OPEN-SOURCE PROJECT · REVISION 3.0

Biaxial testing machine

Four-actuator bench for biaxial tensile tests on textiles and canvases, created for research and developed for the conservation field.



1.5 kN	600 mm	4	1–900 mm/min
FORCE PER AXIS	STROKE PER AXIS	INDEPENDENT ACTUATORS	TEST SPEED

OVERVIEW

A biaxial tensile testing machine designed mainly for textiles and painting canvases. Four opposed actuators load the specimen along X and Y, together or separately, and measure its response: data that help conservators understand how historical materials behave.

The machine was created for Antonio Iaccarino's PhD research project at Delft University of Technology. Revision 3.0 builds on that experience with a sturdier, easier-to-use machine. The project is open source.

KEY FEATURES

- **Four configurations**: biaxial, uniaxial X or Y, single axis for compression and bending
- **One load cell per actuator**, read by a 24-bit Neuron Bridge board
- **Position and force control** and force feedback
- **Temperature and humidity** logged with force and position
- **PLC CODESYS** on Raspberry Pi 4, OPC UA to HMI and network
- **Cortex Interface** on a 13" touch panel: recipes, charts, reports

01 · TECHNICAL DATA

Technical specifications

Data refer to revision 3.0 of the machine.

PERFORMANCE

Configurations	Biaxial, uniaxial X, uniaxial Y, single axis
Maximum force	1.5 kN per axis; fitted 25 kg cells (≈ 245 N)
Stroke	300 mm per actuator, 600 mm per axis
Test speed	1–900 mm/min
Maximum acceleration	5000 mm/s²
Specimens	10 × 10, 25 × 25, 100 × 100 mm
Distance between grips	up to 500 mm, depending on the grips fitted

STRUCTURE AND MECHANICS

Base	Double 3 mm steel plate, spaced 40 mm with 2040 aluminium profiles
Guides	HGR15 recirculating ball guides
Transmission	Ball screw, 5 mm lead
Footprint	1200 × 1200 × 300 mm

ACTUATION

Actuators	4 linear, 2 opposed per axis
Motors	Leadshine iCS-RS2323, closed-loop hybrid steppers, NEMA 23 flange
Holding torque	1.9 N·m
Motor supply	36 V DC (20–50 V DC allowed), 7.0 A peak
Encoder	Integrated 14-bit magnetic incremental
Positioning resolution	0.01 mm
Drive functions	Homing, software limits, JOG, quick stop, 16 programmable positions

MEASUREMENT

Force	1 tension/compression cell per actuator
Accuracy	0.05 % of full scale, 0.05 N resolution
Acquisition	Neuron Bridge, 24-bit NAU7802 ADC, 10–80 samples/s
Position	Motor encoders, 0–300 mm per actuator, 0.5 µm resolution
Ambient	CWT-TH03S-H: -40…+120 °C ±0.5 °C; 0–100 % RH ±5 %
Logging	Force and position every 50 ms, about 20 samples/s per channel

CONTROL AND COMMUNICATION

PLC	Raspberry Pi 4 with CODESYS 3.5 runtime
Control modes	Position, force, force feedback
Internal bus	Modbus RTU over RS485: 4 lines at 115,200 baud, plus 1 line for the T/RH sensor
External	OPC UA server, Ethernet, USB, remote access from the local network
HMI	13" touch panel, Cortex Interface
Software	Test recipes, force-displacement charts, automatic report, CSV export, multilingual

POWER AND ENVIRONMENT

Power supply	Single-phase 110/230 V, 50/60 Hz
Installed power	1 kW
Upstream protection	Residual current circuit breaker
Operating conditions	Indoor laboratory, 10–35 °C, 0–70 % RH non-condensing

02 · CONFIGURATIONS

Test configurations

Four configurations, selectable from the operator panel. In all of them the test speed ranges from 1 to 900 mm/min.

CONFIGURATION	ACTUATORS	TEST TYPE	CONTROL	FORCE	STROKE
Biaxial	4, X and Y axes	Biaxial tension	Position, force, force feedback	1.5 kN per axis	600 mm per axis
Uniaxial X	2, X axis	Tension	Position, force	1.5 kN	600 mm
Uniaxial Y	2, Y axis	Tension	Position, force	1.5 kN	600 mm
Single axis	1	Compression and bending, against a fixed turret	Position, force	1.5 kN	300 mm

The clamping grips hold the specimen on its four sides and are available for 10, 25 and 100 mm specimens. During mounting, the central part of the support rises to the level of the grips and holds the specimen in place until the clamps are closed; it lowers again before the test.

03 · FORCE MEASUREMENT

Acquisition with Neuron Bridge

Each load cell is read by a dedicated Neuron Bridge board mounted on the actuator carriage: the analogue signal travels only a few centimetres before being converted and sent to the PLC over Modbus RTU.

CONVERSION

Boards	4, one per actuator
Converter	NAU7802, 24-bit sigma-delta ADC, up to 23 effective bits
Input	Differential strain-gauge bridge
Gain	Programmable from 1 to 128
Cell excitation	Internal programmable regulator 2.4–4.5 V
Sampling	10–80 samples/s, selectable

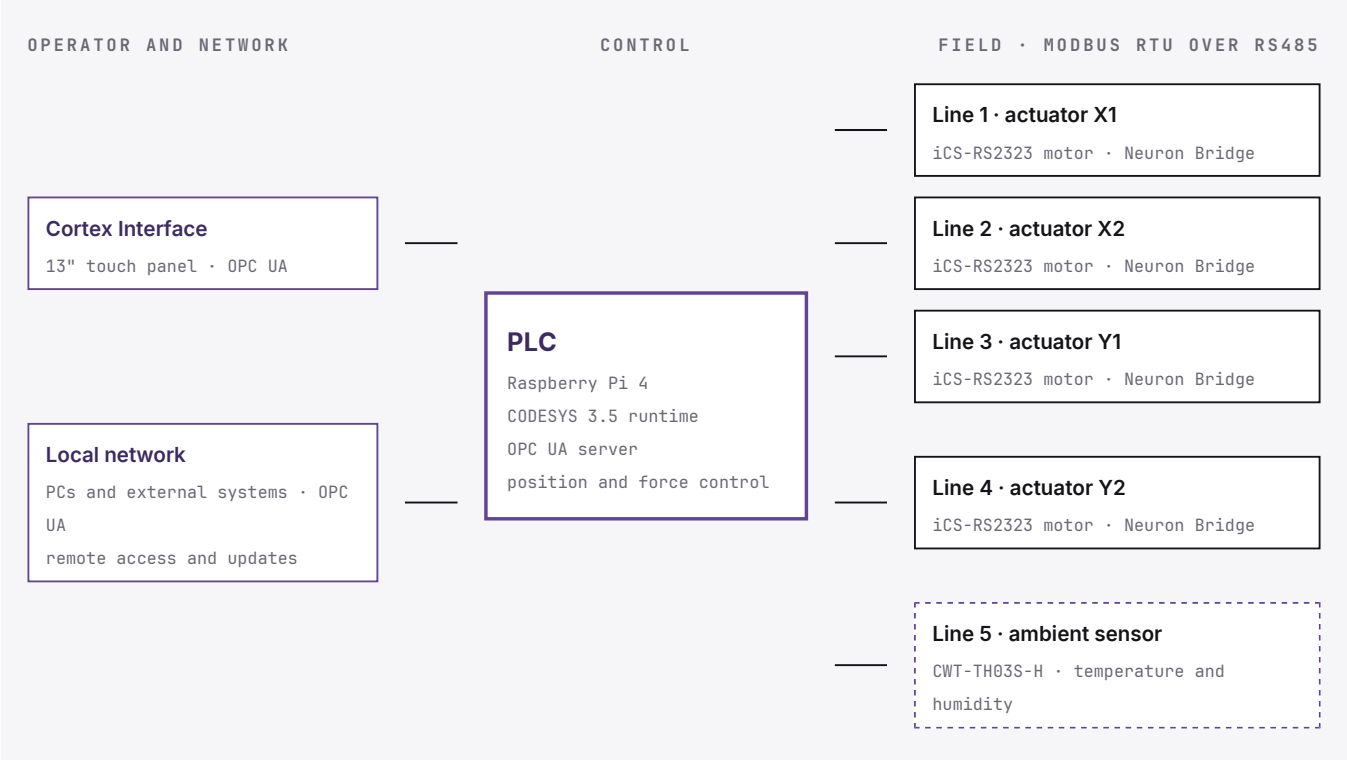
SIGNAL QUALITY AND OUTPUT

RMS noise (gain 128)	50 nV at 10 samples/s; 150 nV at 80 samples/s
Mains rejection	50 and 60 Hz simultaneous, up to -90 dB
Integral non-linearity	±0.0015 % of full scale after calibration
Calibration	Internal offset and gain, then with reference forces
Digital filters	Pyramid average, moving average, outlier rejection; configurable window
Output	Modbus RTU over RS485, 115,200 baud, force in N

04 · ARCHITECTURE

Control architecture

A CODESYS PLC on a Raspberry Pi 4 coordinates four independent instances, one for each motor and load cell pair, each on its own RS485 line. Towards the operator and the network the machine communicates over OPC UA.



Lines 1–4 work in parallel at 115,200 baud, each shared only by the motor and Neuron Bridge board of its own actuator; an exchange with a drive takes about 3 ms. The PLC synchronises the four axes.

05 · SOFTWARE

Software and communication

FUNCTION	DESCRIPTION
Server OPC UA	Built into the CODESYS runtime, Basic256Sha256 security profile
Exposed data	Test commands, setpoints, machine status, forces, positions, temperature and humidity, alarms
Recipes	Test profiles saved and recalled from the operator panel
Real-time test view	Forces and positions of the four axes on force–displacement charts
Report and export	Automatic test report; data in CSV
Diagnostics	Drive status and alarms read over Modbus and shown on the panel
Language	Multilingual interface
Drive configuration	Leadshine MotionStudio, through the drives' RS232 port (service)

06 · SAFETY

Safety

Safety functions and devices of revision 3.0.

- **Emergency stop** with a mushroom-head button.
- **Software limits** on force, stroke and speed, set from the panel and also active in the drives after homing.
- **Maintenance mode** at reduced speed.
- **Hardware limit switches** on every actuator.
- **Overload stop** when the threshold set on the load cell is exceeded.
- **Drive protections**: overcurrent, overvoltage, following error.

07 · PROJECT

An open-source project

The first two revisions of the machine were used by Antonio Iaccarino for his PhD research project at Delft University of Technology. Revision 3.0 builds on that experience and has already been used to test samples of historical canvases.

The project is open source, with the aim of building a community of conservators, researchers and laboratories around the machine who can use it, improve it and share methods and results.

Design and build	**Luca Cortelli**
Test protocols and validation	**Antonio Iaccarino**

08 · REVISIONS

REVISION	DATE	NOTE
Document A	16/11/2026	First issue
Machine 3.0	2026	Current revision
Machine 1.0–2.0	—	PhD research, TU Delft

The data refer to revision 3.0 and may change as the project evolves. The latest version of this document is available at cortexautomations.com.
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