قوسین Qosain scientific

LUMS STARTUP

Technology Development Fund

# General Purpose Stepper Motor Controller

User Manual

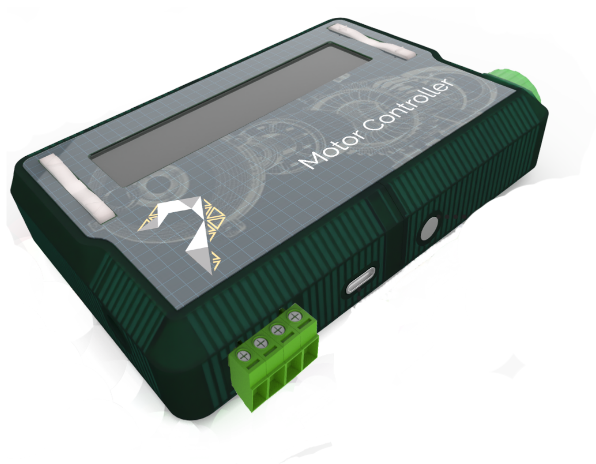
V 3.0

# List of abbreviations

| | |
|---|---|
| A. RPM | Analog revolutions per minute |
| AWM | Appliance wire material |
| AWG | American wire gauge |
| CT | Center tap |
| D. RPM | Digital revolutions per minute |
| ID | Internal diameter |
| LCD | Liquid cathode display |
| NEMA | National Electrical Manufacturers Association |
| QS | Qosain Scientific |
| rad | Radians |
| rev | Revolution |
| RPM | Revolutions per minute |
| sec | Seconds |
| SMC | Stepper Motor Controller |
| SPR | Steps per revolution |
| TF | Transfer function |
| $TF_a^b$ | Transfer function showing conversion from unit $a$ to unit $b$ |

# Scope

The manual is a quick guide to getting acquainted with Qosain Scientific's (QS) General Purpose Stepper Motor Controller (SMC). The SMC can control a bipolar stepper motor (such as the NEMA 17 or NEMA 11), requires minimal electrical setup, and can be used in a vast range of applications. The user manual covers the description of different operational modes of SMC, hardware setup, applications examples, operation procedure, product specifications, errors and troubleshooting guide, and other working details of the system.




QS multi-mode, easy-to-configure and easy-to-use SMC.

# Contents

## 1. Product Description

The QS SMC is typically designed to control a bipolar stepper motor, such as the NEMA 17 or NEMA 11, and any subsequent common line shaft or mechanical assembly component that may be connected to the motor. The easy-to-configure SMC has an inbuilt user interface and demands minimal electrical setup: using only a DC power adapter as the power source. The SMC offers a quick and accurate control of angular speed, angular displacement, linear speed, linear displacement, and time and volume limits in a range of physical units. The motor controller can be used either in tabletop or inbuilt applications such as motorized syringe pumps, stirrers, conical pendulums, and etc. The QS SMC is also compatible with the QS low cost syringe pump (Physpump), a volumetric fluid control device.

## 2. Before You Start

### 2.1. Safety Requirements

To avoid any damage to the equipment, please read the safety protocol carefully before operating the device.

1. **Do not operate in wet conditions.** To avoid any chances of short circuit inside the instrument, never operate the instrument in a humid environment.
2. **Handle with caution.** Please handle with care during transportation to avoid damage to the screen, buttons, and other parts of the device.
3. **Do not operate with suspected failures.** If you suspect that any damage might have occurred to the instrument, have it inspected according to QS's prescribed procedures before proceeding to use. In case any maintenance, adjustment or replacement is required, it must be carried out first.

## 2.2. Work Environment

| | |
|---|---|
| **Temperature** | Operating: +5° C to +40° C<br>Non-operating: +5° C to +60° C |
| **Humidity** | 0° C to +30° C: ≤ 95% relative humidity<br>+30° C to +40° C: ≤ 75% relative humidity<br>+40° C to +50° C: ≤ 45% relative humidity |

## 2.3. Care and Cleaning

**Cleaning**

Clean the instrument regularly according to its operating conditions.

1. Disconnect the instrument from the power source and motor.
2. Clean the external surfaces of the instrument with a soft cloth dampened with mild detergent or water.
3. During cleaning, avoid exerting excessive force on the screen or any other component.

# 3. Product Specifications

## 3.1. Front and Side Panels Overview

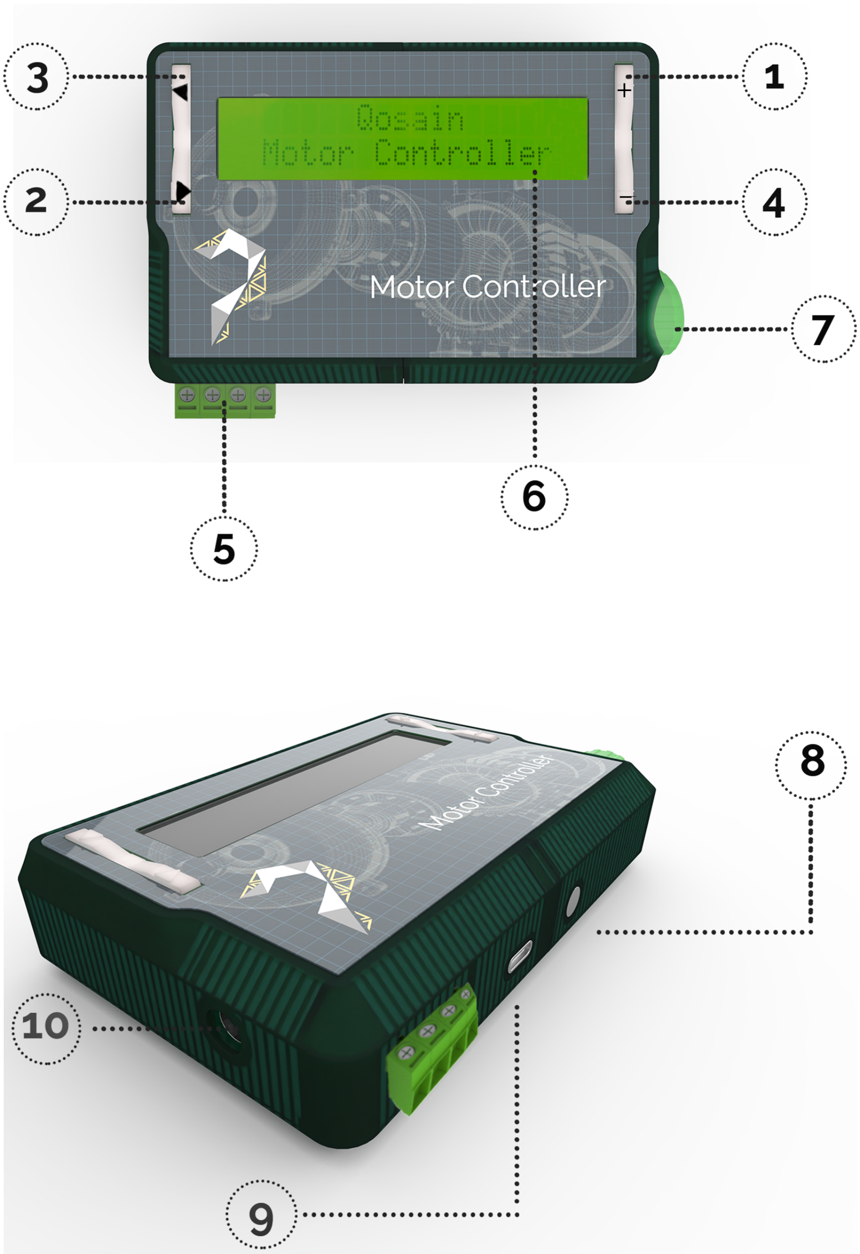



Figure 3.1: Schematic diagram of the front and side panel of the QS SMC. (Please note, the exact form of the product may vary slightly from this illustration.)

| No. | Component and its description |
| --- | --- |
| **1** | **Increment button** + <br>It is used to increase the numeric value of the currently displayed parameter. The size of the increment (step) increases as the button is pressed and continually held down. At startup, the button is used to select a SMC operational mode. |
| **2** | **Next button** > <br>The button is used to select a function and move to next screen. At startup, the button is also used to navigate through different operational modes of SMC. |
| **3** | **Back button** < <br>The button is used to return to the previous screen; pressing and holding it will return the user to the first page of every mode. At startup, it is also used to navigate through different operational modes of SMC. |
| **4** | **Decrement Button** – <br>It is used to decrease the numeric value of the selected parameter. The size of the decrement (step) increases as the button is pressed and continually held down. At startup, the button is used to select a SMC operational mode. |
| **5** | **Motor terminal block** <br>The block allows connection of the SMC to the motor. Connection is made via a pluggable screw terminal block connector, as specified in Figure 3.2 and elaborated in Section 4.1. |
| **6** | **LCD screen** <br>To digitally indicate the variable readings and operational modes. |
| **7** | **Analog control knob** <br>The analog knob can control motor speeds. It only operates in the A.RPM mode. |
| **8** | **Limit switches socket** <br>Limit switches can be attached to the SMC through this 3.5 mm pin connector. |
| **9** | **PhysInstrument Connector** <br>This USB Type-C port can be used to connect the SMC to the QS PhysLogger, a datalogging device. Once connected, all SMC operations can be controlled by the PhysLogger. |
| **10** | **DC power jack** <br>DC power adapter with a 5 mm pin is plugged to the SMC through this socket. Refer to Figure 3.3 for pinout requirements of the jack. |

Table 3.1: Description of all major components of the QS SMC.

## 3.2. General Features

| Motor Requirements | |
|---|---|
| Motor compatibility | NEMA 17 and NEMA 11 Stepper Motors (12 V – 24 V, 2 A, bipolar stepper motor, 200 spr). Also, refer to A.1.1. |
| Motor connector | A 4 pin 0.2 inch pitch screw terminal block connector |
| Motor pinout connections | Refer to Figure 3.2 and Section 4.1. |
| **Power Requirements** | |
| Input power supply voltage range | 12 VDC – 24 VDC, 2 A |
| DC power plug specifications | Core positive 5.5 mm x 2.2 mm DC barrel plug (Refer to Figure 3.3.) |
| **Analog Control Knob and Limit Switch Requirements** | |
| Analog control knob rating | 10 kΩ |
| Socket type | 3.5 mm stereo jack |
| Wiring requirements | A 3 wire stereo cable (e.g. AWM 2547 28 AWG VW-1) is used. For wiring and detailed connection instructions, refer to Figure 3.4 and Section 4.3. |
| **Operating Features** | |
| Number of basic operational modes | 4 (Refer to Section 5.1.) |
| Range of rotational speed control | −2700 deg/s to 2700 deg/s |
| Storage memory | All the parameters are retained after restarting the SMC. |
| **Other Features** | |
| Physical dimensions | 121 mm x 80 mm x 27 mm (L x W x H) |
| User interface | Push button and LCD screen |
| User input methods | Digital and analog user inputs |
| Output display | 2-lines, 20-characters alphanumeric LCD |

Table 3.2: The basic specifications of the QS SMC.

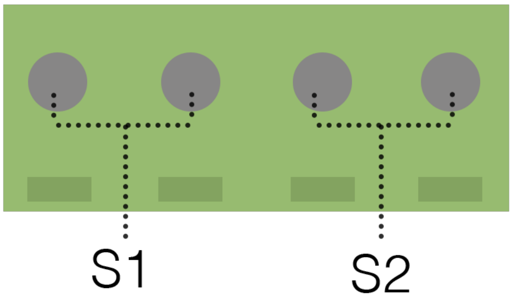



Figure 3.2: The motor pinout connections on the screw terminal block connector must be made according to this schematic. S1 and S2 represent the first and second solenoid of the stepper motor, respectively. This connector is then inserted in the motor terminal block on the SMC.

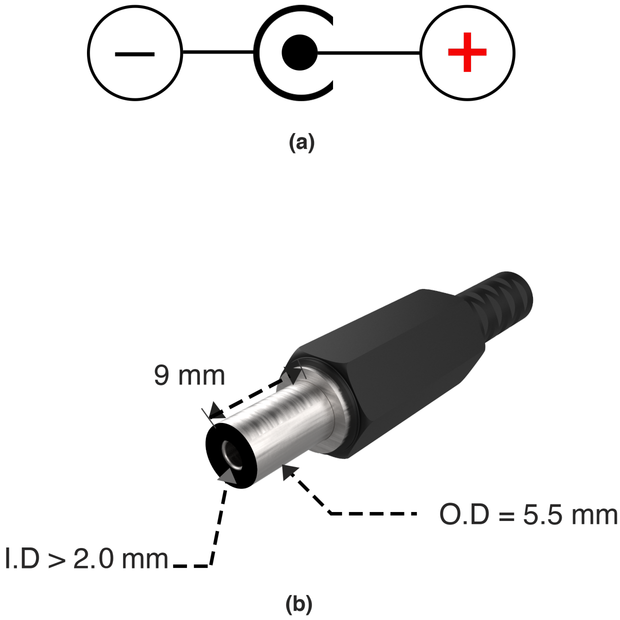



Figure 3.3: A DC barrel plug with (a) core positive polarity and (b) a pin with an outside diameter (O.D) of 5.5 mm and internal diameter (I.D) of more than 2.0 mm must be used.

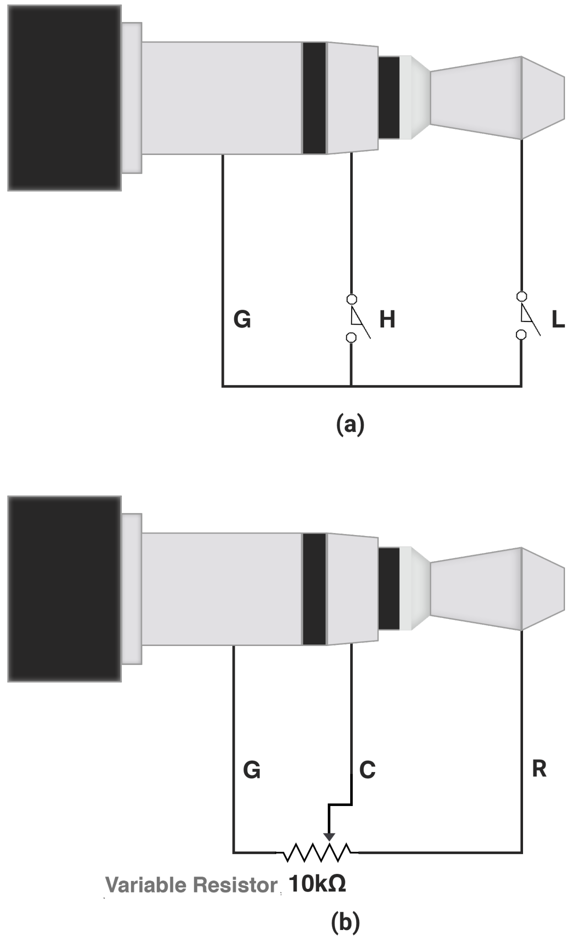



Figure 3.4: (a) A limit switch jack wiring diagram where G, H, and L represent ground terminal, high limit switch, and low limit switch, respectively. (b) Wiring diagram of an analog knob jack where G, C, and R represent the ground, centre, and right terminals of the jack.

## 4. General Hardware Setup

The hardware setup of the SMC system will vary according to the application required by the user – some of the various applications of the SMC are demonstrated in Section 6. However, certain setup details are common to a range of applications. Section 4.1 describes the main procedure of electrically installing the SMC hardware and the sections following Section 4.1 describe the procedures of setting up other components with the SMC such as a limit switch and gearbox.

## 4.1. Main Electrical Setup

1. Before setting up the SMC, ensure a proper understanding of the location and description of all parts of the SMC, as given in Section 3.1.
2. The SMC is connected to the motor (that needs to be controlled) via the motor terminal block on SMC.
   i) To connect the SMC with a motor use wires based on tinted copper conductors and coated with PVC insulation, e.g., UL style 1007 or CSA type TR - 64 cables, with a size in the range of 32 – 16 AWG and rated voltage above 50 V.
   ii) The four wires can be connected to the motor using a 6 pin JST connector or directly soldered to the motor (according to the data sheet of your motor model).
   iii) If using a NEMA 17 motor, refer to the description of motor pins given in [1] to identify the pins of the motor. If using a NEMA 11 motor, refer to the motor pin specifications given in [2]. If using a motor whose pinout connections are unknown, refer to the tutorial given at [3].
   iv) If the motor has more than 4 pin connections, it has center tap (CT) connections as well. However, as the SMC does not require the connection of any CT (as described in A.1.1), the CT wires can be ignored.
   v) To connect the four wires to the SMC, insulation is removed from one end of the wires and each wire is inserted into the 0.2 inch pitch screw terminal block connector (provided with the QS SMC) as shown in Figure 3.2.
   vi) The screw terminal block is plugged in the motor terminal block of the SMC, as shown in Figure 4.1.
   vii) Depending on the application, the wires connecting the SMC and motor can be several feet long. However, to ensure that no proportion of motor power is diminished during transmission, the length should not exceed 6 ft.

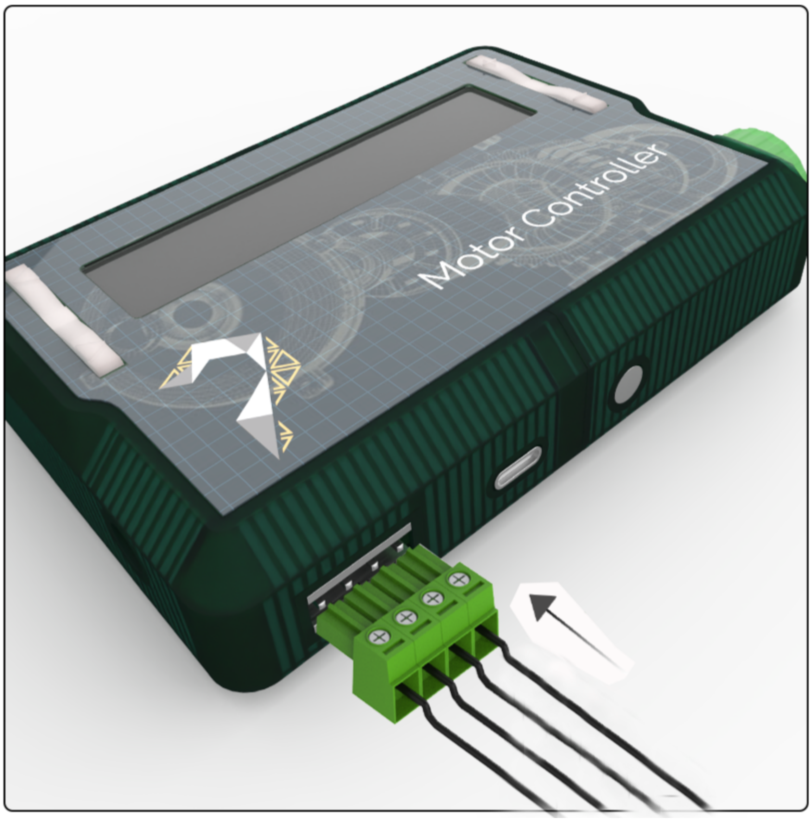



Figure 4.1: The motor is connected to the SMC by plugging the screw terminal block connector in the motor terminal block on SMC.

3. Connect the DC power adapter to the SMC via the DC power jack on SMC, as shown in Figure 4.2. (For output ratings and plug specifications, refer to Table 3.1).
4. After plugging the DC power adapter to a power source and pressing the ON button, SMC will switch on and its LCD screen will light up.

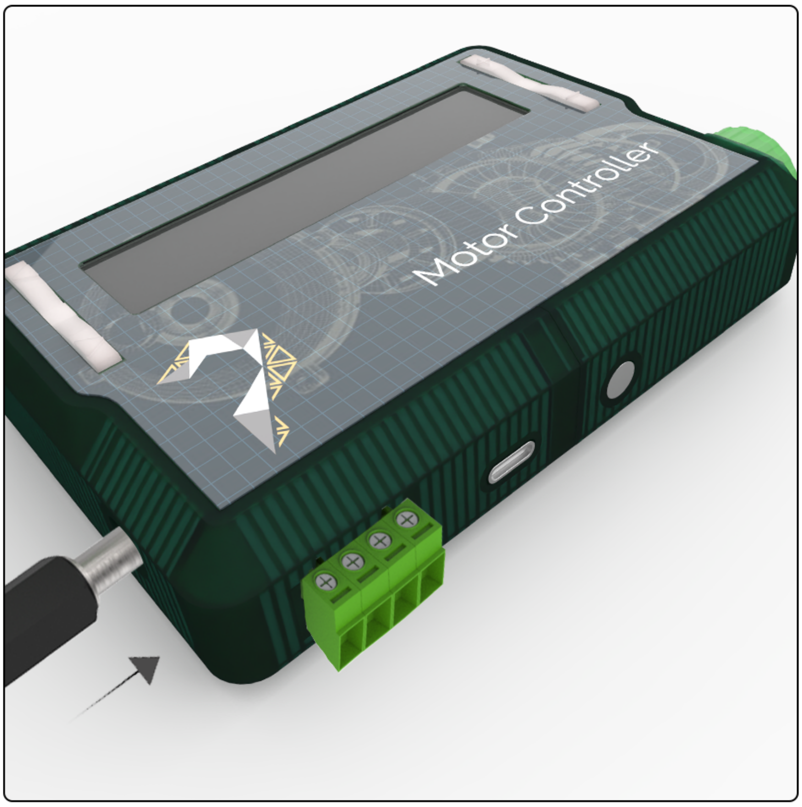



Figure 4.2: The DC barrel plug is connected to the SMC via the DC power jack on the SMC.

## 4.2. Setting up Limit Switches

SMC also allows the integration of limit switches with the motor. Limit switches are installed in industrial applications where the device in motion only has a confined space to move in. Once, a mechanical limit is exceeded by the moving device and it comes in contact with the actuator on the limit switch, the switch is tripped. A switch, when connected to a SMC and motor, can either reverse the direction of the device movement or act as an emergency button and stop its motion when tripped. A limit switch is connected to the SMC via the limit switch socket (Section 3.1) on the SMC that allows a 3.5 mm stereo jack to be plugged in.

Figure 4.3 shows how two limit switches: high (H) and low (L), can be employed to keep a motorized syringe pump oscillating between two limits.

Momentary (spring return) switches with an actuator such as the push rod plunger or spring wire rod can be used in such applications where each switch reverses the rotation of the motor in opposite directions. Normally Open (NO), Normally Close (NC), and Central (C) terminals can be connected to the 3.5 mm stereo jack and thus, the SMC according to the wiring diagram in Figure 3.2.

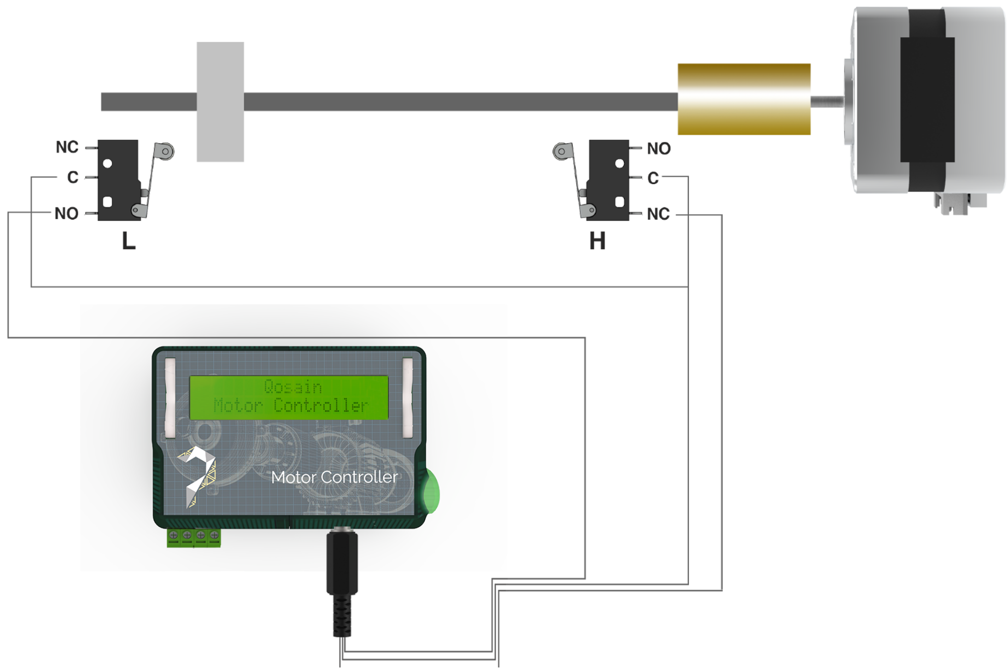



Figure 4.3: Schematic showing the application of limit switches with SMC. In this setup high (H) and low (L) limit switches are used to restrain the movement of the plunger of a motorized syringe pump. NO, NC, and C represent the Normally Open, Normally Close, and Central (also called ground) terminals, respectively, of the limit switches.

## 4.3. Using Gears and Belts

SMC can also be integrated with an intermediate belt and pulley or gearbox arrangement. For these arrangements, the **gear ratio**, i.e., the distance covered by the final component in the gear assembly per revolution of the motor, must be known by the user.

A belt and pulley system can be employed with the motor to convert its rotational motion in translation. A driver pulley wheel is mounted on the shaft of the motor and is connected via a belt to a driven pulley. A rope or cable wound around the driven pulley can be further connected to any component that is required to be translated as the motor would rotate. A rack and pinion gear assembly can be used to convert rotational motion of the motor to translatory motion of a slider or rack, whereas, speed-reducing or speed-increasing gears can be used to achieve speeds outside the specified range (Table 3.1) of the SMC speed control. Figure 4.3 shows the installation of a gearbox driven by a timing belt in a motorized system that is controlled by the SMC.


Figure 4.4: The hardware setup arrangement of the SMC when used with a gearbox (timing gears driven by a belt) mounted on the shaft of the motor.

## 5. Operational Modes

### 5.1. Overview

To support the wide range of applications, SMC comes inbuilt with different operational modes. Fundamentally, the SMC software is designed to interact with the user in a systematic manner and typically follows the steps shown in Figure 5.1.

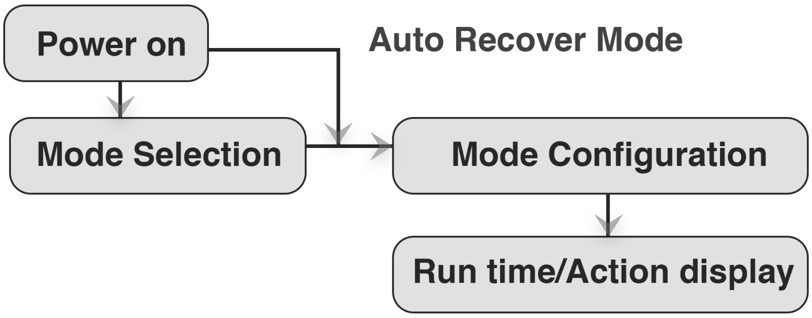



Figure 5.1: The setup of SMC after being switched on typically follows the sequence shown in this flow chart.

The operational functions, common to all modes are as follows:

1. Each screen within the modes usually shows an operational parameter which can be incremented and decremented using + and –, respectively.
2. The user can switch between different configurable parameters using > and <.
3. To proceed to the next screen, > should be pressed.
4. When the motor is actuating, pressing < once pauses the process; thus, halts the motor. Pressing < in the paused state will abort the process.
5. A user may exit a mode and return to the home screen by pressing and holding < on the first screen of each mode.

Please note that changing the value of one parameter may automatically alter the values of other connected parameters (for example, the starting speed of a mode may be overridden by the range of speed, if the values conflict each other). Furthermore, for detailed description of how a user-defined value is interpreted by the SMC through the means of different transfer functions, refer to A.3.

Table 5.1 describes all the operational modes of SMC. The different functions in the Digital RPM (D. RPM), Analog RPM (A. RPM), and Syringe Pump Mode are shown in Figure 5.2, whereas the functions in the Displacement Mode are represented in Figure 5.3. The procedure of selecting a mode is described in Section 5.2, whereas each subsequent subsection after Section 5.2 describes the procedure for a particular operational mode of the controller.

| Sr | Mode | Description |
|---|---|---|
| 1 | D.RPM | In the D. RPM Mode, a starting value of motor's rotational speed is digitally input. The rotational speed of motor can also be changed during operation, within a user-defined range. |
| 2 | A.RPM | In the A. RPM Mode, the rotational speed of the motor is adjusted through an analog knob. The user, by using the knob on the SMC, can adjust the range of speed control; thus, the sensitivity of each knob's turn. |
| 3 | Syringe Pump | In the Syringe Pump Mode, SMC can control the pumping of fluid according to the desired flow rate and volume or time limits. The PhysPump 1 Mode is adapted to work with QS Physpump. For a different syringe and TF, use Custom Mode |
| 4 | Angular Displacement | The Angular Displacement Mode offers control in a range of rotational speed units. In this mode, SMC can control the rotational speed, angle rotated, and starting position of any shaft or rotational component connected to the motor. |
| | Linear Displacement | The Linear Displacement Mode offers units of linear speed and can be used to control the displacement, speed, starting position, and motion of components such as motorized linear stages, slides, racks, or cylinders. |

Table 5.1: The different modes and their descriptions for QS SMC.

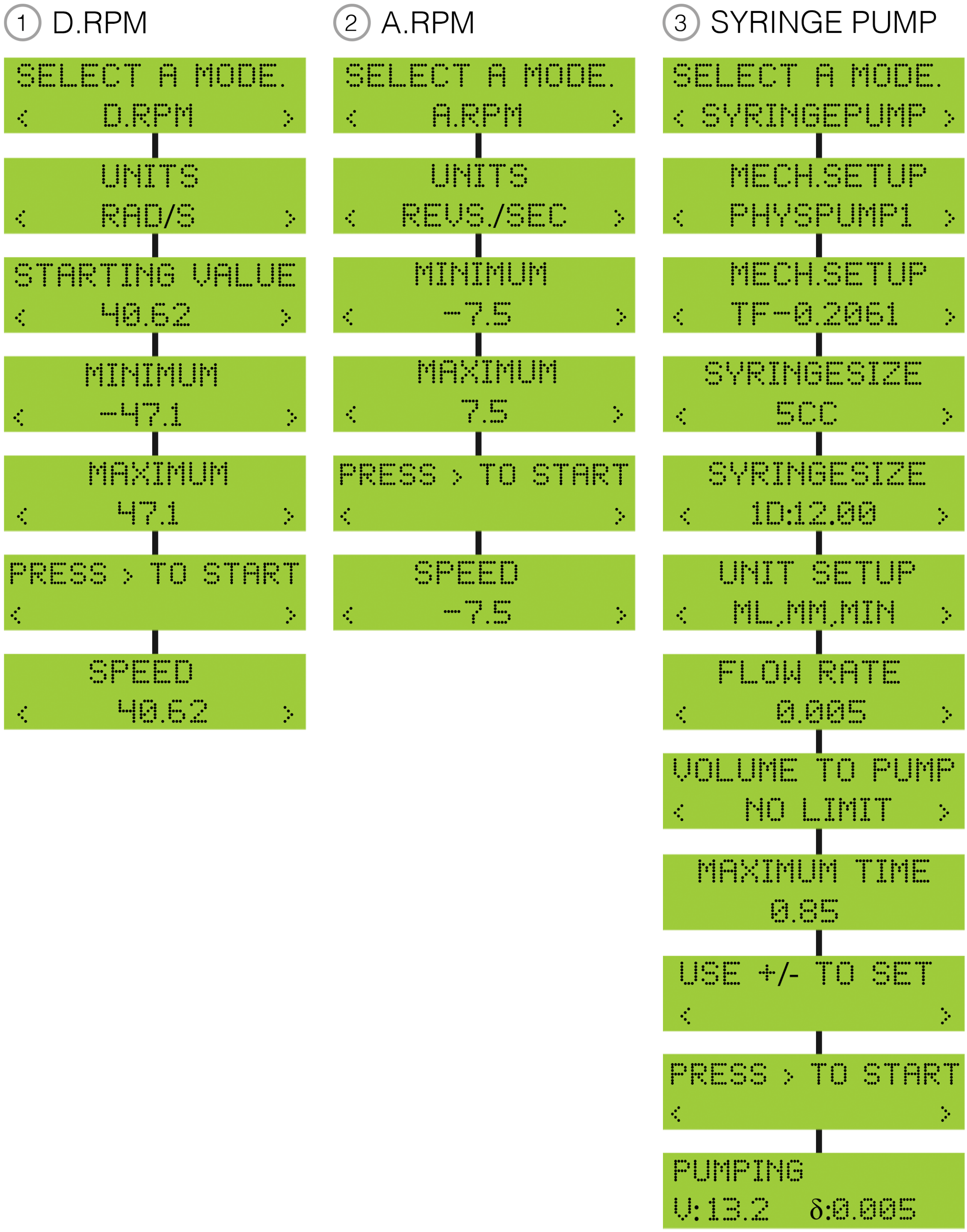



Figure 5.2: Summary of the operation of D. RPM, A. RPM, and Syringe Pump Modes.

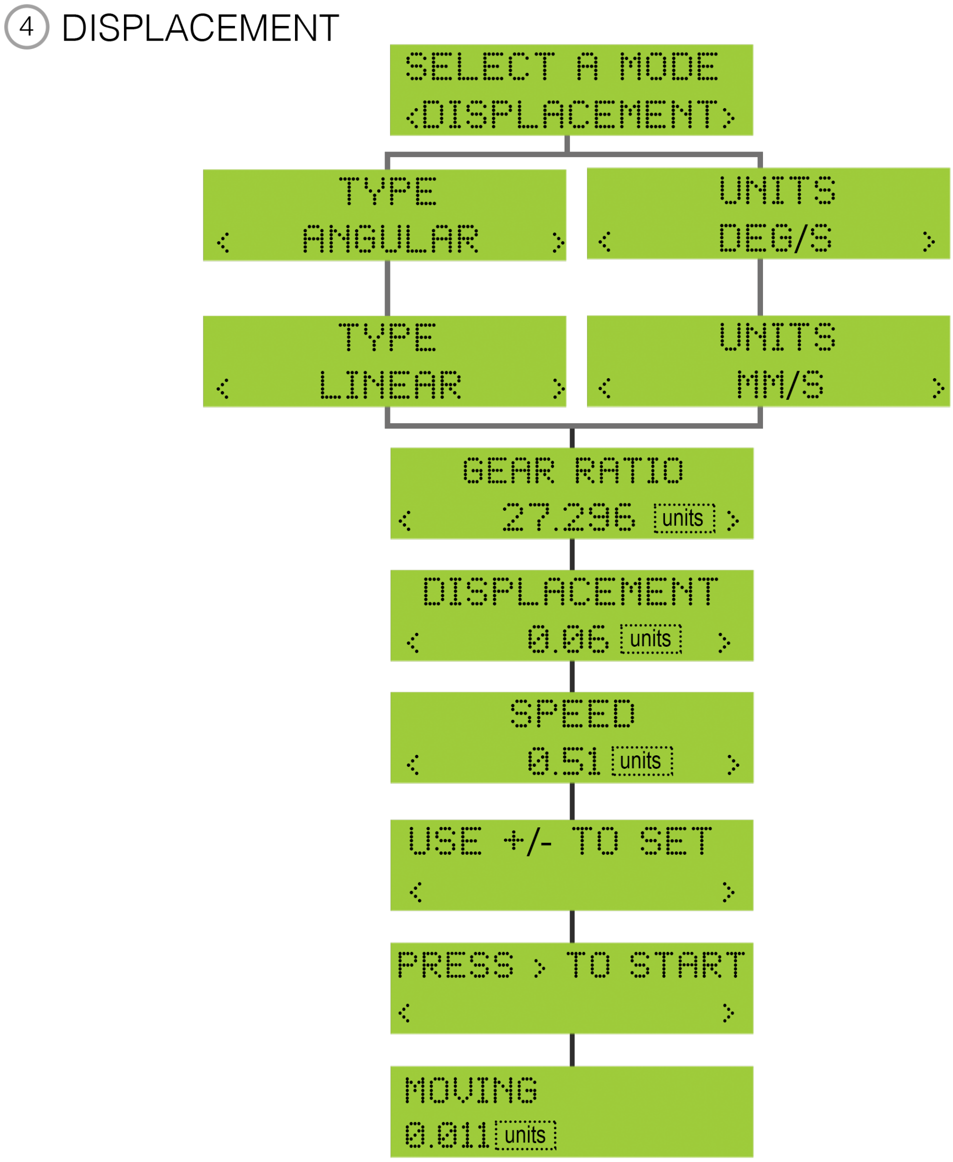



Figure 5.3: The functions of the Displacement Mode (the Displacement Mode further has an Angular and Linear Mode of operation).

## 5.2. Selecting a Mode of Operation

1. Once switched on, the user will be prompted to select a mode. The modes (as described in Table 5.1) are: D. RPM, A. RPM, Syringe Pump, and (Angular and Linear) Displacement Mode.
2. The modes can be scrolled through using > and < and can be selected using + or –.

## 5.3. Digital RPM

D. RPM offers a fine control of the motor speed, and some of its application examples include a laboratory stirrer (Section 6.3), dripping faucet (Section 6.4). The functions of the D. RPM Mode can be observed from Figure 5.2 and are further elaborated below.

1. Select the D. RPM Mode.
2. Scroll and select the preferred measurement units and proceed to the next screen.
3. The Starting Value, i.e., the speed at which the motor will begin its rotation, is set and selected. (A.3.2 shows how the input speed value is interpreted by the SMC to determine the number of steps the motor needs to move). To reverse the direction of motor rotation, select a speed with the opposite sign.
4. Define the range in which rotational speed can be altered during rotation by setting the Maximum and Minimum values (Table 3.2).
5. Begin the rotation of motor. (Once, started, the LCD screen will start displaying the current rotational speed of motor.)
6. If required, the angular speed of the motor can also be changed during operation.

## 5.4. Analog RPM

In the A. RPM mode, the analog knob on the side of SMC is used to control the motor speed. The application examples of this mode include the conical pendulum (Section 6.2), laboratory stirrer (Section 6.3, and a setup to translate loads (Section 6.5). All major functions of this mode have been summarized in Figure 5.2 and are also described below.

1. Select the A. RPM Mode
2. Define the range of rotational speed and the sensitivity of each turn of knob by setting the maximum and minimum values of the range. The maximum range limits are given in Table 3.2.
3. Once the rotation of the motor is initiated, the LCD screen will display the current rotational speed of motor.
4. During rotation, the speed of rotation can be changed using the analog control knob.

## 5.5. Syringe Pump

The Syringe Pump Mode, as described in Table 5.1, allows the precise pumping of a fluid. Section 6.1 demonstrates the application of this mode with a syringe pump. The procedure of operating the mode is elaborated below.

1. Select the Syringe Pump Mode.
2. To use the SMC with the QS PhysPump, select PhysPump 1 as the Mechanical Setup. To use the SMC with another motorized syringe pump, scroll and select the Custom mechanical setup.
3. The **Transfer Function (TF)** of the syringe pump that needs to be controlled should be known and input by the user. TF is the linear displacement in millimeters moved by the pump per every revolution rotated by the motor. See A.3.3 for details regarding the parameters conversion using TF.
   **Note:** The TF for QS Physpump is configured by default in the QS SMC.
4. The internal diameter (ID) of the syringe should be measured and input. The IDs for typical 3 cc, 5 cc, 10 cc, 12 cc, and 20 cc syringes are configured by default in the SMC.
5. Select the preferred units of volume, displacement, and time.
6. Set the desired initial flow rate of pumping (the flow rate may be changed during operation too).
7. The maximum volume limit and time limit are specified if the pumping

is required to be stopped after a particular time interval or pumped volume.

8. Before pumping starts, the starting position of the plunger can be adjusted using + and –.
9. Start pumping. During pumping, the LCD screen displays the current flow rate and amount of pumped volume.

## 5.6. Displacement (Linear and Angular)

The Displacement Mode of the QS SMC further has two types: **Angular Displacement Mode** and the **Linear Displacement Mode**. Both modes differ in terms of physical units and applications but have the same underlying procedure of operation. For further description of each mode, refer to Table 5.1. An application example of this mode, the controlled translation of a load, is described in Section 6.5.

The detailed general procedure of the mode is as described below.

1. Select the Displacement Mode.
2. Next, select the Angular or Linear Displacement Mode according to the type of motion of the final component of the assembly line that needs to be controlled by the SMC.
3. Select the units of time and (linear or angular) displacement measurements. The linear and angular displacement modes will have different units.
4. Set the **Gear Ratio** of the assembly that has to be controlled. A.3.2 describes how the gear ration in combination with other TFs is utilized by the SMC during operation.
   **Note**: The gear ratio is the angle rotated (in Angular Displacement Mode) or the linear distance moved (in Linear Displacement Mode) by the final component in the controlled assembly line per each revolution rotated by the motor.
5. Set the displacement that the component (to be controlled) must cover.
6. The speed at which the component must move is input.

7. Before the movement process starts, use **+** and **–** to adjust the initial position of the component.
8. Start the displacement process. The screen will display the travelled (linear or angular) displacement. When the component has travelled the set amount of displacement, the process will end, and 'Stopped' will be displayed on the screen.

# 6. Applications Examples

The SMC can either be used as a standalone system or in connection to other components such as the QS PhysPump, stirrer, conical pendulum, lift pulley systems, etc. If required in an application, limit switches can be connected to the SMC, by inserting their jack in the 3.5 mm pin connector on the SMC (Section 3.1) and gear assembly can be mounted on the shaft of the motor controlled by the SMC (4.3). In most of the applications, an intermediate coupling is required to connect the drive shaft of the motor to the driven shaft. The coupling would improve the performance of the motor-driven shaft by compensating for any mounting misalignment and absorbing equipment vibrations or impacts. The following subsections describe the setup requirements for some of the applications for a SMC.

## 6.1. Syringe Pump

One of the most significant applications of the SMC is its use with a motorized syringe pump to control the pumping of any fluid with utmost precision. The integration of a SMC with the QS PhysPump is shown in Figure 6.1.

The SMC is connected to the NEMA 17 motor that is housed inside the syringe pump using a JST and screw terminal block connector (as described in detail in Section 4.1). The syringe pump can be mounted vertically or placed horizontally in a table-top position, as illustrated in Figure 6.1. A connecting pipe or infusion tube can also be connected to the tip of the syringe. For this system, the application-specific Syringe Pump Mode (Section 5.5) of the

SMC is used. The syringe pump motor is connected to the pump's shaft via a coupling.

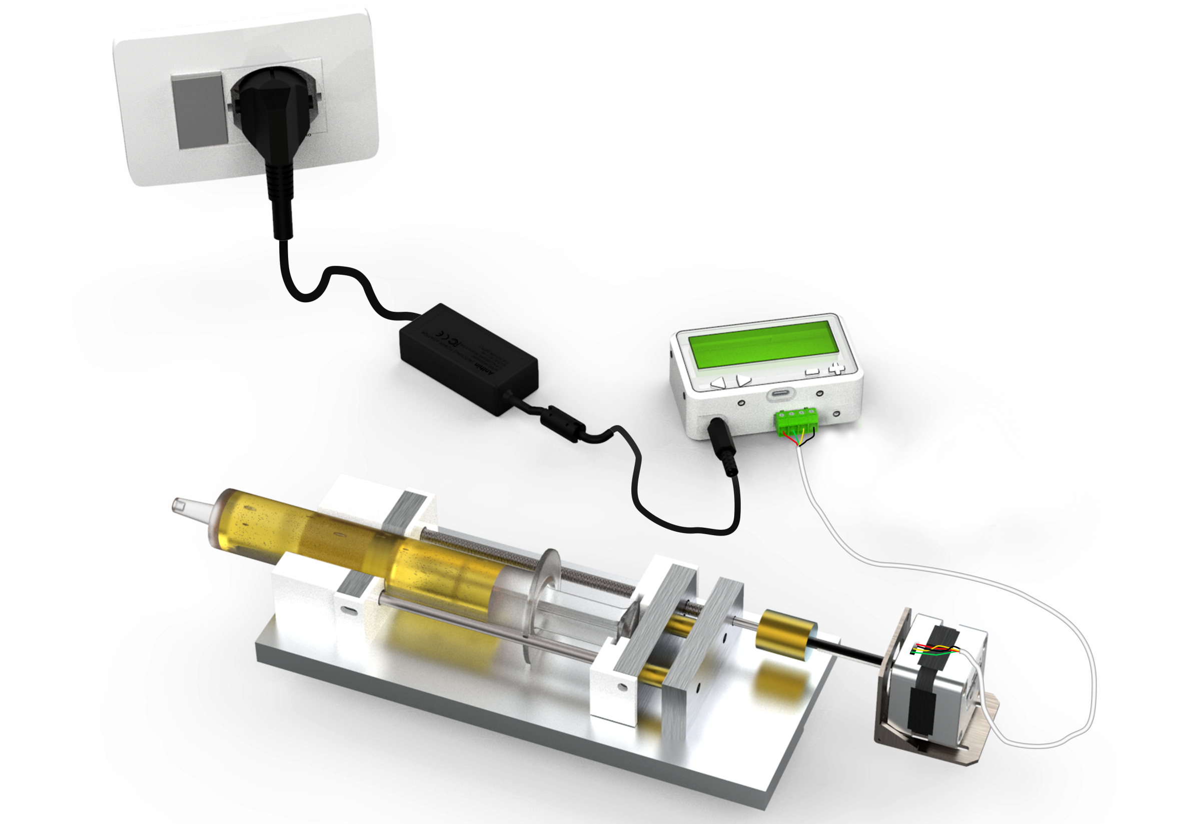


Figure 6.1: SMC being used to control the precise motion of the QS Physpump. SMC is connected to the NEMA 17 motor (mounted in the PhysPump) and connected to the driven shaft via a coupling. The SMC must be operated in the Syringe Pump Mode.

## 6.2. Conical Pendulum

The SMC, in an inbuilt application, can be used to control the rotational speed of a conical pendulum energized by a stepper motor. The setup is shown in Figure 6.2. In a conical pendulum, the bob attached to the end of a pivoted rod must be moved in circular motion at a constant angular speed. The setup is an important tool in the study of the dynamics of rotational motion and for experimentally measuring the value of gravitational acceleration [4].

The motor is mounted inside an enclosure by drilling 4 holes in the top plate of the casing and using 4 M3 screws. The casing can be made of plastic, acrylic, or metallic sheets. The metallic shaft, that rotates the disk and thus, the two masses that are attached to the aluminium rod, is connected to the motor via a shaft coupling. The SMC is placed inside the casing with an aperture being cut out at the front sheet of the setup allowing the user to access the SMC and control the motor's motion. The sheets can be cut using a jigsaw, laser cutter, or another similar technique.

Connecting an external limit switch (Section 4.3) as an emergency button to the SMC will allow the process to be immediately stopped. This demonstration can be performed using the D. RPM (Section 5.3) or A. RPM (Section 5.4) Mode of the SMC, depending on the required finesse in control.

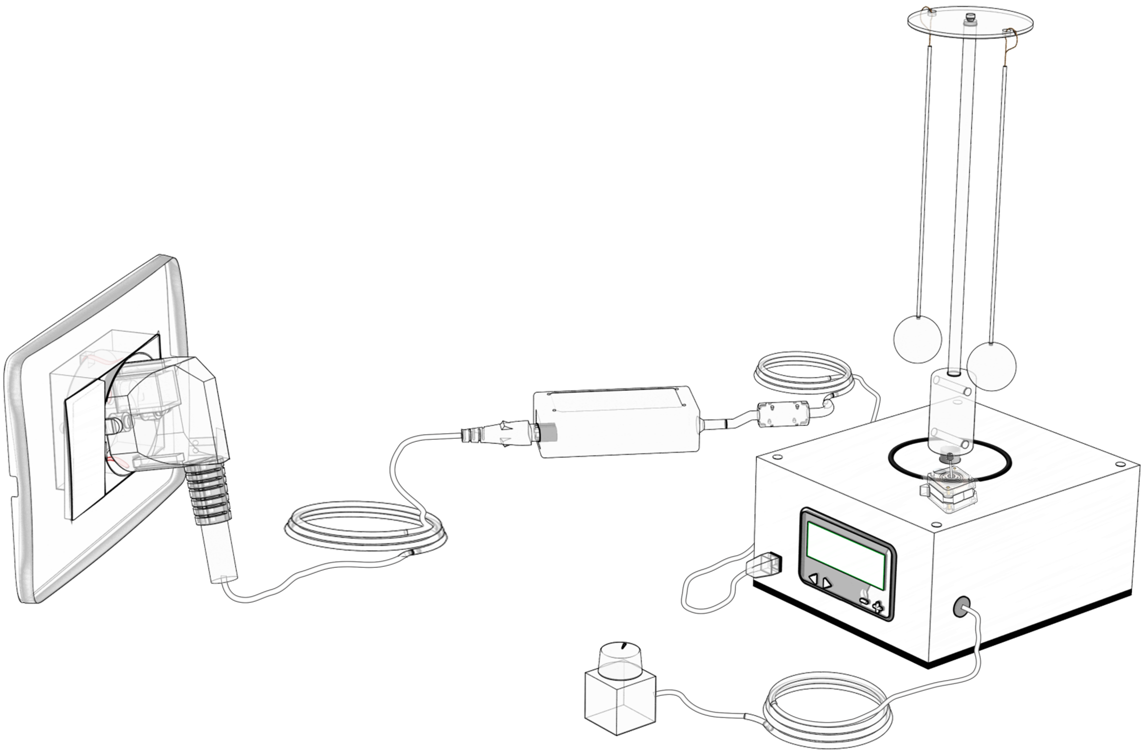


Figure 6.2: QS SMC and a limit switch being used to control a motor-driven conical pendulum.

## 6.3. Laboratory Stirrer

The SMC along with a stepper motor can be used to design a simple yet powerful motorized stirrer for laboratory use. The motor is vertically clamped on a lab stand with the motor drive shaft connected to a stainless steel propeller shaft (to prevent corrosion) via a coupler. The SMC is connected to the motor and placed in a table top position as shown in Figure 6.3. The propeller can either be rotated at a constant rotational speed or used as an agitator with the rotational speed and direction being changed during operation. For both scenarios, the suggested operational mode is the D.RPM Mode Section 5.3.

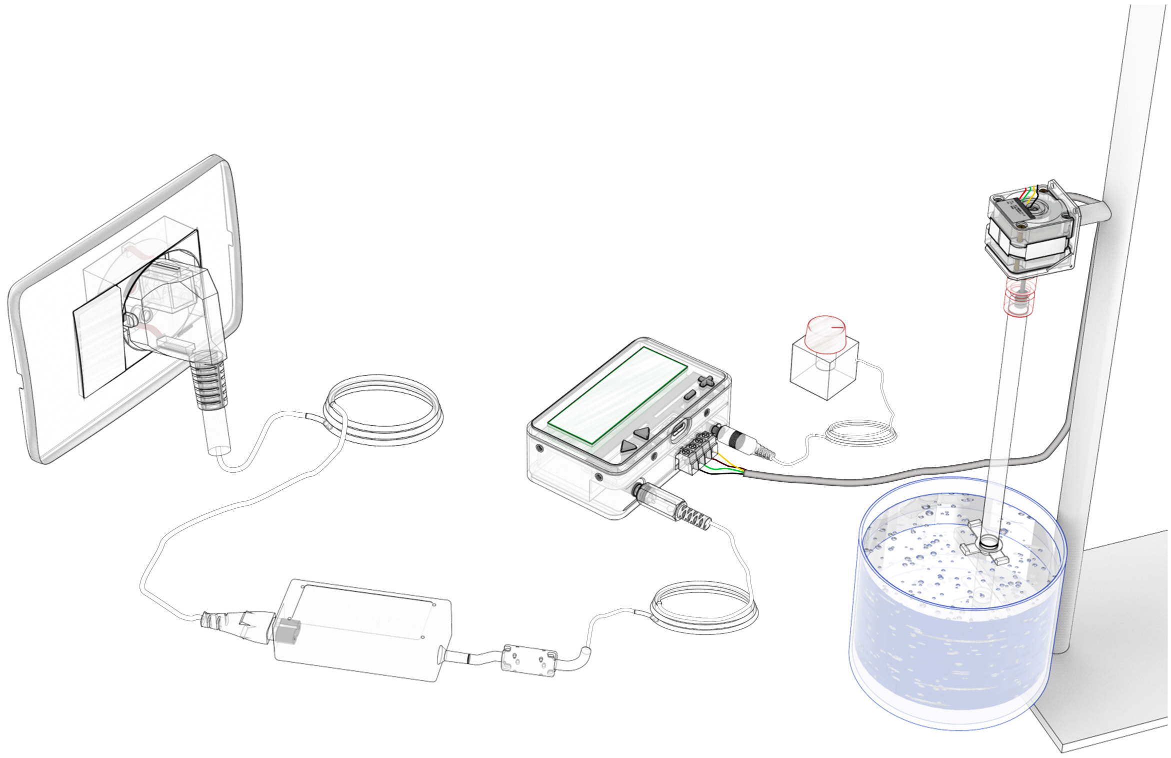


Figure 6.3: SMC, in a table-top application, can be used to control the rotational speed of a propeller shaft in a laboratory stirrer. The rotational speed can be controlled in the A. RPM or D. RPM mode.

## 6.4. A Controlled Dripping Faucet

A motor can be used to control the water drop rate in an imitation of the dripping faucet experiment by Robert Shaw. This setup is used to investigate non-linear dynamics by observing the periodic or aperiodic nature of the dripping water oscillation. The setup is shown in Figure 6.4.

In this setup, water from a reservoir flows to the tip of the burette via a connecting pipe. The water reservoir is placed at a certain height above the burette, and the burette is held vertically upright using a lab stand. A stopcock, attached to the tip of the burette, is rotated to control the drop rate from the burette. A horizontal photogate is positioned below the burette tip and connected to the QS Physlogger (a datalogging device) to record the drip rate. A stepper motor connected to the SMC can ensure precision in the rotation of the stopcock. As the motor is rotated by an equal number of steps per unit time, a constant increase in the rate of drip rate is achieved. The motor is mounted to the stopcock by drilling a hole that is 0.5 mm larger in diameter than the shaft of the motor. The SMC is connected to the motor as per the instructions given in Section 4.1. It is recommended to operate the motor in the D. RPM mode at a constant rpm.

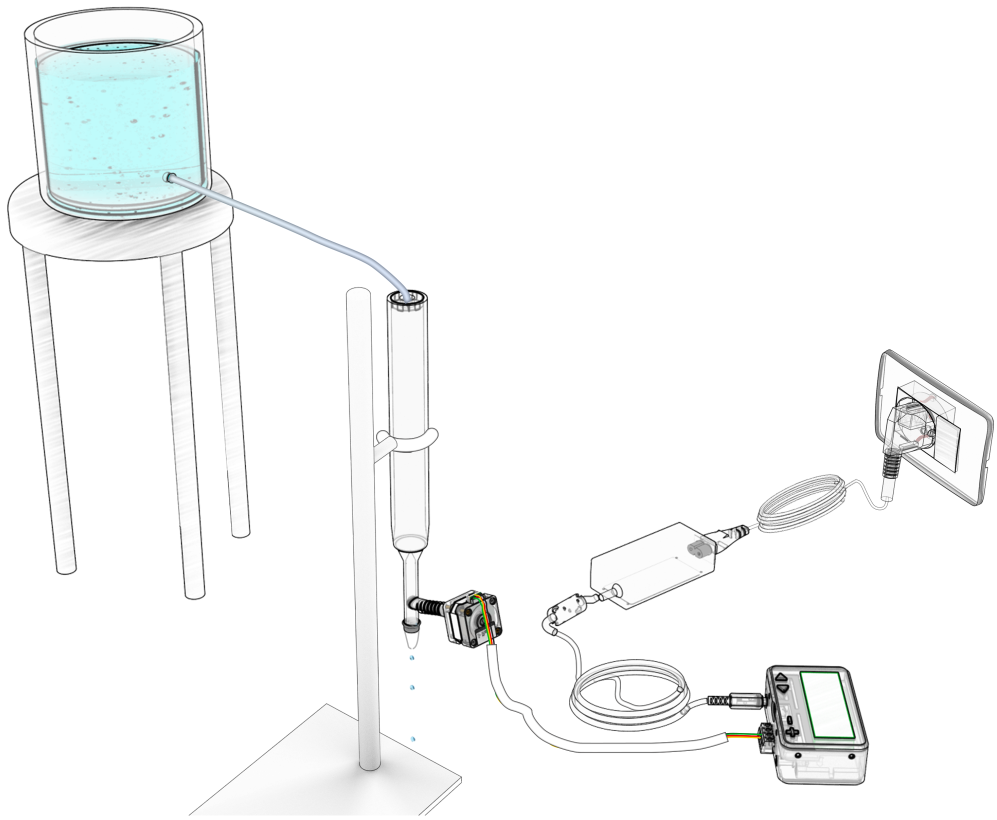


Figure 6.4: A stepper motor, controlled by the SMC, and connected to the stopcock at the tip of the burette is used to control the drip rate of water. This setup can be used to investigate how a changing flow rate affects the period of water drops. This setup imitates the famous dripping faucet experiment by Robert Shaw.

## 6.5. Controlled Translation of a Load

A motor can be used to automate a load's vertical lifting or translation on an inclined or horizontal surface. Figure 6.5 shows a load being translated on an inclined surface. The motor is mounted on the surface using a L-clamp and the other end of a rope wound around the motor shaft is attached to a hook on the load. This setup allows the investigation of how the speed of the load impacts the force components (such as the weight and friction) acting on the load. The rotational speed of the motor and thus the velocity of the mass can be controlled by operating the motor in the A. RPM Mode or the SMC can also be operated in the Linear Displacement Mode for this application Prior to operation in the Linear Displacement Mode, the user must measure the gear ratio by recording the linear displacement moved by the mass per every rotation of the motor.

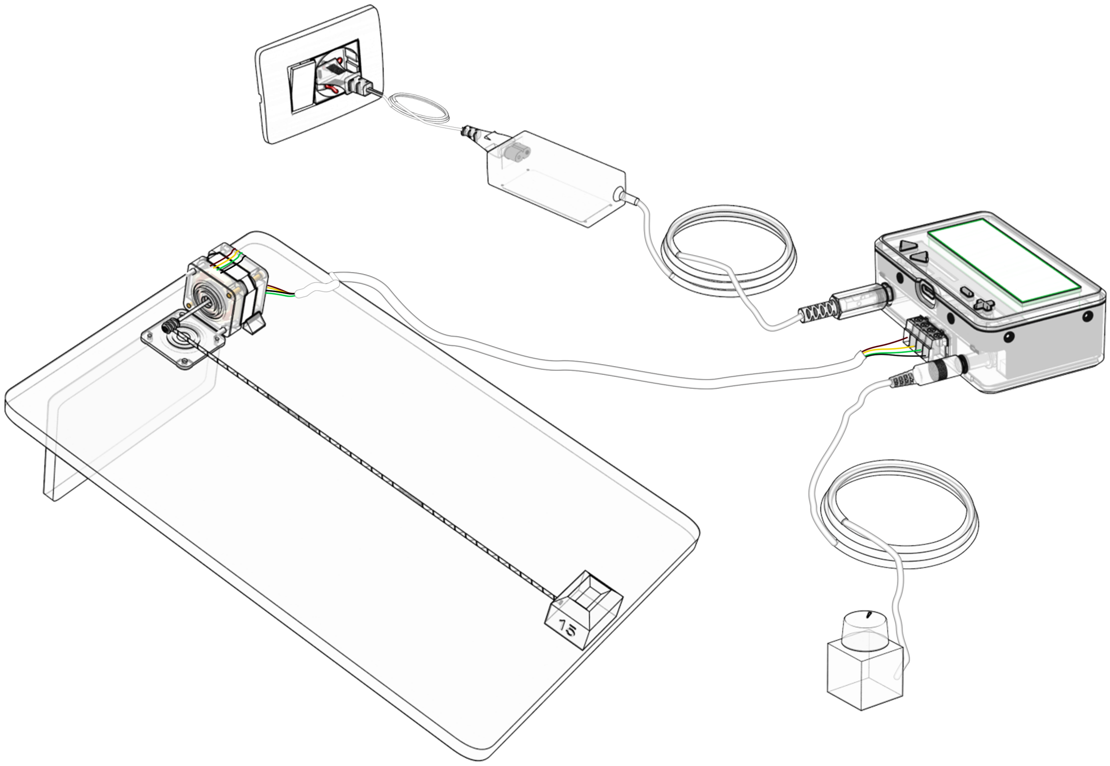


Figure 6.5: A mass is translated on a plain surface using a motor controlled by the SMC. If a coarse control of velocity is acceptable, the SMC can be operated in the A. RPM Mode. If an accurate control of translation is required, the SMC is operated in Linear Displacement Mode.

# 7. Errors and Troubleshooting

| Error/Symptom | Reason(s) | Solution |
|---|---|---|
| The motor turns in the opposite direction. | The stepper motor is connected incorrectly to the SMC. | Perform swapping between either the two wires of S1 solenoid or between the two wires of S2 solenoid. (Refer to Figure 3.2.) |
| | The speed, Gear Ratio or TF is entered incorrectly. | Reverse the sign of speed, TF/Gear Ratio. |
| The motor vibrates but does not rotate. | The set speed is too high. | 1. Lower the speed.<br>2. Ensure that the power supply rating conforms to the installed motor. |
| | Inappropriate power supply. | The power supply must conform to the rating on the motor and Section 3.1. |
| | The connections between the motor and SMC are wrong. | Ensure that the connections correspond to the order shown in Figure 3.2. |
| In the D. RPM or A. RPM, the speed is limited and the required speed is not achieved. | The speed is restricted due to the programmed mechanical limits. | 1. The speed range/limits must be increased.<br>2. Use a speed increasing gearbox. |
| The LCD screen shows no display. | Faulty hardware. | Disconnect the SMC from the main supply and restart the system. |
| The motor halts momentarily at the beginning and/or during motion. | The starting speed is set very high. | Reduce the starting speed. |
| | Inappropriate power supply. | The power supply must conform to the rating on the motor and Section 3.1. |
| | The motor's speed is changed very abruptly during rotation. | Avoid drastically changing the speed during operation. |
| | There is a blockage in the mechanical assembly. | Ensure that there is no restriction within the mechanical assembly that is exerting excessive load on the motor. |

Table 7.1: The possible errors in the QS SMC with their reasons and solutions.

# A. Appendix

## A.1. Motor Compatibility

### A.1.1. Compatibility with SMC

The QS SMC employs a current-limiting A4988 DMOS microstepping driver. For a motor to be compatible with the QS SMC, its features should correspond to the specifications defined in the data sheet [5] of the driver. For instance, the A4988 driver is designed for bipolar stepper motors and has a rated output drive capacity of 2 A; both NEMA 11 and NEMA 17 bipolar stepper motors have a current rating within this range, and are therefore recommended for the QS SMC.

A hybrid unipolar motor (e.g. NEMA 17 that has 6 wires) can also be used as a bipolar motor by ignoring the 2 CT wires when connecting the motor to the SMC (as elaborated in Section 4.1). However, a 5 wire unipolar motor cannot be used with the SMC.

### A.1.2. Compatibility with an Application

To ensure that a particular stepper motor is suitable for an application, the user must first calculate the required torque in the application. A motor that has a rated holding torque capacity of at least 1.5 times more than the required torque in the application should be selected. The torque curve of a stepper motor with the recommended operational speeds can be found in the data sheet of the motor model being used.

## A.2. Controlling Angular Speed with SMC

In an operational mode, such as D. RPM or A. RPM, the motor begins its rotation at an angular speed value that has been defined by the user (the physical units, also set by the user, can be deg/s, rad/s, rev/min or rev/s). For all operational modes, the angular speed of the motor follows a continuous function when being changed. For D. RPM, Syringe Pump, and Displacement Mode the angular speed of the motor can be changed using + or –, with each incremental or decremental step size increasing as the button is pressed and held down. (The increase in step size is, however, an iterative process and does not follow any set equation.) For the direction of rotation to be reversed during motion, the angular speed of the motor must first become zero.

Figure A.1 demonstrates how an arbitrary angular speed of a motor can be controlled by a user. In this scenario, the starting speed of the motor is set to 47.1 rad/s. Depending upon the user's requirements, the angular speed of the motor can be maintained at a constant value, as shown in Phase 1 of the figure or its value can be changed as shown in Phases 2, 3, and 4. In Phase 2, – is pressed multiple times (but not held down), resulting in a constant decremental step size or rate of change. In Phase 3, the decremental step size increases due to – being pressed and continually held down. Phase 4 also represents an increase in the incremental step size due to + being pressed and held down. The different rates of increase in step size in Phase 3 and Phase 4 represent the iterative nature of this step size acceleration process.

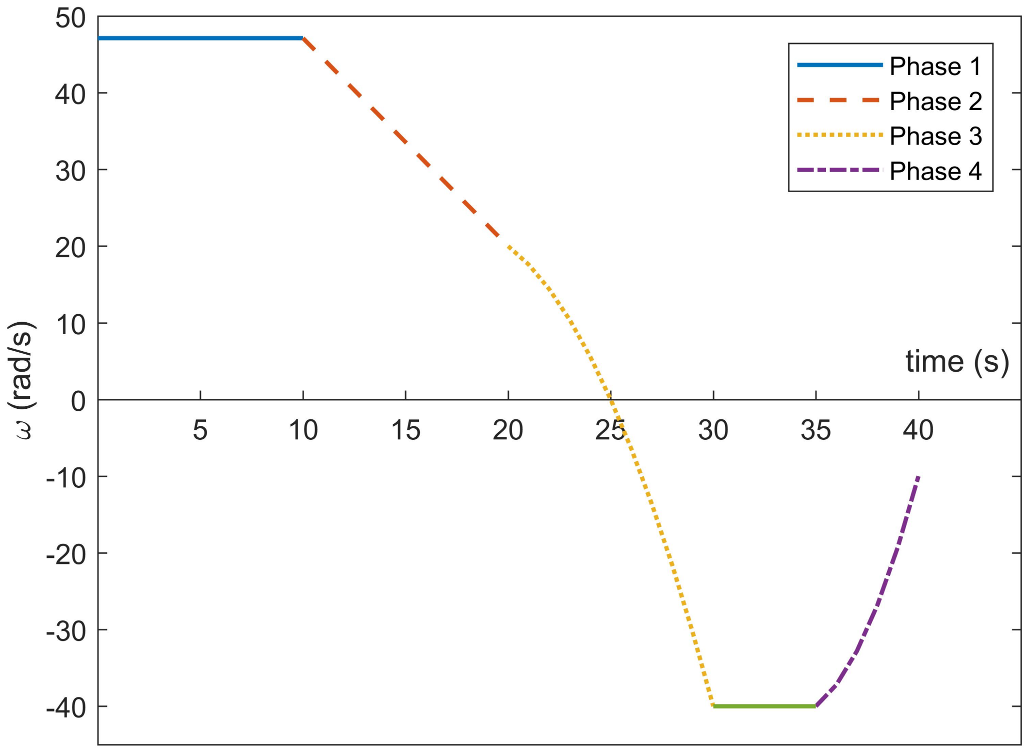



Figure A.1: This graph demonstrates how a user may control the angular speed of motor in the D. RPM Mode. In Phase 1, the motor is rotated at a constant speed; in Phase 2, the value of angular speed is changed at a constant rate by singularly pressing – ; in Phase 3, – is pressed and held down that causes an increase in the step size; and in Phase 4 + is pressed and held down causing an acceleration in the step size.

## A.3. Steps Transfer Functions

The QS SMC has been configured for stepper motors (motors that rotate the driven shafts by discrete steps). The number of steps required to complete one revolution depends on the specific motor's model, for example, NEMA 17 and NEMA 11 have a 200 spr and rotate 1.8° (360°/200 spr) per each full step. To improve the smoothness of the motor's operation, the QS SMC deploys the A4988 microstepping driver that reduces the size of each step by 16 parts and achieves a 3200 spr.

Within an operational mode, when certain rotational or translational parameters with the desired physical units are input, the QS SMC utilizes a series of Transfer Functions (TFs) to calculate the number of steps that the motor is required to rotate per second.

### A.3.1. D. RPM

In the D. RPM Mode, when an arbitrary rotational speed value $x$ in the user-defined units of angle $a$ and time $t$ is input, the SMC uses the sequence of operations shown in Eq. A.1 to determine the steps that the motor is required to move,

$$x \times \frac{TF_a^{rad}}{TF_t^s} \times TF_{rad}^{steps} = \frac{\text{Motor steps}}{\text{sec}}, \tag{A.1}$$

where,

$$TF_{rad}^{steps} = \frac{3200 \text{ steps}}{2\pi \text{ rad}}. \tag{A.2}$$

### A.3.2. Displacement

In the displacement mode, if a component needs to be moved at a velocity of $v$ (in user-defined units of displacement $d$ and time $t$) for a displacement of $y$ (in user-defined units of displacement $d$), the system-dependent **gear ratio** (Section 4.3), input by the user, is also used to determine the required steps per second of the motor. The reciprocal of gear ratio performs the same function as $TF_{rev}^{mm}$.

Eq. A.3 shows the conversion of $v$ to motor steps per second, in the displacement mode,

$$v \times \frac{1}{TF_t^s} \times \frac{1}{\text{Gear Ratio}} \times TF_{rev}^{rad} \times TF_{rad}^{steps} = \frac{\text{Motor steps}}{\text{sec}} \tag{A.3}$$

.

If a displacement limit has been defined by the user, Eq. A.4 is used by the SMC to determine the total number of steps that the motor should cover before being stopped,

$$y \times \frac{1}{\text{Gear Ratio}} \times TF_{rev}^{rad} \times TF_{rad}^{steps} = \text{Motor steps} \tag{A.4}$$

### A.3.3. Syringe Pump

To determine the required steps of the motor for a syringe pump with an internal diameter $ID$ and an input volume flow rate $\delta$ (in user-defined volume unit $q$ and time unit $t$), the SMC first calculates the Volume $V$ that has to be pumped, in $mm^3$ and the linear displacement $z$, that the plunger needs to be translated through in $mm$. The user-input $TF_{syringe}$, i.e., the distance moved by the plunger in $mm$ per revolution of the motor is also utilized by the SMC in this conversion. Eq. A.5 represents the conversion of $\delta$ to motor steps per second,

$$\delta \times \frac{TF_q^{mm^3}}{TF_t^s} \times TF_{mm^3}^{mm} \times \frac{1}{TF_{syringe}} \times TF_{rev}^{rad} \times TF_{rad}^{steps} = \frac{\text{Motor steps}}{\text{sec}}, \tag{A.5}$$

where,

$$TF_{mm^3}^{mm} = \frac{4 \times V}{\pi \times ID^2}. \tag{A.6}$$

Eq. A.6 has been derived from the syringe pump's volume formulation,

$$V = \frac{\pi}{4} \times ID^2 \times z. \tag{A.7}$$

If required, volume $V$ (in user-defined volume unit $q$) and time $T$ (in user-defined volume unit $t$) limits can also be input, to restrict the pumping operation. The following equations, Eq. A.8 and Eq. A.9, represent how these limits are interpreted by the SMC,

$$V \times TF_q^{mm^3} \times TF_{mm^3}^{mm} \times \frac{1}{TF_{syringe}} \times TF_{rev}^{rad} \times TF_{rad}^{steps} = \text{Motor steps}, \tag{A.8}$$

$$t \times \frac{1}{TF_t^s} = \text{sec}. \tag{A.9}$$

## References


[1] Minebea Mitsubi Inc. *17PM-K Product Catalog.* URL: https://www.eminebea.com/en/product/rotary/steppingmotor/hybrid/standard/__icsFiles/afieldfile/2017/09/29/17pm-k_1.pdf. (Accessed: 08.01.2021).

[2] GEMS Motors. *28mm (NEMA 11) GM28BYG Stepper Motors.* URL: http://gemsmotor.com/stepper/nema11-stepper-motor.pdf. (Accessed: 11.01.2021).

[3] *How to identify the wires of a stepper motor?* URL: https://www.youtube.com/watch?v=vbTmGOHuZYU. (Accessed: 08.01.2021).

[4] *Conical Swing of a Pendulum and Centripetal Forces.* URL: https://physlab.org/experiment/conical-swing-of-a-pendulum-and-centripetal-forces/. (Accessed: 22.01.2021).

[5] *A4988.* URL: https://www.pololu.com/file/0J450/a4988_DMOS_microstepping_driver_with_translator.pdf. (Accessed: 04.02.2021).