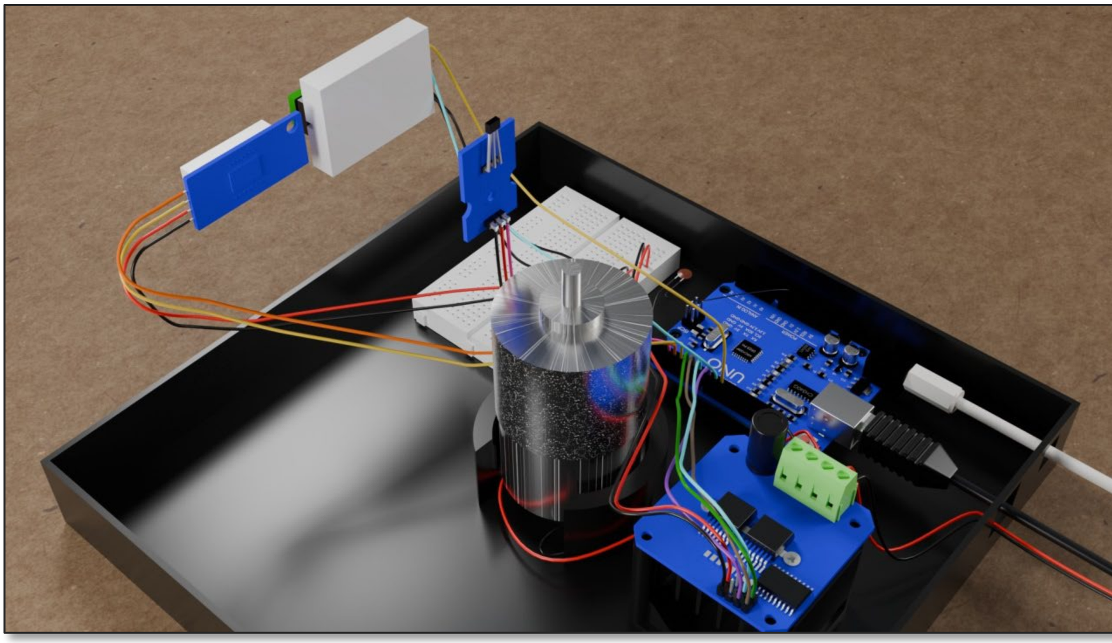

Figure S24: All the wires connected where they need to be from yet another angle.

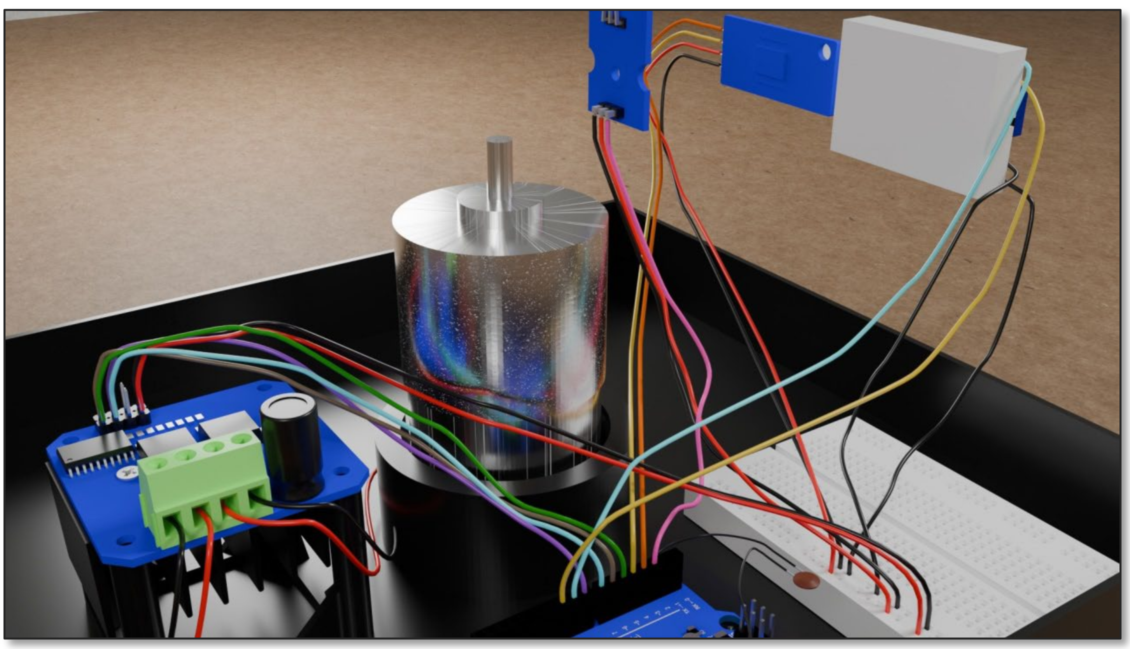

Figure S25: All the wires connected where they need to be from a final angle.

STEP 3: [S4: 03,13] When all parts are in place and some confirming tests using the ArduinoIDE serial monitor for testing is finished, move forward to add the second layer of the box that holds the buttons and the display, and secure them accordingly.

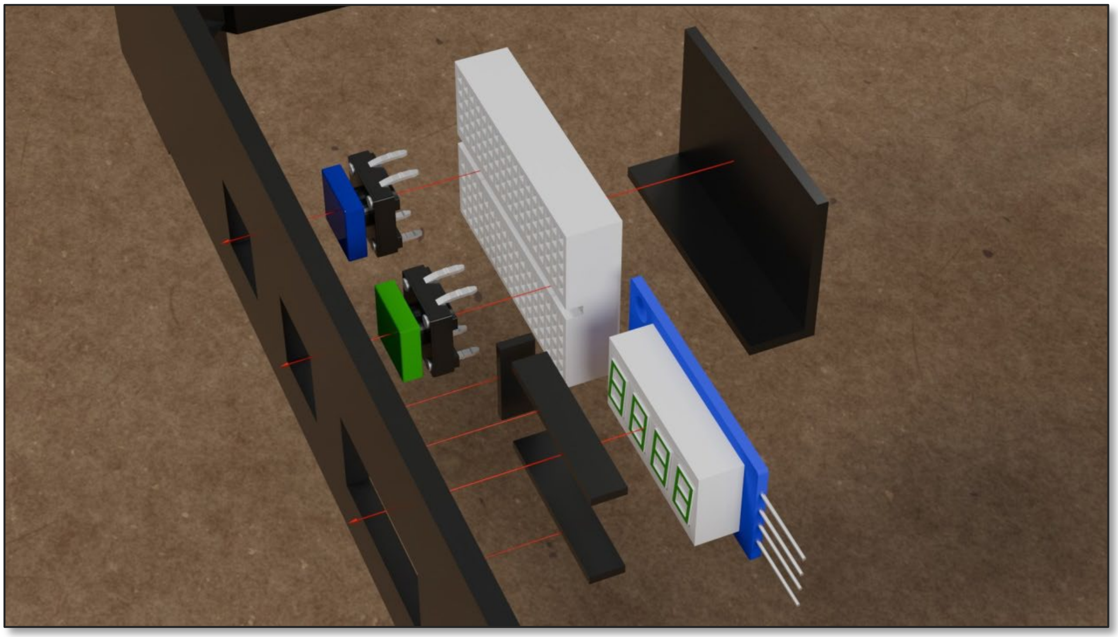

Figure S26: How to add the buttons and the display to the box frame (the wires are not shown).

Figure S27: After secured to the frame wall and properly wired.

STEP 4: *[S3: 07-10, 13-14, S4: 11]* Assemble the rotating tube holder, but do not yet attach it to the shaft, just put the assembled holder aside after it is done. Take note that the two small magnets should be glued together and not only rely on magnetism to hold them together and that the pair of magnets gets glued in its slot on the holder. The nut used on the opposite side to counterweight the magnets should be confirmed that they are basically the same weight in order to make the spinning smooth and stable. Make also sure that the magnets are slightly sticking out from its slot, to increase the magnetic range, and that the nuts are not, in order to avoid touching the Hall sensor.

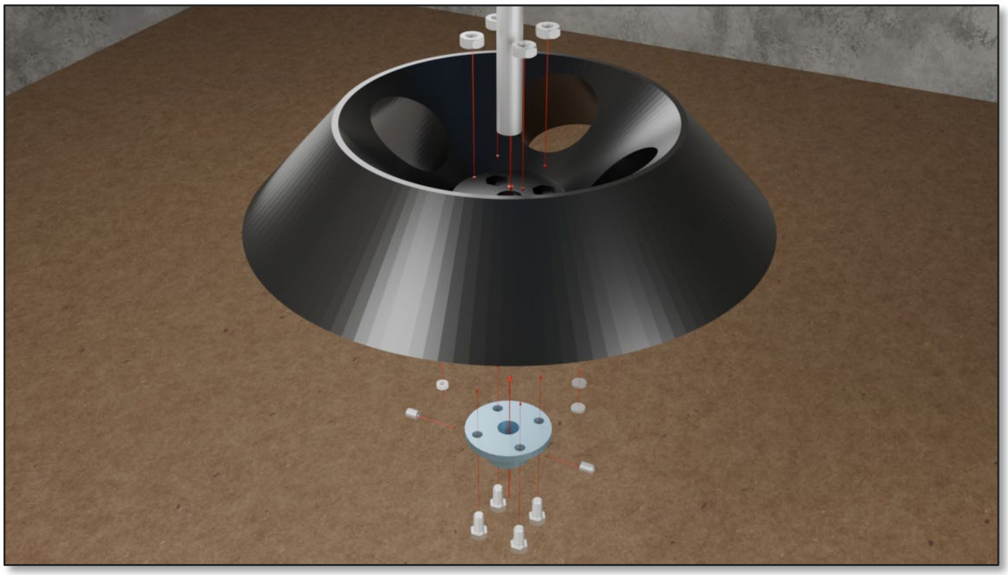

Figure S28: This image is showing how all parts of the spinning tube holder is related. The shaft Is seen in the image as reference, but should not be added yet.

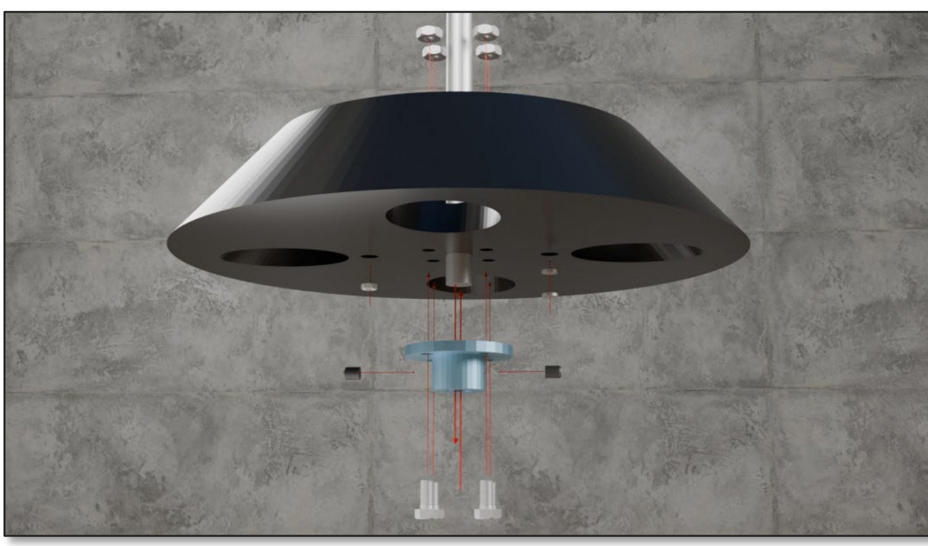

Figure S29: This image is showing the same as previous image, but from an angle below. As mentioned, ignore the shaft which is attached later.

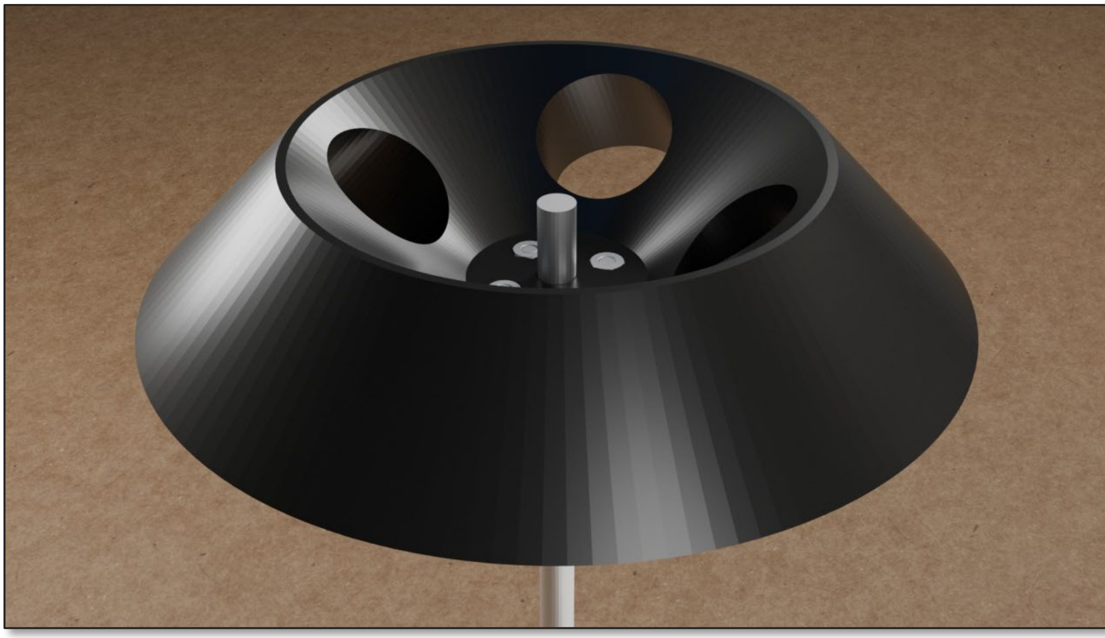

Figure S30: This image is showing how all parts are attached when we finished assembling the spinning test tube holder. Once again, the shaft is just for reference and should not yet be attached.

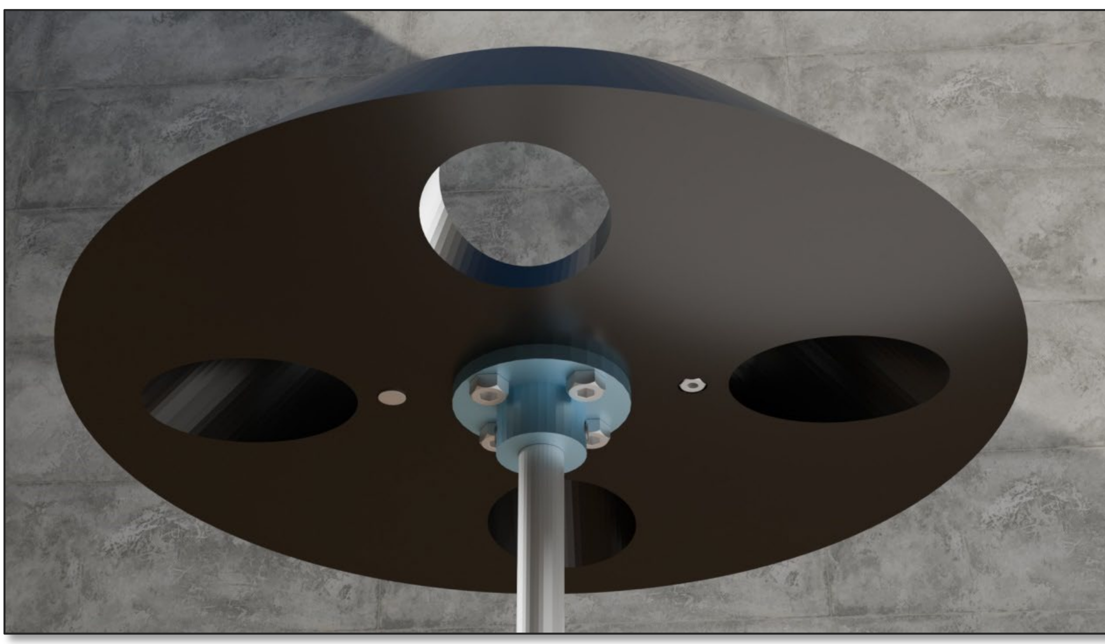

Figure S31: This image is showing the same as previous image, but from an angle below. As mentioned, ignore the shaft which is attached later.

After the test tube holder is assembled, just put it aside for later.

STEP 5: [S3: 04-07, 09, S4: 15-18] Now we are about to assemble the shaft to the motor and also to the box itself. That has to be done in layers to make sure all is properly connected and rests nicely on each layer. In the first image below (*Figure S32*) we just see the shaft with all mechanical parts attached and a fake rotating holder, just so we get a full understanding of what goes where as we start to assemble.

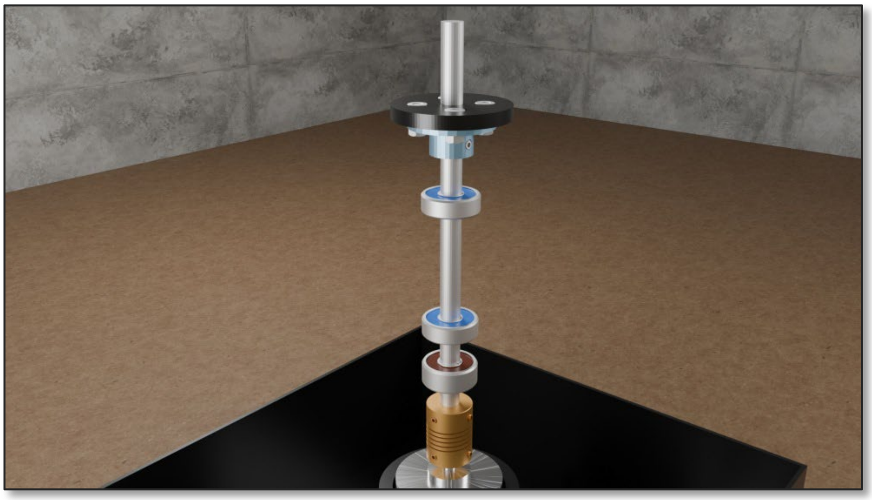

Figure S32: This image is showing how the shaft is connected to the motor with all the ball bearings and the flange. It does not show the support structure that also needs to be in place.

Next we see an image that shows how all the 3D-printed box parts are related and will be stacked during the assembly. In that picture we do not see the motor and the shaft so it is only for reference, because during proper assembly we must assemble the stacks of the shaft and the stacks of the box simultaneously.

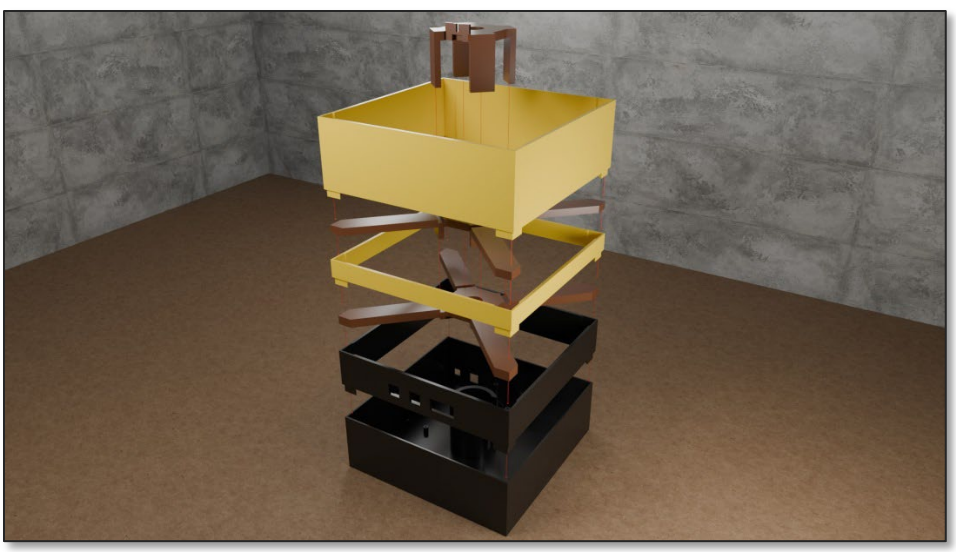

Figure S33: This is how all parts of the 3D-printed box are related together and how they should be stacked during assembly.

Now we will start the assembly and the stacking. Next we see an image that shows how all the 3D-printed box parts are related and will be stacked during the assembly.

Start by attaching the shaft (S3:15) to the motor (S3:E06) using the coupler (S3:16), as seen in the images in this section. Next, you add the box frame level 3 (S4:04) and slide it down as far as it goes, followed by the lv03 Ball Bearing House Cross (S4:06) through the shaft and pushed down for a perfect fit into the corners of lv03 box frame. Finally you push down the One Way Bearing Clutch (S3:17) through the shaft and into its place in the ball bearing house. Make sure the direction of the clutch is spinning in the same direction as the motor or you will have major problems. You can see the finished result in the image, *Figure S34*, below.

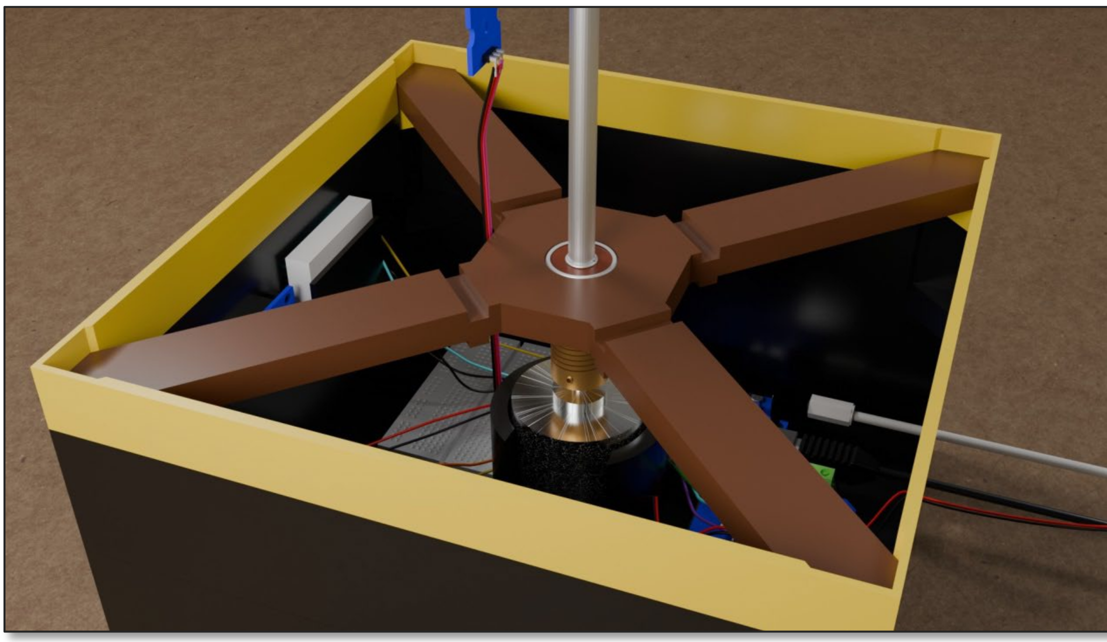

Figure S34: Layer level 3 is now assembled properly.

Next you slide on the box frame level 4 (S4:05) until it is all way down, and then the lower ball bearing house cross (S4:07) through the shaft and into the corners of the frame as well as down the slots of the cross below it for a perfect and stable fit. Finally push down the first ball bearing (S3:18) through the shaft and into its house slot. You see the result in Figure S35.

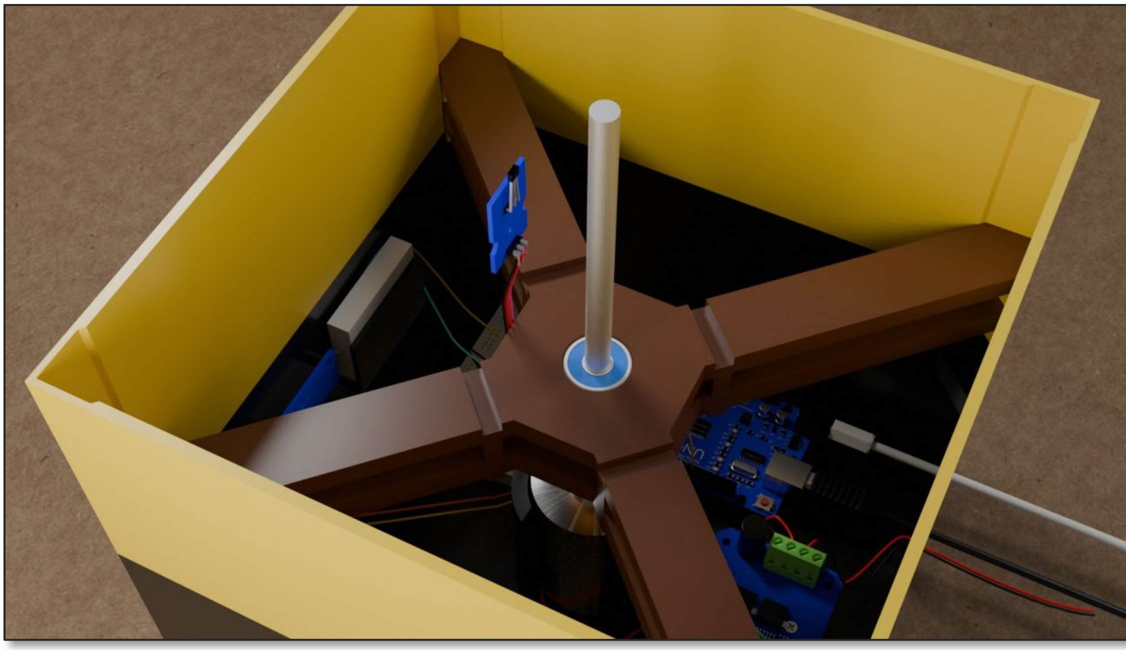

Figure S35: Layer level 4 is now assembled properly.

The last upper ball bearing house (S4:09) is just pushed down into the cross below it into the dedicated slots through the shaft, followed by the last ball bearing *(S3:18)* though the shaft and into the house slot. This is also the time where we fasten the Hall sensor (S03:E07) to the upper ball bearing house using a nut and bolt (S3:11+12). The finished result can be seen in *Figure S36*. Next you slide on the box frame level 4 (S4:05) until it is all way down, and then the lower ball bearing house cross (S4:07) through the shaft and into the corners of the frame as well as down

Figure S36: The final layer of the shaft and ball bearings are now in place.

In Figure S37 we can see how the parts attached to the shaft is layered and placed in a view where the box wall frames are removed (reference view only, not real).

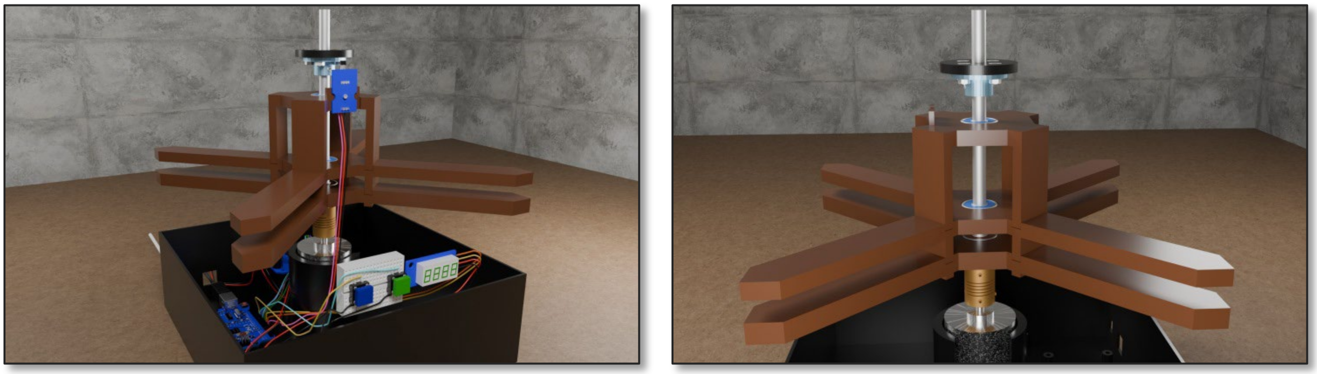

Figure S37: This is how the ball bearings and the houses is layered and attached to the shaft if the box wall frames was not visible.

STEP 6: *[S3: 10, Assembled test tube holder]* Now we will take the finished assembled test tube holder and slide it down onto the shaft as we see in Figure S38. The goal is to be about 1-1,5 mm above the Hall sensor, and there fasten the flange secure bolts (S3:10) so that the test tube holder is safely and stabled secured on the shaft at that position.

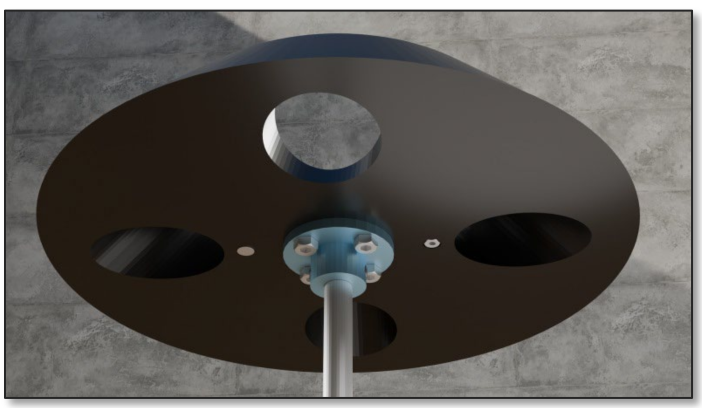

Figure S38: Sliding on the test tube holder onto the shaft so that is just above the hall sensor.

In Figure S39 below one can see how the whole contraption is assembled for proper spinning and RPM sensing.

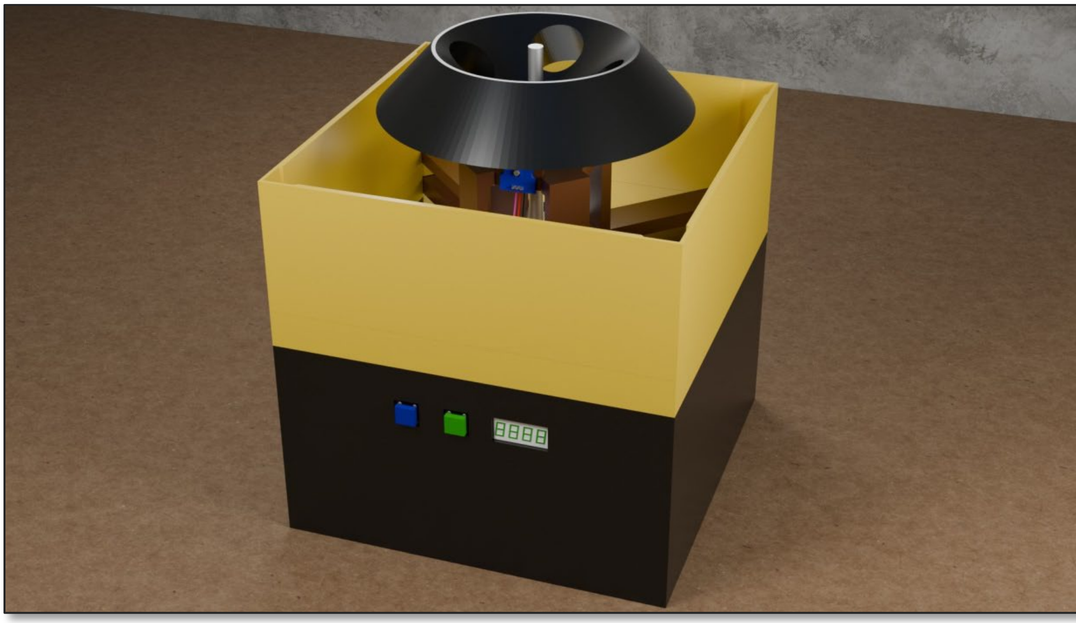

Figure S39: The test tube holder secure on the shaft just above the hall sensor.

STEP 7: *[Assembled* Base Frame*, Assembled Centrifuge]* Now we will ease down the finished centrifuge box in its place of the base frame. It is recommended that a few pieces of friction rubber tape are attached at the inside of the box holder corners of the base frame, to make movements more stable and soft. In Figure S40 one can see how they fit together.

Figure S40: Placing the Centrifuge box into the base frame.

STEP 8: *[Fully Assembled Centrifuge with* Base Frame*, Centrifuge Lid]* The last and final step is of course to place the lid on top of it all as seen in Figure S41. We also added some completely optional black tape to the corners of the CENTRIFUGE as seen in Figure S42 for mainly visual reasons but also initially to hold things better in place, which was not actually needed (unless the print was done in a way that the parts are too loose).

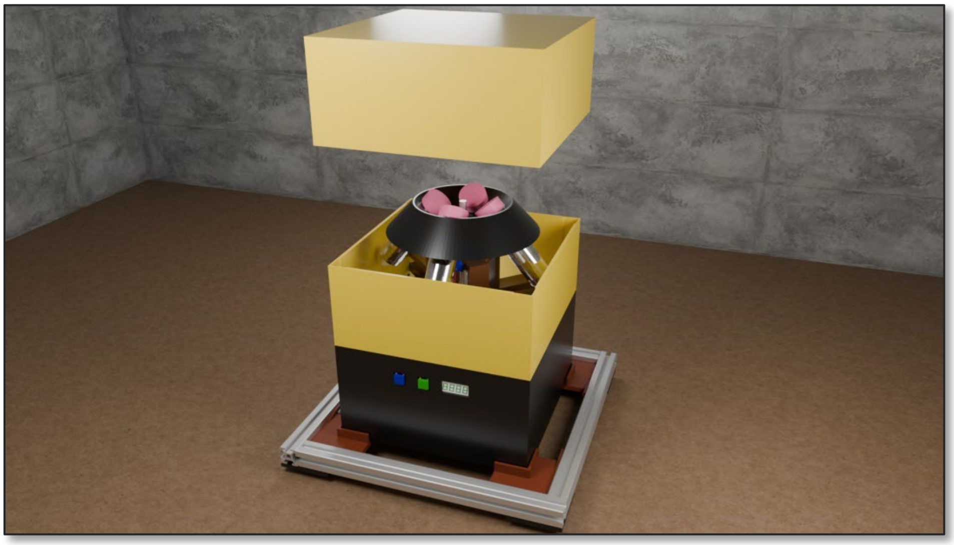

Figure S41: The assembling of the 'gripper'-claw with both its jaws and movable joints. (Top High)

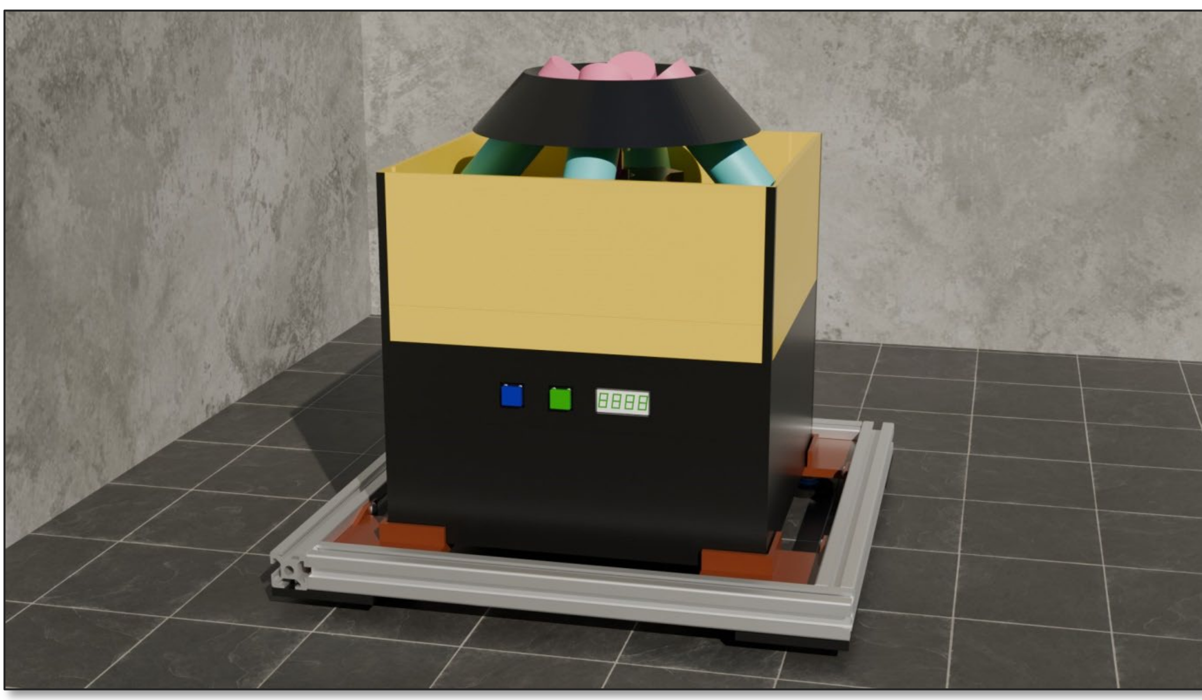

Figure S42: The CENTRIFUGE also got some corner tape for 50% stylish reasons, 20% additional stability reason and 30% better lid fit reasons. This is fully optional.

T9. Firmware

Firmware Code

The CENTRIFUGE firmware is available at GitHub on the following address:
https://github.com/Materials-Informatics-Group/Centrifuge/blob/main/Centrifuge_Controller_Firmware_v1.0.ino

All the code is contained in one single Arduino compatible *.ino file and comprised and polished down to less than 1000 lines of code (of C++) including a lot of comments and descriptions for easy reading and editing (if needed).

The file is best managed with the ArduinoIDE development software that is free to download from Arduino website. Learning and setting up ArduinoIDE is not the scope for this document but it is fairly simple and should not be any major problems.

Additional libraries that are needed to compile the CENTRIFUGE firmware in its default state is 'TM1637Display' 4-digit 7-segment display control library, and can be found via the built-in library manager.

All functions are clearly marked and commented for easy understanding. For basic usage of CENTRIFUGE the only need to edit the code would be the set or unset one of the two available flags SHOW_TARGET_WHEN_LOCKED which basically make the display work more like a commercial product where any fluctuation in the RPM be hidden while we are close enough to the target. Default is to always show the real RPM, and SERIAL_ENABLED which let the user control and get feedback using the Serial Monitor in ArduinoIDE to run the CENTRIFUGE.

```
// Build options (safe to toggle; do not change control behavior)
// Display option:
// true = when locked, show the target RPM (commercial-style UX)
// false = always show measured RPM (honest mode)
static const bool SHOW_TARGET_WHEN_LOCKED = false;
// Optional serial interface (debug / fallback control)
static const bool SERIAL_ENABLED = false;
```

All other constants used in the firmware should be fine and no need to change, but if any specific needs occur to do so the comments in the code should help enough to know which value does what and how to tweak them.

Reasons that might validate code edits could be the use of a different motor, so PWM values and related needs to be changed; if other hardware is used, buttons, display, hall sensor etc. different from what has been used in the default CENTRIFUGE; if the PINS are changed on the Arduino, or even a different Arduino board is used.

An additional reason to change the code is if one wants to push the centrifuge harder. The default code caps the speed at 4200 RPM for safety reasons, and allows for maximum 4000 RPM at the highest state 4. Technically that can all be changed in the code, to allow for more states and higher speeds. During testing we pushed CENTRIFUGE to 8000 RPM for a few seconds, but due to limitations in our PSU of maximum 10A we could not go further, and we also felt that perhaps those speeds were not suitable for an all PLA-printed device. But for anyone who wishes to test, it is possible to do higher speeds with the parts already available in CENTRIFUGE. We just want to stress that at those higher speeds, if something goes wrong, it might go very wrong fast, so whatever one does, safety first!

Firmware Usage

The CENTRIFUGE is used as described below.

To start or stop the motor, press the button named BTN1 to toggle the states of Off/On, or if Serial Communication has been enabled, send ‘r’ to toggle run/stop.

The speed of the motor rotation is all controlled in the firmware and divided into 5 steps, 0-4, where 0 is a safe, slow test mode, and 1-4 is for actual use, representing the RPMs of 1000-4000. If one press one time on the button named BTN2, the display will show the current speed state from ‘---1’to ‘---4’. After 3 seconds the display will return to showing the current RPM. If one clicks BTN2 again before it returns to showing RPM, then the state will change to the next state, from 1 to 2 or, 2 to 3 etc.   is not available in the natural rotation of state, since that speed is not usable under ordinary use. To go to 0 the user needs to hold the BTN2 for 3 seconds until the display shows ‘---0’. Next state change will go to 1. If one uses the Serial Monitor in ArduinoIDE, the state change by sending the numerical value ‘0’-‘4’. To get display values and other state information in the Serial Monitor when send an ‘s’ and to get help info one send an ‘h’.

More detailed information can be found in the code file.

For safety reasons, we do not recommend to spin the centrifuge without the lid on, except perhaps for state 0 (~350 RPM), but even then one should exercise caution.

Figure S43: Spinning the CENTRIFUGE without the lid is not recommended for safety reasons.