Getting started with the evaluation kit for education on motor control and control systems

Introduction

The STEVAL-EDUKIT01 is designed to represent a complex, non-linear and unstable oscillator for university-level robotics projects. It consists of a transparent structure holding a free-swinging pendulum, whose movement has to be stabilized by a stepper motor with feedback from a high performance rotary encoder reading the pendulum angle.

The STSW-EDUKIT01 firmware includes critical, high-speed algorithms that interpret encoder data and allow the stepper motor to counter the movement of the pendulum so that it remains vertical.

The educational set, with real-time Matlab viewer and interface, helps you build your understanding of ARM-based embedded architecture (STM32CubeIDE), stepper motor control and real-time systems based on proportional, integral, derivative (PID) control, as well as more advanced techniques such as State Space or State Space with linear quadratic regulator (LQR).

A further set of open source tutorials and training material is at your complete disposal at www.st.com/motorcontrol-edu.

Figure 1. STEVAL-EDUKIT01 evaluation kit

1 Overview

The STEVAL-EDUKIT01 evaluation kit features:

- Rotary inverted pendulum kit for education
- Included stepper motor and quadrature rotary encoder
- Low cost and easy to assemble interlocking acrylic frame
- Included power supply (100-240 V): 12 V, 1 A
- Based on the NUCLEO-F401RE development board
- X-NUCLEO-IHM01A1 expansion board with L6474PD microstepping motor driver
- Open source educational material available

1.1 Kit content

The STEVAL-EDUKIT01 contains all components, control boards and mechanical parts to build a high performance rotary inverted pendulum.

Figure 2. STEVAL-EDUKIT01 evaluation kit content (1 of 2)

1. Motor shaft flange and M3x8 mm machine screws
2. Nema17 stepper motor and encoder L-bracket
3. Motor cables
4. 12 V power supply
5. Rotary encoder with M3x8 mm precision screw and washer
6. M3x20 mm machine screw and 10 mm stand-offs
7. X-NUCLEO-IHM01A1 motor driver expansion board
8. NUCLEO-F401RE development board
9. Zip ties
10. M3x16 mm machine screws
11. Adhesive rubber cushions and paper clip
12. M3 machine nuts

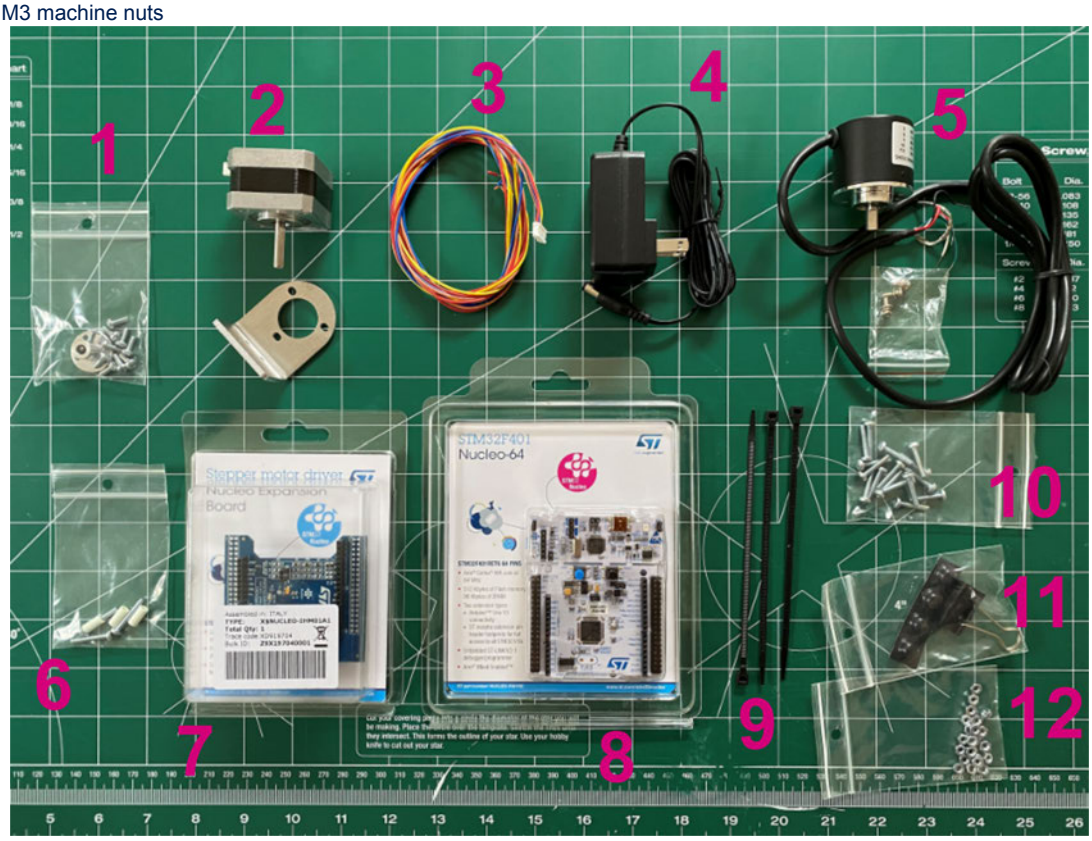
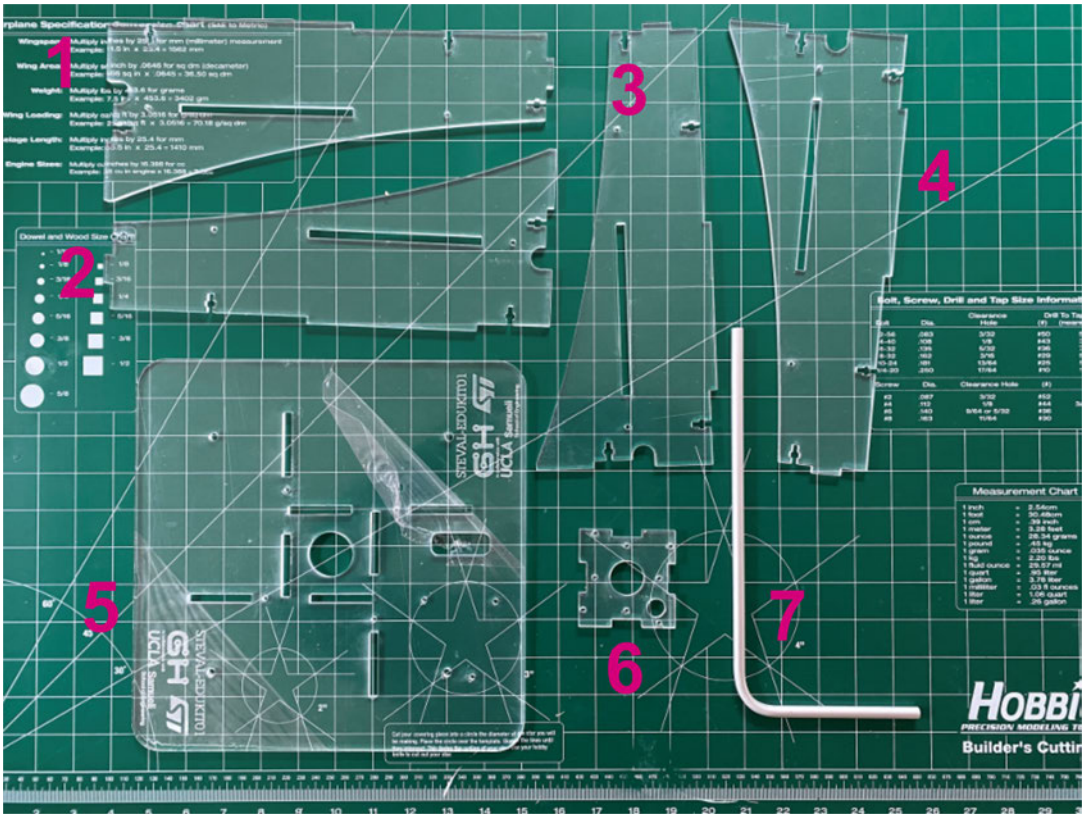


Figure 3. STEVAL-EDUKIT01 evaluation kit content (2 of 2)

1-4. Acrylic pendulum tower sidewalls
5. Acrylic pendulum base
6. Acrylic motor mount
7. Aluminum pendulum rod



2 How to assemble the kit

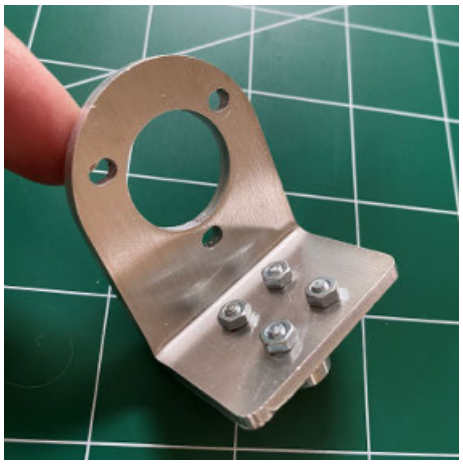
To assemble the STEVAL-EDUKIT01 evaluation kit, you need:

- a medium sized Phillip screwdriver
- a pair of electrician scissors
- a wire cutter
- a basic soldering iron with solder
- a small flathead screwdriver
- thread lock compound (optional)

Follow the procedure below to assemble the kit.

Step 1. Attach the motor shaft flange to the encoder L-bracket with four M3x8 mm screws and secure them with four M3 nuts.

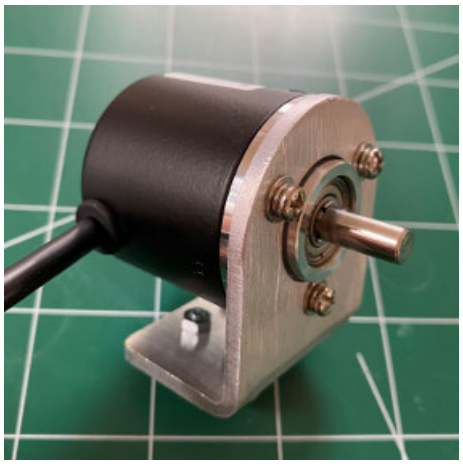
Figure 4. STEVAL-EDUKIT01 assembly sequence (1 of 11)



Step 2. Install the rotary encoder on the flange with the encoder body over the previously installed M3 nuts. Use the provided M3x8 mm precision screws with washer and spring tensioner.

Note: The encoder needs to be aligned to its flange so that the cable is oriented on the side (as shown below) to ensure the optimum range of motion when the system is operating.

Figure 5. STEVAL-EDUKIT01 assembly sequence (2 of 11)



Step 3. Peel off the acrylic motor mount protective film (see Figure 6) and install the stepper motor using four M3x8 mm machine screws (see Figure 7).

Important: *Do not overtighten the screw.*

Tip: *You can use some thread lock to prevent the screw from loosening due to vibration.*

Figure 6. STEVAL-EDUKIT01 assembly sequence (3 of 11)

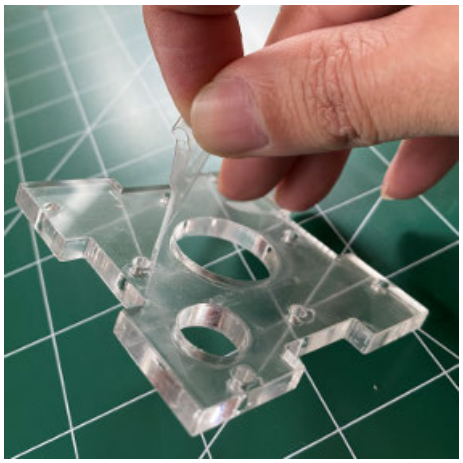
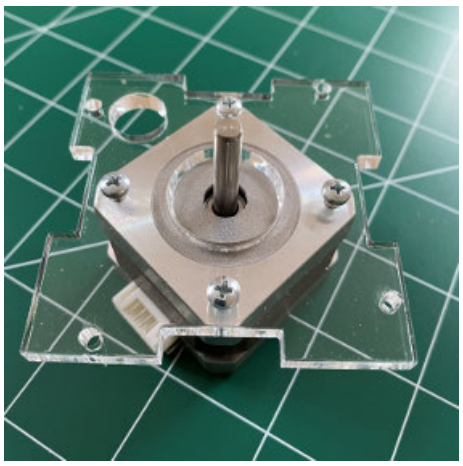


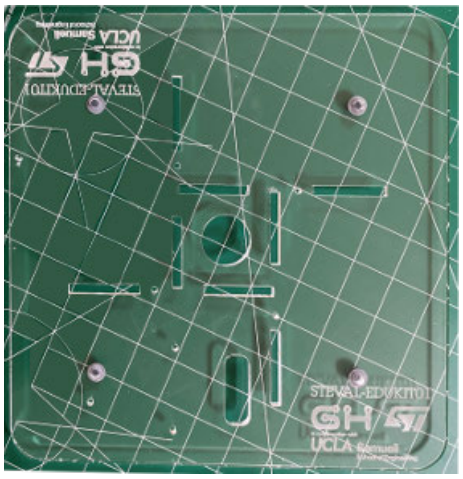
Figure 7. STEVAL-EDUKIT01 assembly sequence (4 of 11)



Step 4. Peel off the protective film on both sides of the system acrylic base.

Step 5. Attach the four rubber pads over the 5 mm holes to ensure a firm grip on any surface.

Figure 8. STEVAL-EDUKIT01 assembly sequence (5 of 11)

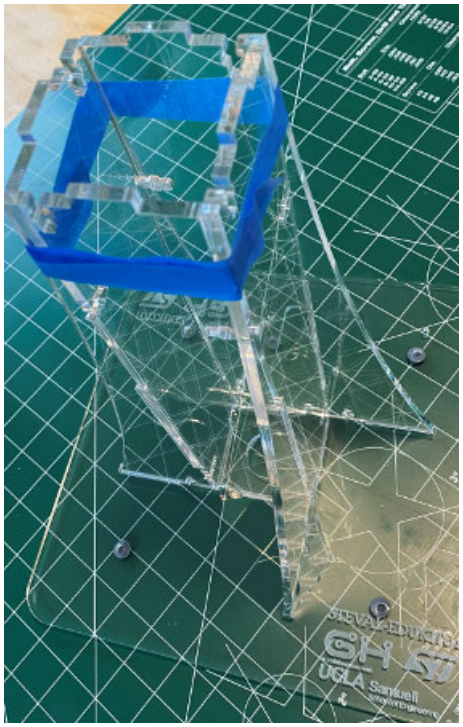


Step 6. Build the system tower:

- **Step 6a.** remove the protective film on both sides of the four structural acrylic sidewalls
- **Step 6b.** interlock the sidewalls to each other and place them on the base
- **Step 6c.** fix them with screws and nuts

Note: As shown in the figure below, you can use adhesive tape to keep the pieces together during assembly.

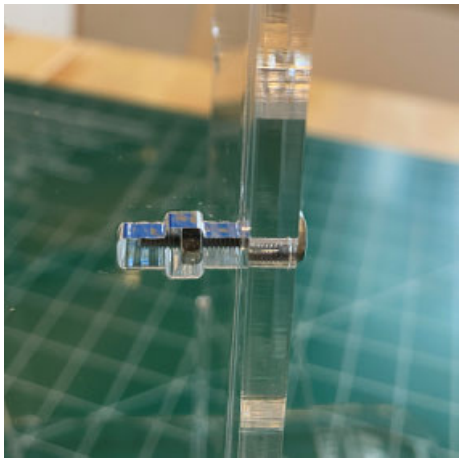
Figure 9. STEVAL-EDUKIT01 assembly sequence (6 of 11)



Step 7. Install eight screws while holding the retaining nut in the corresponding pocket hole.

Important: Do not overtighten the screws to avoid cracking the acrylic.

Figure 10. STEVAL-EDUKIT01 assembly sequence (7 of 11)

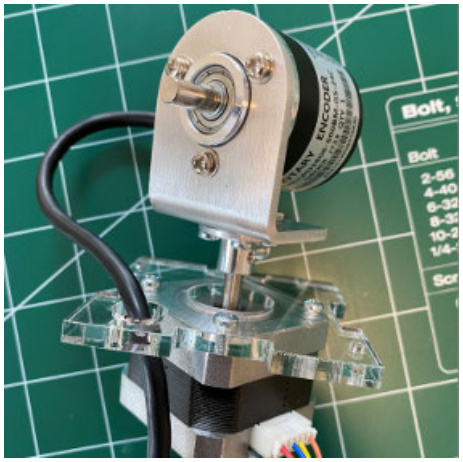


Step 8. Assemble the motor and the encoder system:

- **Step 8a.** install the motor cable
- **Step 8b.** place the motor mount on top of the tower and secure it with four M3x16 mm screws and four nuts
- **Step 8c.** insert the motor shaft in the motor flange and secure it with a M3x8 mm screw

Note: The encoder cable should be inserted inside the hole in the acrylic motor mount as shown below.

Figure 11. STEVAL-EDUKIT01 assembly sequence (8 of 11)



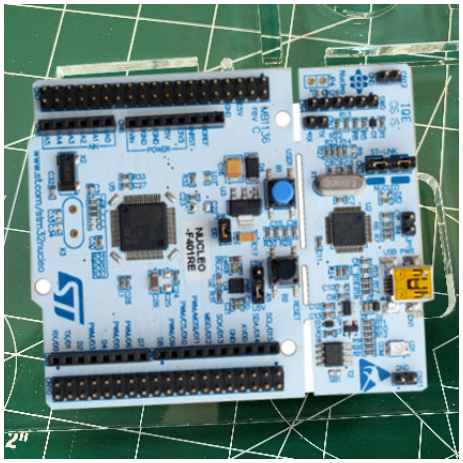
Note: The motor cable and the encoder cable can be tied together using the provided zip ties.

Step 9. Attach the tower assembly to the system base using four M3x16 mm screws and nuts. The motor and encoder cables should exit from the evaluation board sides (see Figure 14).

Step 10. Fix the NUCLEO-F401RE development board to the base using the M3x20 mm screws and plastic standoffs.

Note: The screws should be secured with four M3 nuts under the system base.

Figure 12. STEVAL-EDUKIT01 assembly sequence (9 of 11)



Important:
One of the screws might interfere with the Arduino connector on some boards, so you may need to file the side of the connector or the head of the screw.

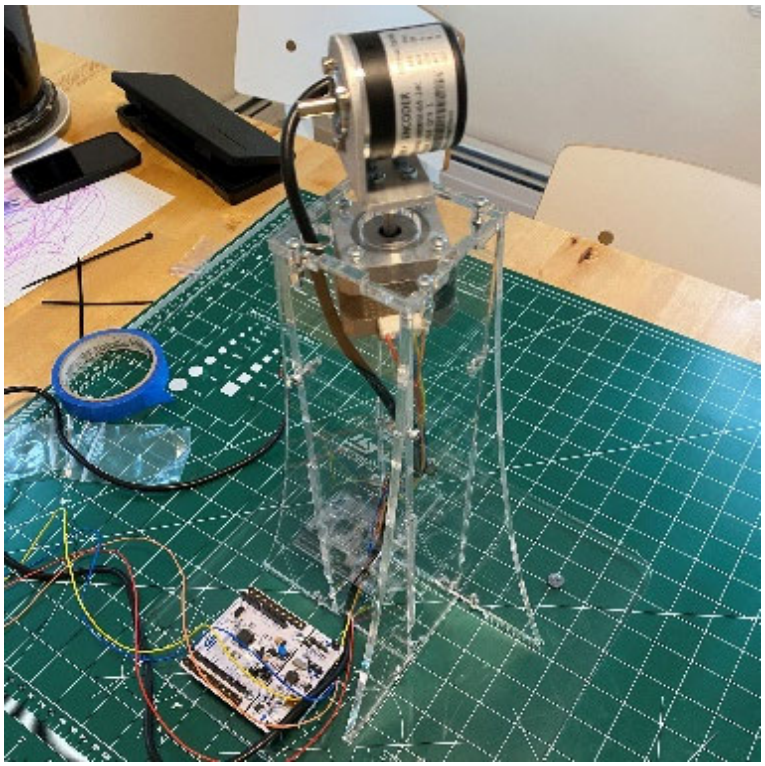
Figure 13. STEVAL-EDUKIT01 assembly sequence (10 of 11)

Step 11. Install the pendulum rod on the encoder shaft and secure it with a M3x8 mm screw.

Important: Do not overtighten as the thread on the aluminum rod could break.

Step 12. Place the paper clip as a pendulum counterweight.

Figure 14. STEVAL-EDUKIT01 assembly sequence (11 of 11)



3 Electrical connections

To mount the X-NUCLEO-IHM01A1 expansion board on top of the NUCLEO-F401RE development board, you need to align the Arduino connectors pins and sockets on the two boards.

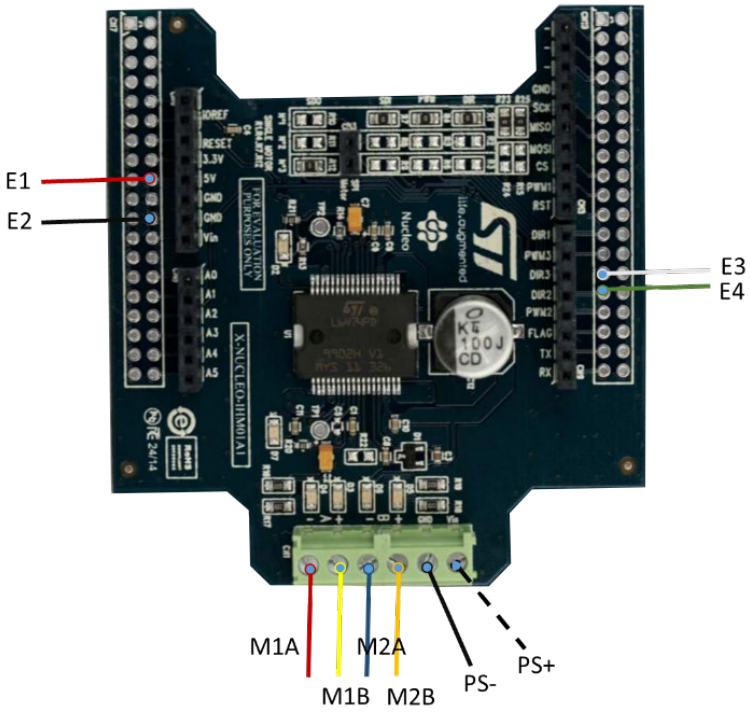
Important:
The X-NUCLEO-IHM01A1 green Molex connector has to face the opposite side of the ST-LINK and USB connector of the NUCLEO-F401RE.

Connect the following cables to the X-NUCLEO-IHM01A1:

- the rotary encoder cables:
  1. positive (power) wire – E1 (red)
  2. negative (ground) wire – E2 (black)
  3. phase 1 – E3 (white)
  4. phase 2 – E4 (green)
- the stepper motor cables:
  1. phase A1 – M1A (red)
  2. phase A2 – M1B (blue)
  3. phase B1 – M2A (yellow)
  4. phase B2 – M2B (orange)
- the power supply cables:
  1. positive (12 V) – PS+ (black with white stripe)
  2. ground – PS- (black)

Caution: Check that all the wires are connected as indicated to avoid damaging the X-NUCLEO-IHM01A1 board.

Figure 15. X-NUCLEO-IHM01A1 cable connections



4 Firmware installation

The STSW-EDUKIT01 firmware for the STEVAL-EDUKIT01 is provided in binary format and includes the bootloader. To install it, follow the procedure below.

Step 1. Connect the NUCLEO-F401RE development board to a PC USB port though a mini USB to USB cable.

Step 2. As the board is recognized as a flash drive on the PC, drag and drop the `pendulum01.bin` file to the STM32 flash drive.

Step 3. If the NUCLEO-F401RE is not recognized, install the STM32 Virtual COM port driver (STSW-STM32102) on your PC.

The software package contains four installation files based on the various versions of the Microsoft operating system.

Once installed, the STM32 Nucleo development board is recognized as a flash drive and the firmware installation will not require any other utilities.

5 Rotary inverted pendulum operation

5.1 How to start pendulum operation

Step 1. Check the pendulum is assembled as per instructions.

The encoder cable should be routed to allow 360 degree rotation along its axis, the pendulum shaft should be firmly installed without being overtightened and the pendulum upper shaft counterweight must be installed.

Step 2. Remove system power before attempting to manually rotate the rotor, as system power prevents motor rotation.

Step 3. Let the pendulum rod point downwards as the system is calibrating the encoder vertical orientation offset.

Step 4. Twist the rotor until it points to the desired starting position.

Step 5. Attach the 12 V motor controller supply to a power outlet and then connect the NUCLEO-F401RE development board USB cable to a laptop/PC USB port or a battery charger.

Remember:
Reset the NUCLEO-F401RE board by pushing the black button before operation. Otherwise, power the 12 V power supply before powering the USB source to ensure the proper settings for the stepper motor are loaded into the X-NUCLEO-IHM01A1 board.

If the pendulum is motionless and oriented downwards, system operation begins and is signalled by a small oscillation.

Step 6. Manually rotate the pendulum counterclockwise so that it is oriented vertically.

Rotation must be completed within 3 seconds.

Step 7. Ensure the pendulum is oriented as close to vertical as possible as the system detects an error and does not start if the angle exceeds a certain threshold.

Step 8. Release the pendulum to let the motor control start.

5.2 How to stop pendulum operation

Step 1.

– Switch the power off for both motor controller power supply and USB cable charger.
– Alternatively, push the black reset button on the NUCLEO-F401RE development board to reset the system.

Power remains and the rotor is locked in its position by the motor controller and stepper motor.

Important: Do not attempt to rotate the rotor with power applied.

The rotary inverted pendulum control system prepares to resume operation.

5.3 Stopping operation by displacing the pendulum

Operation can be stopped during operation by applying a small force to deviate the pendulum angle from the vertical. The control system detects the movement and terminates control.

Operation can be resumed by pushing the black button on the NUCLEO-F401RE development board to restart the system.

5.4 Causes preventing operation to start

If pendulum motion is detected before applying power or a system reset, the control system waits until the pendulum is still and pointing vertically downwards.

If, after power application or system reset, the pendulum is not manually rotated to the upright vertical position within a certain period of time, system operation stops and a subsequent reset is required.

5.5 Output data

The rotary inverted pendulum also provides output data via USB cable with a baud rate of 115200.

Output data values include:

1. time (seconds)
2. cycle delay (milliseconds)
3. pendulum angle (degrees)
4. rotor angle (degrees)
5. current combined pendulum, rotor and auto slope correction PID
6. rotor control output (degrees)
7. rotor position reference command (degrees)

6 Bill of materials

Table 1. **STEVAL-EDUKIT01 bill of materials**

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
1	1	NUCLEO-F401RE		STM32 Nucleo-64 development board with STM32F401RE MCU	ST	NUCLEO-F401RE
2	1	X-NUCLEO-IHM01A1		Stepper motor driver expansion board based on L6474 for STM32 Nucleo	ST	X-NUCLEO-IHM01A1
3	1			Acrylic base	GH	Custom
4	1			Acrylic motor support	GH	Custom
5	4			Acrylic vertical strut	GH	Custom
6	19			M3 - 16 mm pan head screws	Any	Any
7	19			M3 hex nut	Any	Any
8	3			Standoff	Any	Any
9	4			M3 - 10 mm pan head motor support screw	Any	Any
10	1			Rotary encoder	GH	Custom
11	1		12 V, 1 A, 12 W	Power supply	Any	Any
12	4			Rubber grommets	Any	Any
13	1			Aluminum motor flange	GH	Custom
14	1		12 V, 0.8 A, 10 W	Stepper motor	GH	Custom
15	1			Flange for L-bracket support	GH	Custom
16	1			Aluminum L-Bracket	GH	Custom
17	1			Rotary Encoder	GH	Custom
18	1			Stepper motor cable	Any	Any
19	1			Pendulum L-shaped tube	GH	Custom
20	3			M3-8 mm pan head screw for rotary encoder	Any	Any
21	4			M2.5-6 mm pan head screw for L-Bracket	Any	Any
22	2			M3-6 mm set screw	Any	Any
23	1			Pendulum counterweight	GH	Custom

Revision history

Table 2. **Document revision history**

Date	Version	Changes
08-May-2020	1	Initial release.

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