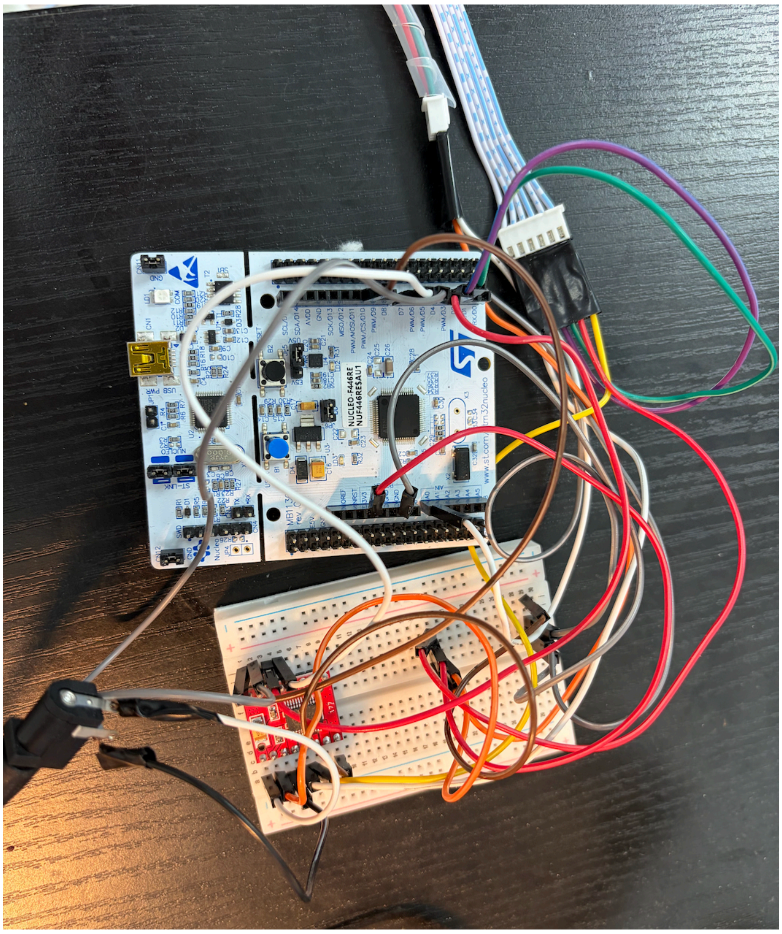
Rotary Inverted Pendulum Hardware Wiring Guide

Class 8 Laboratory Technical Manual

AI Enabled Control Engineering



DANGER

The STM32 logic voltage is 3.3 V, not 5 V.

Wear anti-static gloves whenever you touch the STM32 board.
Do not connect the 12 V motor supply until a teaching assistant has inspected and approved the complete circuit.

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Contents

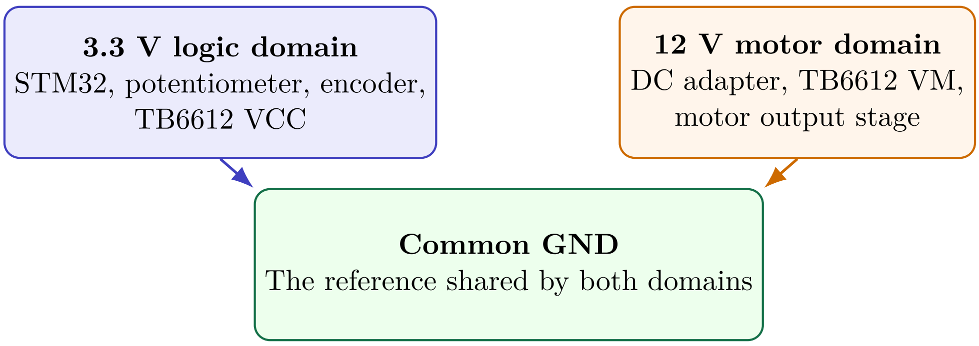
This manual gives a step-by-step procedure for assembling the electrical system of the rotary inverted pendulum.

1 Non-Negotiable Safety Rules

DANGER

1. **Wear anti-static gloves before touching the STM32 board.**
2. **Use 3.3 V for STM32 logic, the potentiometer, the encoder, and TB6612 VCC. Never use 5 V.**
3. **Never connect 12 V to any STM32 pin, to A0, to D2–D10, or to TB6612 VCC.**
4. Keep the 12 V adapter disconnected while building or modifying the circuit.
5. Do not allow bare wire strands to touch adjacent terminals.
6. Do not move wires while the motor supply is on.
7. Keep hands, cables, tools, and other objects outside the arm's rotation area.
8. The 12 V adapter may be connected only after a TA has signed the inspection checklist.

1.1 Two voltage domains and one common ground



IMPORTANT

VCC and VM are not interchangeable. TB6612 `VCC` is the 3.3 V logic supply. TB6612 `VM` is the 12 V motor supply. Swapping them can permanently damage the controller, driver, or sensors.

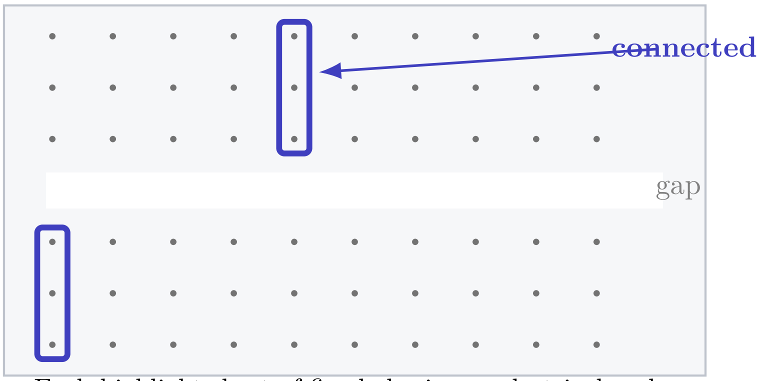
2 Parts and Tools

Item	Function	Important note
STM32 Nucleo-F446RE	Real-time controller, ADC, encoder counting, PWM, USB communication	Logic is strictly 3.3 V; wear anti-static gloves
TB6612FNG module	H-bridge motor driver	VCC = 3.3 V; VM = 12 V
Rotary motor with encoder	Drives the arm and measures arm rotation	Six-pin connector uses the pin order listed in Section 7
Pendulum potentiometer	Measures pendulum angle	The green signal wire must connect to A0
Breadboard	Creates organized electrical junctions	Hole connectivity must be understood before wiring
12 V DC adapter and jack	Motor power supply	Do not energize before TA approval
Dupont wires	Electrical interconnections	Two wires must be stripped for the DC jack
USB data cable	Powers/programs STM32 and provides serial communication	A charge-only cable will not work
Small wire stripper, tape, multimeter	Preparation and checking	Use continuity mode only with all power disconnected

3 Breadboard Fundamentals

3.1 Which holes are connected?

With the breadboard oriented as shown below, each group of holes in a vertical column is internally connected. Adjacent columns are separate. The central gap separates the two terminal blocks.



Each highlighted set of five holes is one electrical node.
A wire inserted into any one of those five holes is connected to the other four.

4 Plan the Wiring Before Inserting Wires

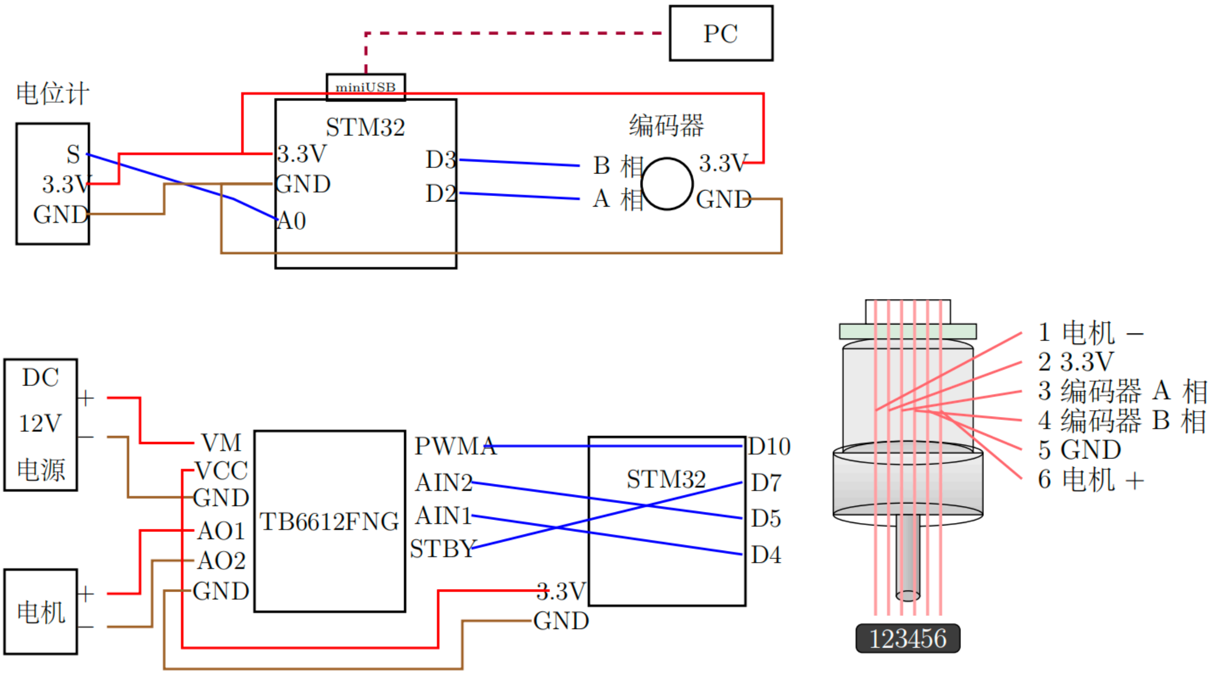


Figure 1: Complete circuit diagram.

5 Create the 3.3 V and GND Aggregation Points

Choose two clearly separated five-hole columns on the breadboard:

- one column is the **3.3 V aggregation point**;
- one column is the **GND aggregation point**.

Mark them mentally or with small labels. Never place them in neighboring columns if that makes accidental contact likely.

5.1 Exactly four leads at the 3.3 V point

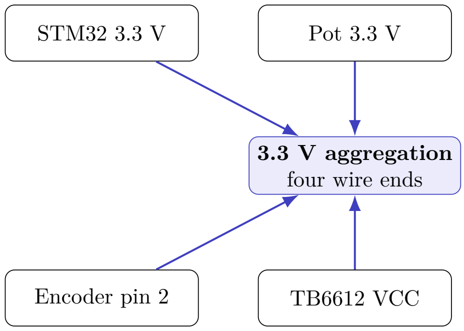
The four wire ends inserted into the 3.3 V aggregation point are:

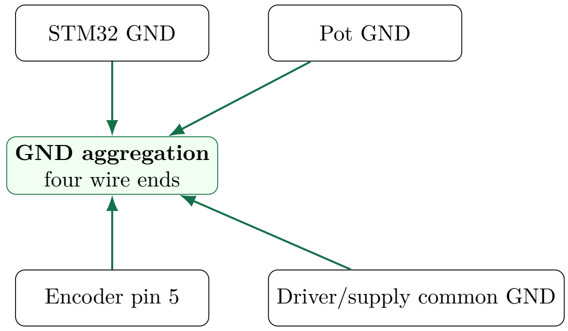
1. STM32 `3.3V`;
2. potentiometer `3.3V`;
3. motor encoder connector pin 2 (`3.3V`);
4. TB6612 `VCC`.

5.2 Exactly four leads at the GND point

The four wire ends inserted into the GND aggregation point are:

1. STM32 `GND`;
2. potentiometer `GND`;
3. motor encoder connector pin 5 (`GND`);
4. the single common-ground lead from the TB6612/12 V negative junction.





DANGER

Before continuing, visually confirm that the 3.3 V and GND aggregation columns are different and are not connected by any jumper. A short between these two nodes can shut down or damage the STM32.

6 Wire the Potentiometer

The potentiometer has three electrical connections: supply, signal, and ground.

Pot connection	STM32/bus destination	Purpose	Check
`3.3V`	3.3 V aggregation point	Supplies the potentiometer	Must not be connected to 5 V
Green signal wire	STM32 `A0`	Pendulum-angle analog signal	Green wire must go to A0
`GND`	GND aggregation point	Signal reference	Must share STM32 ground

DANGER

The green wire on the three-pin potentiometer connector is the A0 signal wire.

Do not connect the green wire to 3.3 V or GND.

6.1 Why the signal must remain between 0 and 3.3 V

STM32 `A0` is an analog input. The potentiometer acts as a voltage divider, so the signal should move within the 0–3.3 V range as the pendulum rotates. The firmware converts the ADC reading into the pendulum angle. A 12-bit reading is normally within

$$0 \leq \texttt{pot\_raw} \leq 4095.$$

A value permanently near 0 or 4095 may indicate incorrect wiring, a loose connector, or a missing ground.

7 Wire the Motor and Encoder Connector

The motor assembly uses a six-pin connector. Always determine the connector orientation from the pin numbers and the supplied drawing; do not rely only on wire color.

1	**2**	**3**	**4**	**5**	**6**	connector pin numbering

Pin	Function	Connect to	Reason
1	Motor −	TB6612 `AO2`	Motor power lead; keep this orientation for the fixed motor sign
2	Encoder 3.3 V	3.3 V aggregation point	Encoder logic supply
3	Encoder phase A	STM32 `D2`	Quadrature encoder input A
4	Encoder phase B	STM32 `D3`	Quadrature encoder input B
5	Encoder GND	GND aggregation point	Encoder reference
6	Motor +	TB6612 `AO1`	Motor power lead; keep this orientation for the fixed motor sign

IMPORTANT

Pins 1 and 6 are motor-power leads, not logic signals. Pins 2–5 belong to the encoder. Do not place 12 V on pins 2, 3, 4, or 5.

7.1 Quick sensor check before motor power

With only USB power connected and the 12 V adapter still unplugged:

- rotating the arm by hand should change the encoder count;
- the direction of count change should reverse when the arm direction reverses;
- if the count does not change, check D2, D3, 3.3 V, GND, and connector orientation.

8 Wire the TB6612 Motor Driver

8.1 Logic and control connections

TB6612 pin	Destination	Function
`VCC`	3.3 V aggregation point	Logic supply for the TB6612
`GND`	Common GND junction	Shared reference for STM32 and motor supply
`PWMA`	STM32 `D10`	PWM magnitude command
`AIN1`	STM32 `D4`	Motor direction input 1
`AIN2`	STM32 `D5`	Motor direction input 2
`STBY`	STM32 `D7`	Driver enable/standby control

8.2 Motor-power connections

TB6612 pin	Destination	Function
`VM`	DC jack positive, +12 V	Motor power input
`GND`	DC jack negative and common system GND	Motor-power return and logic reference
`AO1`	Motor connector pin 6	H-bridge output to motor + lead
`AO2`	Motor connector pin 1	H-bridge output to motor − lead

DANGER

Never connect 12 V to TB6612 VCC. The only TB6612 pin that receives +12 V is `VM`. The TB6612 `VCC` pin must receive 3.3 V.

9 Prepare the DC Barrel Connector

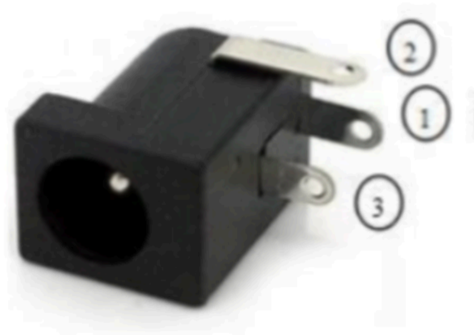


Figure 2: Three-terminal DC barrel jack. In this experiment, only terminal 1 and terminal 3 are used.

Pins used in this experiment

Terminal 1	Terminal 3
+12 V input	**GND**
Connect to TB6612 `VM`	Connect to the common GND junction

IMPORTANT

Use only terminal 1 and terminal 3.

- Terminal 1: +12 V, connected to TB6612 `VM`.
- Terminal 3: GND, connected to the common GND junction.
- Terminal 2: not used and must remain unconnected.

9.1 Manually attaching the two Dupont wires

1. Make sure that the 12 V adapter is completely disconnected.
2. Prepare two Dupont wires:
   - one wire for +12 V;
   - one wire for GND.
3. Cut off one connector end from each Dupont wire.
4. Carefully remove approximately 5–7 mm of insulation from the cut end of each wire.
5. Use your fingers to twist the exposed copper strands tightly together. No individual copper strand should remain loose.
6. Insert the twisted bare copper of the +12 V wire through the small hole in terminal 1.
7. Bend the bare copper around terminal 1 and rotate it tightly around the metal terminal for at least two turns.
8. Insert the twisted bare copper of the GND wire through the small hole in terminal 3.
9. Bend the bare copper around terminal 3 and rotate it tightly around the metal terminal for at least two turns.
10. Pull both wires gently to confirm that they cannot slide out.
11. Check that no loose copper strand can touch terminal 2 or the other connected terminal.

12. Cover any excessive exposed copper using insulating tape.
13. Connect the other end of the terminal-1 wire to TB6612 `VM`.
14. Connect the other end of the terminal-3 wire to the common GND junction on the breadboard.

IMPORTANT

Do not connect the 12 V adapter after completing this step.
The teaching assistant must first check:

- terminal 1 is connected to TB6612 `VM`;
- terminal 3 is connected to common GND;
- terminal 2 is unconnected;
- no exposed copper strands are touching adjacent terminals;
- the two wires are mechanically secure.

Only after TA approval may the 12 V DC adapter be connected.

10 Reference Hardware Assembly

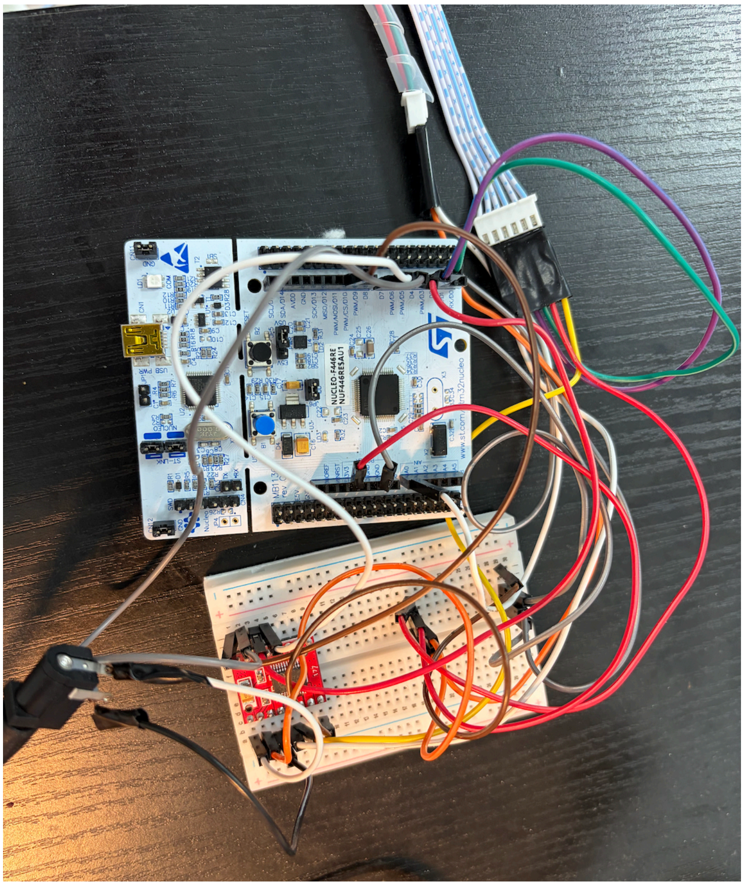


Figure 3: Reference assembly. Use the labels and connection tables rather than copying wire colors blindly. Cable colors may differ between groups.

11 Complete Point-to-Point Wiring Table

Use this table as the final netlist. Place a check mark only after physically tracing each wire from one endpoint to the other.

	From	To	Notes
☐	STM32 `3.3V`	Breadboard 3.3 V aggregation point	Logic supply source
☐	STM32 `GND`	Breadboard GND aggregation point	Common reference
☐	Potentiometer `3.3V`	3.3 V aggregation point	Never 5 V
☐	Potentiometer green signal	STM32 `A0`	Pendulum angle signal
☐	Potentiometer `GND`	GND aggregation point	Analog reference
☐	Encoder pin 2	3.3 V aggregation point	Encoder supply
☐	Encoder pin 3, phase A	STM32 `D2`	A-phase input
☐	Encoder pin 4, phase B	STM32 `D3`	B-phase input
☐	Encoder pin 5	GND aggregation point	Encoder ground
☐	TB6612 `VCC`	3.3 V aggregation point	Driver logic supply
☐	TB6612 `GND`	Common GND junction	Shared with 12 V negative
☐	TB6612 `PWMA`	STM32 `D10`	PWM
☐	TB6612 `AIN1`	STM32 `D4`	Direction 1
☐	TB6612 `AIN2`	STM32 `D5`	Direction 2
☐	TB6612 `STBY`	STM32 `D7`	Driver enable
☐	Motor connector pin 6	TB6612 `AO1`	Motor + lead
☐	Motor connector pin 1	TB6612 `AO2`	Motor − lead
☐	DC jack positive	TB6612 `VM`	+12 V, connected only after approval
☐	DC jack negative	Common GND junction	12 V return
☐	STM32 USB connector	PC USB port	Data cable, not charge-only

12 Implement Dual-Loop PID Control on the Physical System

After the wiring has been inspected and the firmware has been uploaded, use the supplied Python control panel to operate the physical rotary inverted pendulum.

The STM32 executes the complete real-time control loop. The Python panel is used to calibrate the potentiometer, adjust controller parameters, send the parameters to the STM32, start or stop the experiment, display the real-time motion, and save the experimental data.

12.1 Adjustable parameters

All parameters shown in the Python panel can be adjusted, including:

- maximum PWM;
- swing-up PWM;
- PID entry and exit angles;
- soft-blending coefficient;
- pendulum PID gains;
- rotary-arm PID gains;
- integral limits;
- velocity low-pass-filter coefficient;
- potentiometer upright and hanging-down calibration values.

Students should refer to the parameter-design procedure used in the simulation environment during the previous laboratory session.

12.2 Recommended workflow

1. Tune and test the swing-up and dual-loop PID controller thoroughly in simulation.
2. Check that the simulated system can repeatedly swing up and remain stable.
3. Connect the Python panel to the STM32.
4. Hold the pendulum upright and calibrate the upright potentiometer position.
5. Let the pendulum hang naturally and calibrate the downward position.
6. Enter the selected parameters and click **SAVE**.
7. Wait until the panel confirms that the parameters are active on the STM32.
8. Confirm that the mechanism has sufficient free space.
9. Click **GO** to start the experiment.
10. Click **STOP** immediately if abnormal motion, excessive vibration, or wiring movement is observed.

IMPORTANT

The mechanical assembly is a consumable experimental component. Its expected cumulative operating life is approximately two hours when repeated operation starts from the swing-up stage.
Do not use the physical system for extensive trial-and-error tuning. Complete as much parameter tuning as possible in simulation and deploy the controller to the physical system only when the expected behaviour is sufficiently reliable.
Unnecessary physical trials may loosen joints, wear the transmission components, damage the potentiometer, or shorten the service life of the mechanism.

12.3 Before each physical trial

Before clicking **GO**, confirm that:

- the parameter set has already been tested in simulation;
- the potentiometer has been calibrated correctly;
- the parameter set has been saved successfully;
- all cables are clear of the rotating arm;
- no person or object is inside the motion range;
- the **STOP** button is immediately accessible.

Build carefully. Trace every wire. Ask before powering.