UNIVERSAL ROBOTS

Kinematic Calibration User Manual

e-Series

UR Series

Original instructions (en)

PolyScope 5

Contents

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1. Preface

About this document

This document describes how to set up and do Dual Robot Calibration on identical robots from Universal Robots. During Dual Robot Calibration, two robot arms are connected and perform coordinated movements to different positions to calibrate the robot kinematics.
This document also describes how to use key waypoints to correct programs automatically.

Terminology and abbreviations

In this document the following terms and corresponding abbreviations are used:

- Corresponding Tool Position (CTP)
- Tool Center Point (TCP)

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2. Liability and Intended Use

2.1. Limitation of Liability

Description

Any information provided in this manual must not be construed as a warranty, by UR, that the industrial robot will not cause injury or damage, even if the industrial robot complies with all safety instructions and information for use.

2.2. Intended Use

Description

NOTICE

Universal Robots takes no responsibility and assumes no liability for unapproved uses of its robots or uses for which its robots are not intended and Universal Robots will provide no support for unintended uses.

READ MANUAL

Failure to use the robot in accordance with the intended use can result in hazardous situations.

- Read and follow the recommendations for intended use and the specifications provided in the User Manual.

Universal Robots robots are intended for industrial use, to handle tools/end effectors and fixtures, or to process or transfer components or products.

All UR robots are equipped with safety functions, which are purposely designed to enable collaborative applications, where the robot application operates together with a human. The safety function settings must be set to the appropriate values as determined by the robot application risk assessment.

The robot and Control Box are intended for inside use where, normally, only non-conductive pollution occurs i.e. Pollution degree 2 environments.

Collaborative applications are only intended for non-hazardous applications, where the complete application, including tool/end effector, work piece, obstacles and other machines, is low risk according to the risk assessment of the specific application.

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WARNING

Using UR robots or UR products outside of the intended uses can result in injuries, death and/or property damage. Do not use the UR robot or products for any of the below unintended uses and applications:

- Medical use, i.e. uses relating to disease, injury or disability in humans including the following purposes:
  - Rehabilitation
  - Assessment
  - Compensation or alleviation
  - Diagnostic
  - Treatment
  - Surgical
  - Healthcare
  - Prosthetics and other aids for the physically impaired
  - Any use in proximity to patient/s
- Handling, lifting, or transporting people
- Any application requiring compliance with specific hygienic and/or sanitation standards, such as proximity or direct contact with food, beverage, pharmaceutical, and /or cosmetic products.
  - UR joint grease leaks, and can also be released as vapor into the air.
  - UR joint grease is not “food grade”.
  - UR robots do not meet any food, National Sanitization Foundation (NSF), Food and Drug Administration (FDA), or hygienic design standards.

  Hygienic standards, for example ISO 14159 and EN 1672-2, require a hygiene risk assessment be conducted.
- Any use, or any application, deviating from the intended use, specifications, and certifications of UR robots or UR products.
- Misuse is prohibited as the result could be death, personal injury, and /or property damage

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WARNING

Failure to consider the added risks due to the reach, payloads, operating torques and speeds associated with robot application, can result in injury or death.

- Your application risk assessment shall include the risks associated with the application's reach, motion, payload and speed of the robot, end effector and workpiece.

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3. Your Robot – Preparation

Description

This section describes how to mount two UR robot arms to a Calibration Horse and how to prepare them for dual calibration.

Calibration kits

You can order two different calibration kits:

- purchase number: 185500
- purchase number: 200977

Calibration kit (18550) is packaged with a smaller calibration horse and can be used with the following robots:
All e-Series robots.

Calibration kit (number: 200977) is packaged with a larger calibration horse and can be used with the following robots:
UR10e, UR16e and UR Series robots (UR8L, UR15, UR20 and UR30).

Calibration Kits Contain

- Calibration Horse with alignment pins
- Calibration Tool Connector with alignment pins
- Screws
- Go / NoGo tools
- Manual for dual arm calibration

Required items for Calibration

You need the following items to set up the robots for dual calibration:

- Two Universal Robots of the same type and software version.
- A Calibration Horse.
- A 0.5 m stand for the smaller Calibration Horse.
- A 0.81 m stand for the larger Calibration Horse.
- A network cable.
- A Dual Robot Calibration kit.

NOTICE

Robot software versions 5.8 and later saves calibration results in the robot arm. Robots using older software versions save calibration results to the Control Box, so a calibrated robot arm and Contol Box must be used together.

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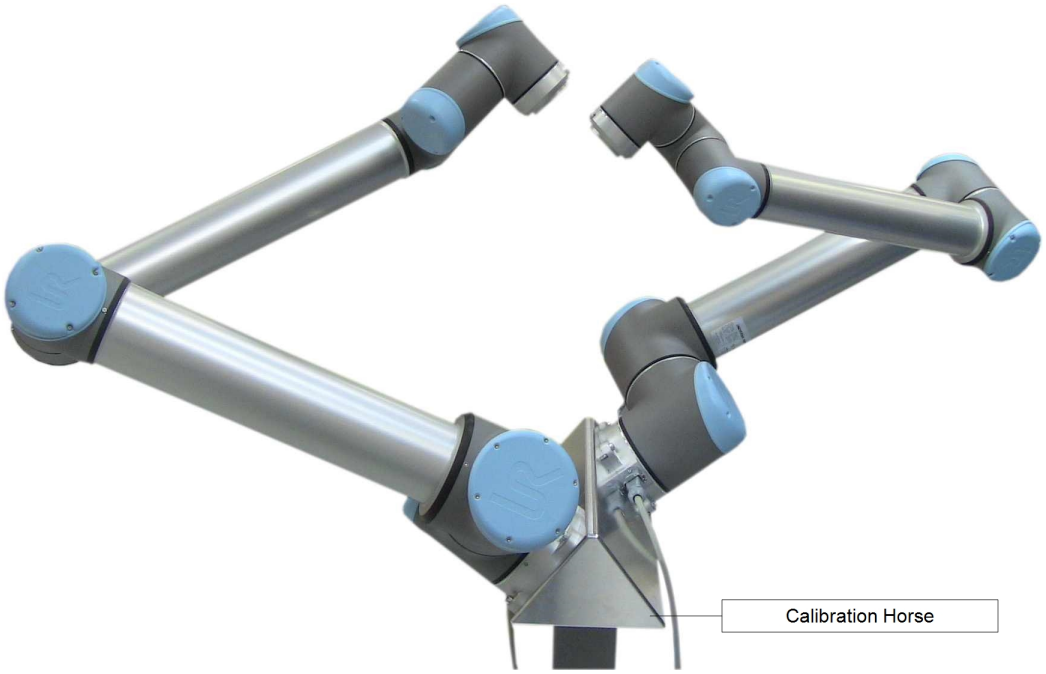
3.1. The Calibration Horse

Description

The Calibration Horse connects one robot arm to another via the base, as illustrated in the image below. Using the Calibration Horse allows you to attach the two tool flanges. The result is a closed robot arm circuit that makes coordinated movements, while performing a number of measurements.



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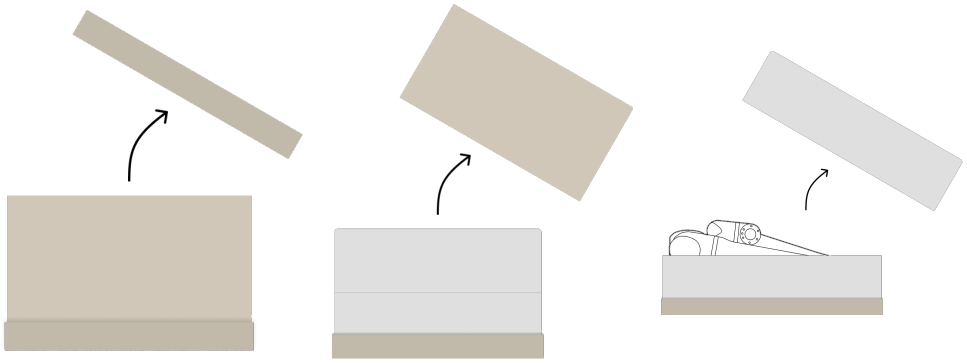
3.2. Lifting and Handling

Description

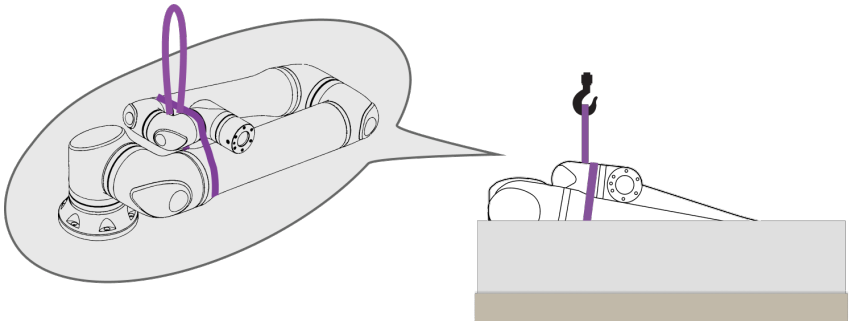
The robot arms come in different sizes and weights, so it is important to use the appropriate lifting and handling techniques for each model. Here you can find information on how to safely lift and handle the robot.

Proper lifting and handling

1. Transport the robot to the site using a forklift.
2. Open the box as illustrated.



3. Securely strap the robot arm with the lifting sling.



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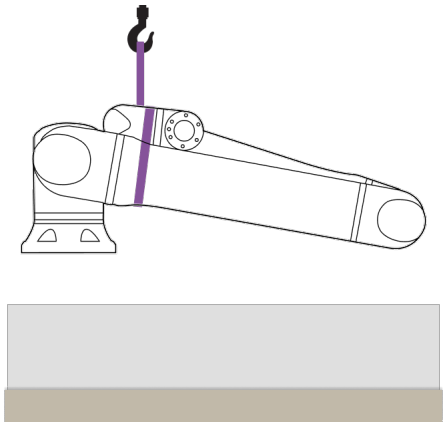
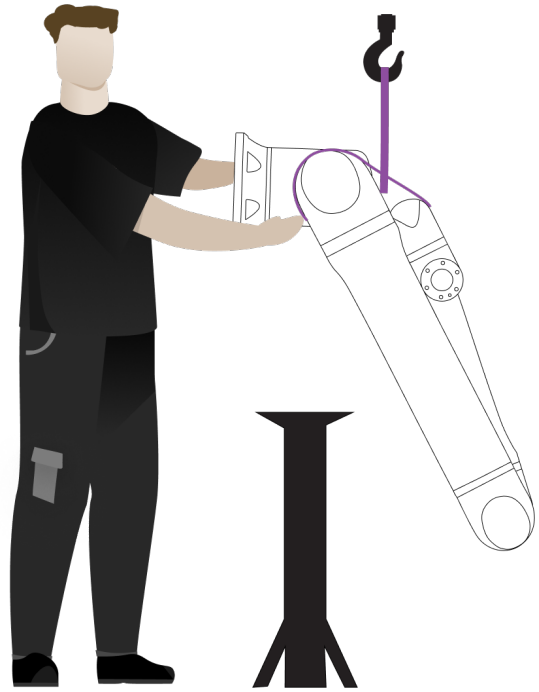
4. Lift the robot arm out of the box using the strap and hook.



> **CAUTION**
> Use a lifting equipment when lifting heavier robot arm.

5. While the robot is lifted, support it to rotate and hang as illustrated.



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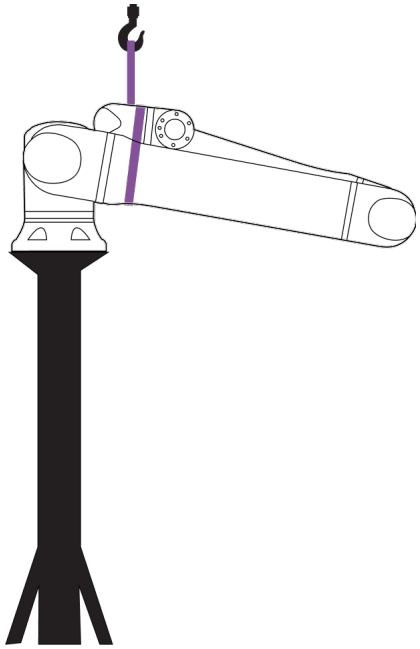
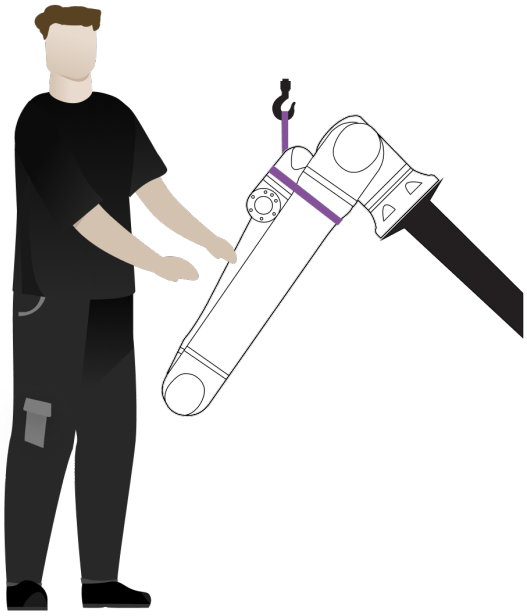
Mounting the Robot Arm

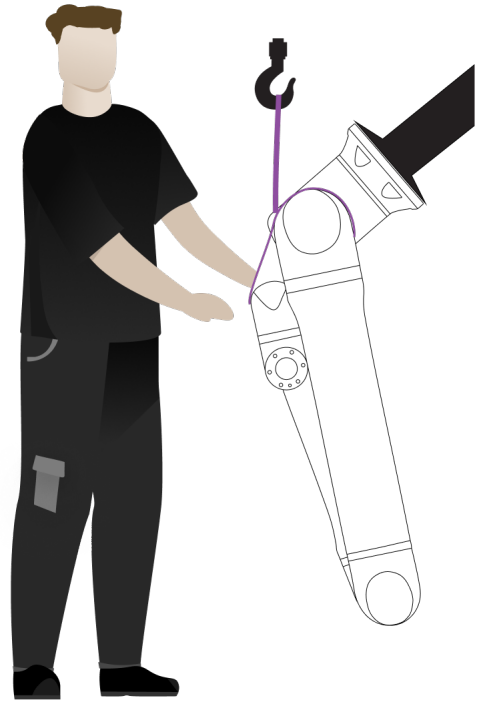
The robot arm can be mounted sideways, upside-down or in an angle (±45°).



Sideways mounting



Angular mounting (±45°)



Upside-down mounting

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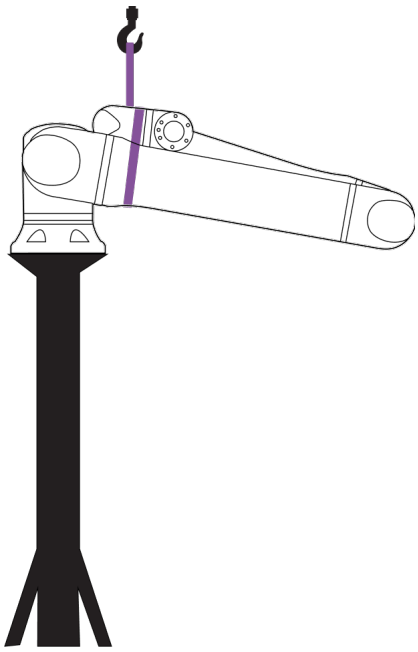
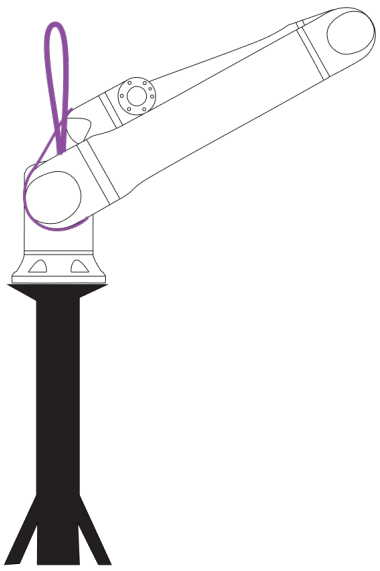
1. Mount the robot arm. Tighten the screws and apply torque as specified in the relevant user manual.



2. Remove the strap.
3. Power on the robot and reposition shoulder joint as intended.

> **NOTICE**
> For sideways mounting, no need to power on the robot.

4. Re-place the strap.



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3.3. How To Mount Robot Arms To The Calibration Horse

Description

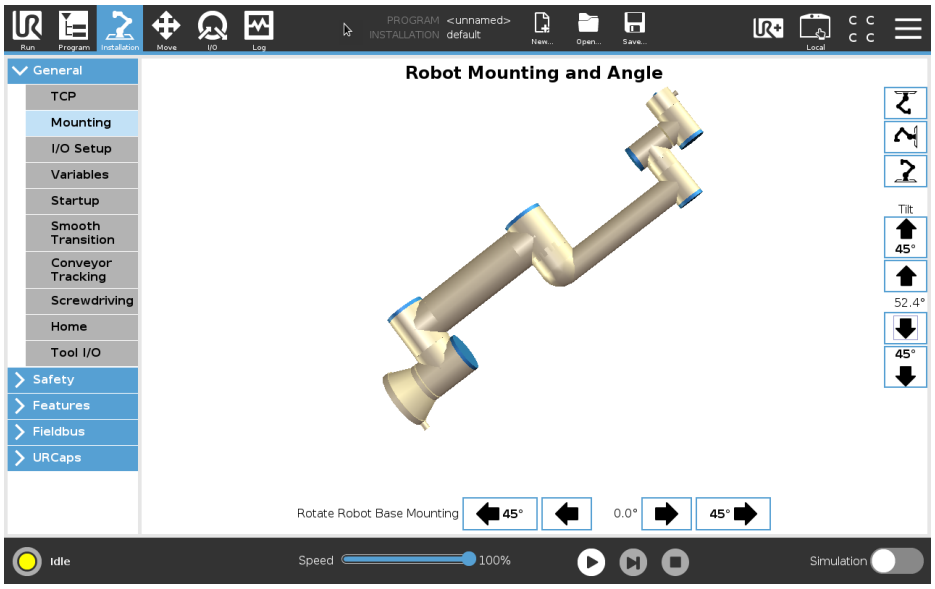
When mounting the arms for calibration, there are a few things that you should be aware of.

- Mount the robots on the calibration horse.
- Please refer to the user manual for the correct torque for mounting the robots.
- Mount the robots at approximately 52.4°.
- Use a custom installation before activating the robots.

To mount each robot arm in SW.

1. Use the screws to mount each robot to the Calibration Horse.
2. Turn on the control box, then leave the robot arm in the Idle state (Yellow indicator).

   The screen, below shows the robot arm in the Idle state.



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To configure the mounting software

1. On PolyScope, in the Header, tap **Installation**.
2. Under General, select **Mounting**
3. Use arrow buttons to set the Tilt and the Rotate Robot Base Mounting, according to the values in the table below.

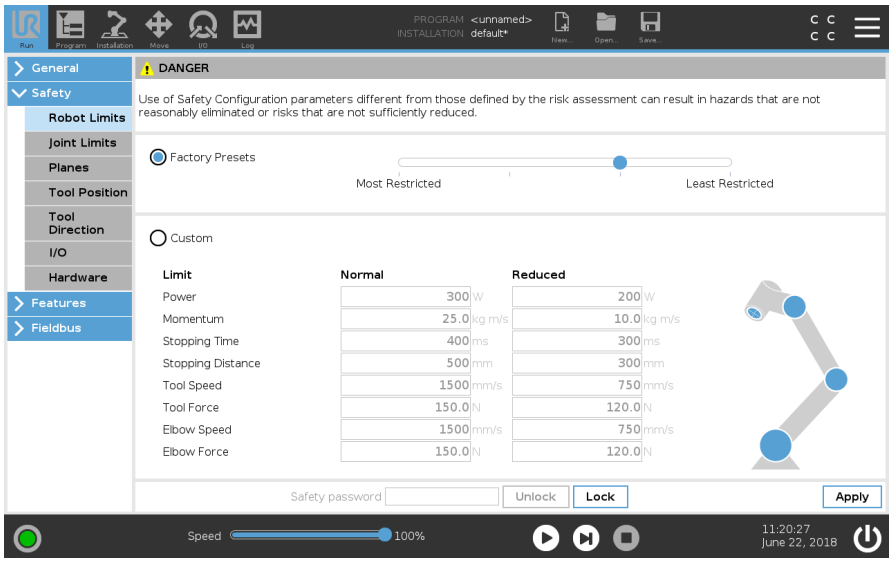
Use the following numbers to your robot:

Robot size	Tilt	Rotate Robot Base Mounting
UR3e	52.4°	270°
UR5e	52.4°	90°
UR10e	52.4°	90°
UR16e	52.4°	90°
UR8 Long	52.4°	90°
UR15	52.4°	90°
UR20	52.4°	90°
UR30	52.4°	90°

3.4. How To Prepare Robot Safety Settings

Description

Configure the robot safety settings in PolyScope, as shown in the screen shot below.



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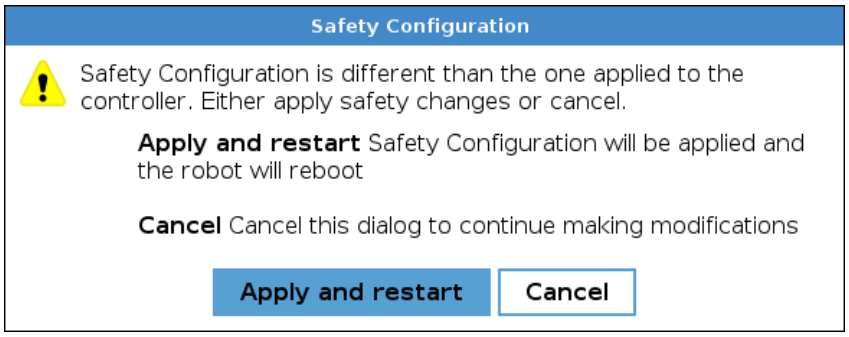
To configure the robot safety settings

1. Tap **Safety** and select **Robot Limits**.
2. Enter the password: `lightbot` and tap **Unlock**.
3. Tap **Apply** to unlock the Safety Configuration.
4. When the Safety Configuration dialog box appears, select **Apply and restart**.



3.5. How to prepare the robot network connection

Description

Select a method, based on your connection type.

- Method 1 Manual: When the robots are already connected to a local area network
- Method 2 Master/Slave: for robots connected directly with single network cable

3.5.1. Method 1: Manual Connection

Description

Use this method when the robots are already connected to a local area network.

NOTICE

Connecting the robots to a Local Area Network (LAN) can interfere with other devices sharing these IP addresses.

- Do not connect the robot to a LAN. Connect the two robots directly to eachother.

NOTICE

Connection between the two networks can break down, causing the calibration screen to change.

- Follow the on-screen instruction to resolve the network conflict and restart the calibration process.

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Connecting the Manual network (Method 1)

Define the network connection types as listed in the following table:

Network connection type	Definition
Master	The main robot in the calibration process. Uses a single cable.
Slave	The subordinate robot in the calibration process.
Manual	A Master robot is selected and a Slave robot selected by a user supplied IP-address.

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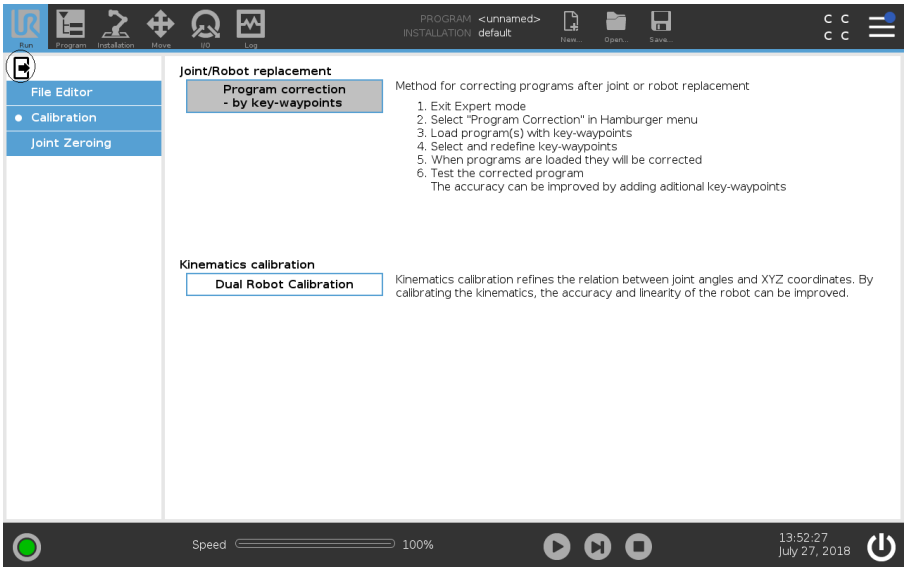
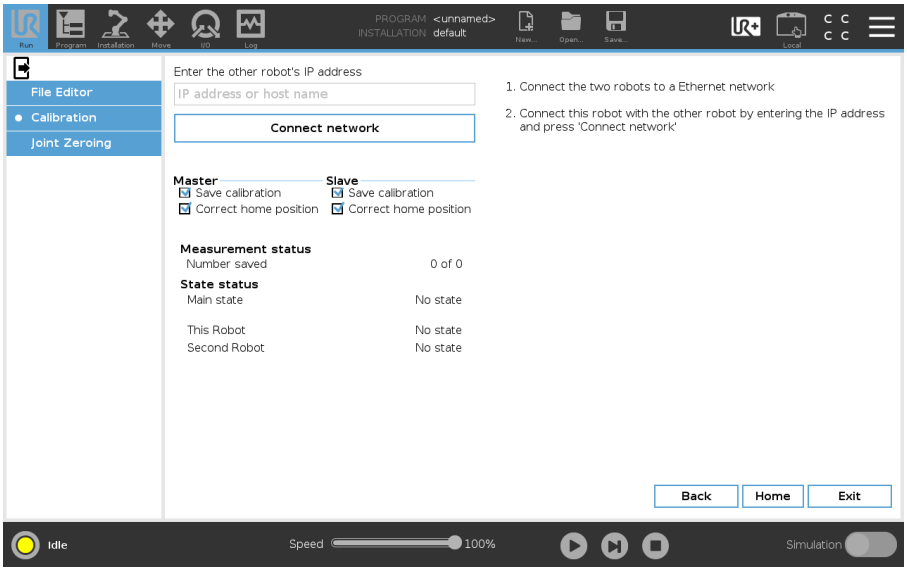
To connect the Manual network

1. In the Header, hold down **Run** to access Expert Mode.
2. Enter password and tap **OK**
3. Under **Kinematics calibration**, select **Dual Robot Calibration**.



4. Choose the Master robot and the Slave robot:
   a. On the Master robot, tap **Master**.
   b. On the Slave robot, tap **Slave**.
5. On the Master robot tap the IP address field and enter the IP address or the host name of the Slave robot.
6. Tap **Connect network** to establish the network connection.



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3.5.2. Method 2: Master/Slave connection

Description

Use this method only for robots connected directly with single network cable.

NOTICE

The network communication between the Master robot and the Slave robot can break down, causing the calibration to stop.

- Follow the on-screen prompt to resume the process

NOTICE

The Master / Slave network connection uses self-assigned IP addresses, which can interfere with local area network devices.

Connecting the Master / Slave network (Method 2)

Define the network connection types as listed in the following table:

Network connection type	IP Address
Master	10.17.17.18
Slave	10.17.17.19

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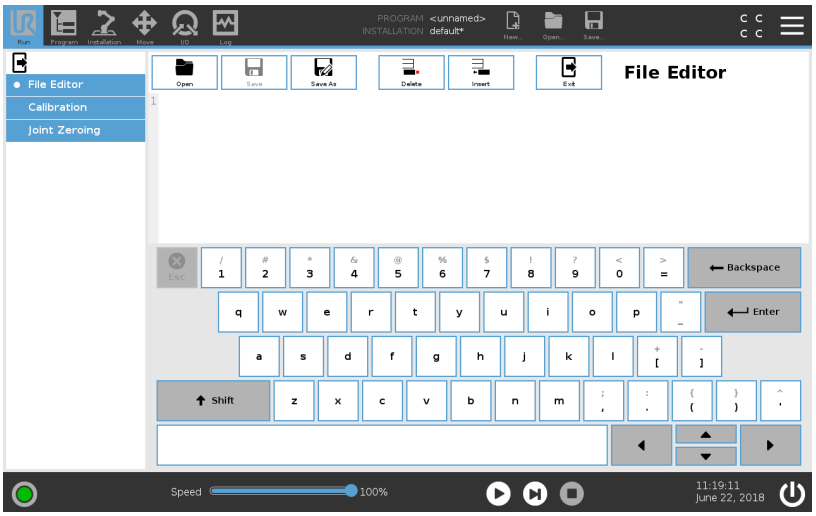
To connect the Master / Slave network

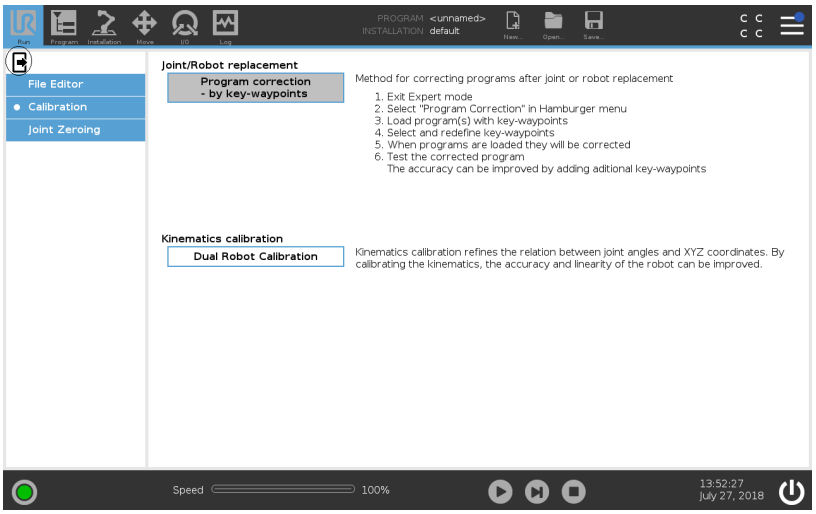
NOTICE

Please verify that all installed services are enabled, such as Modbus. If they are disabled the connection will fail.

1. Use a network cable to connect the Ethernet ports of the two robot Control Boxes.
2. On PolyScope, in the Header, hold down **Run** to access Expert Mode.
3. Enter the password: `lightbot` and tap **OK**.



4. Under **Kinematics calibration**, select **Dual Robot Calibration**.



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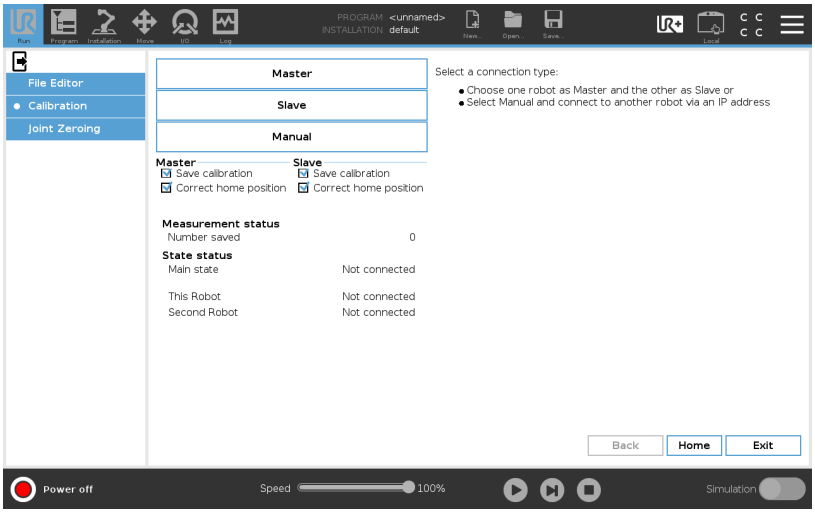
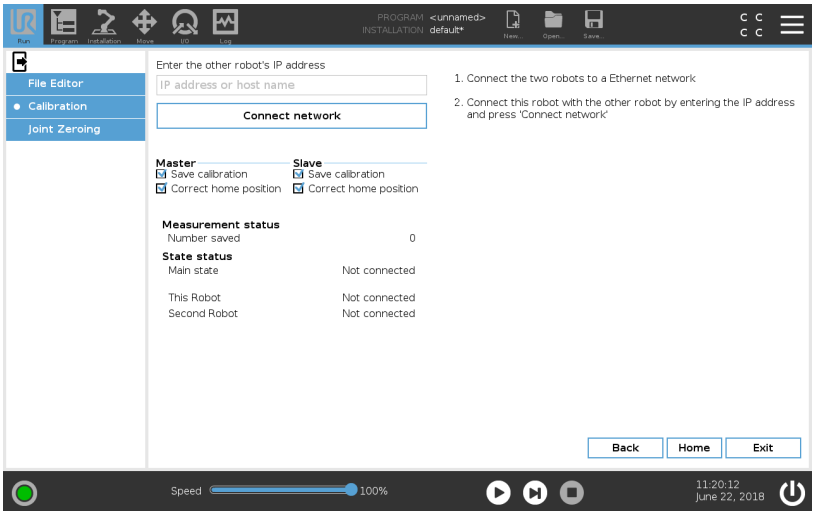
5. Choose the Master robot and the Slave robot:
   a. On the Master robot, tap **Master**.
   b. On the Slave robot, tap **Slave**.



6. On the Master robot, tap **Connect network** to establish the network connection.



3.6. How To Attach The Calibration Connector

Description The Calibration Connector attaches the two robot arms via the tool flanges.

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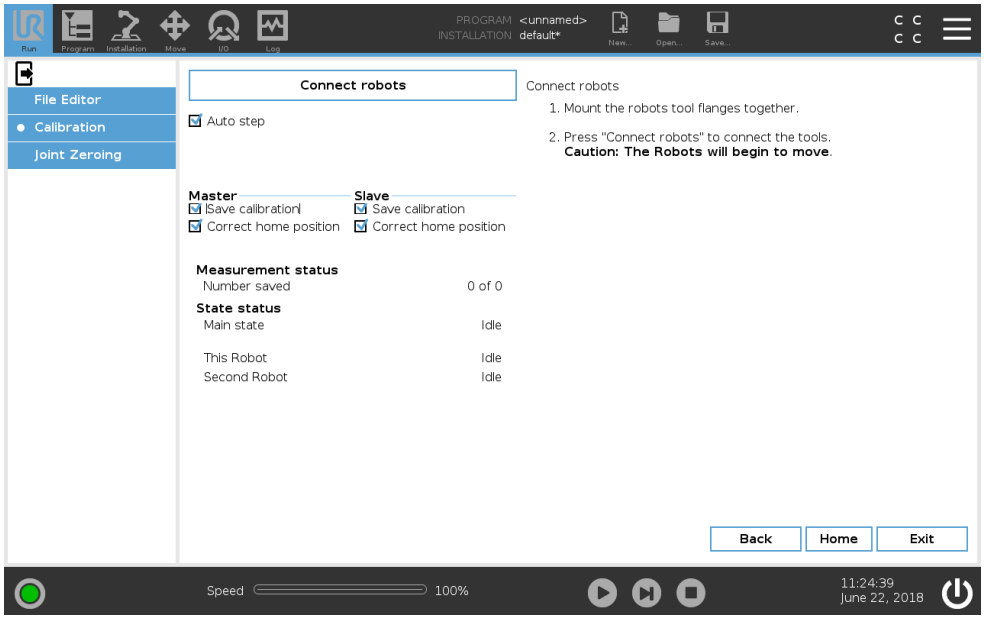
To attach the Calibration Connector

1. Verify both robot arms are correctly attached to the Calibration Horse.
2. For each robot arm: On PolyScope, tap **Move** and select the **Home** button to return each robot arm to the Home position.
3. Tab **Proceed**.
4. The robot arms will move into a parallel position for connecting the Calibration Connector.
5. Attach the Calibration Connector to the designated Master robot.



As both robots move to bring the tool flanges close to each other, the Slave robot enters Freedrive.

6. Align the Slave robot's tool flange with the Calibration Connector.
7. Use the four screws and washers to attach the Slave robot's tool flange to the Calibration Connector.

The following illustrations show the Calibration Connector in use

Calibration Connector attached to the Master robot's tool flange (step 2).

Calibration Connector attached to the Master robot's tool flange and the Slave robot's tool flange (step 5).

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4. Safety

Safety Please see the different types of safety messages, and the specific safety settings during a calibration of your robots.

4.1. Safety Message Types

Description Safety messages are used to emphasize important information. Read all the messages to help ensure safety and to prevent injury to personnel and product damage.

WARNING
Indicates a hazardous situation that, if not avoided, can result in death or serious injury.

WARNING: ELECTRICITY
Indicates a hazardous electrical situation that, if not avoided, can result in death or serious injury.

WARNING: HOT SURFACE
Indicates a hazardous hot surface where injury can result from contact and non-contact proximity.

CAUTION
Indicates a hazardous situation that, if not avoided, can result in injury.

GROUND
Indicates grounding.

PROTECTIVE GROUND
Indicates protective grounding.

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NOTICE

Indicates the risk of damage to equipment and/or information to be noted.

READ MANUAL

Indicates more detailed information that should be consulted in the manual.

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4.2. General Safety Precautions

Description For more information on safety, refer to the Safety section in the robot User Manual.

WARNING: ELECTRICITY

Installing or maintaining equipment connected to a power source can lead to electric shock.

- Disconnect the equipment from the power source before installation or maintenance.

WARNING

Incorrect connection of the power source or ground wires can result in equipment damage or personnel injury.
Damage caused by invalid power source connection is not covered by warranty. Before starting the operation:

- Ensure that the power source wiring is correct.
- Ensure that the grounding is correct.

WARNING

Failure to verify and validate safeguarding and functionality can result in death or serious injury.

- Ensure all risk reduction works as intended and achieves the needed risk reduction.

WARNING

Failure to perform a risk assessment before installation and operation can result in personnel injury or equipment damage.

- Perform a risk assessment before installation and operation.
- Read the UR User Manual and UR Service Manual.

NOTICE

This product includes the Universal Robots e-Series robot. General safety considerations that are valid for the Universal Robots e-Series robot are also valid for this product.

- For more information on safety, refer to the Safety section in the Universal Robots e-Series robot User Manual.

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4.3. Dual Calibration Safety Precautions

Description This section contains safety precautions specific to Dual Robot Calibration and Program Correction.

WARNING

Obstructing the robots during the dual calibration process can result in equipment damage or personnel injury.

- Stay clear of the robots once the calibration starts.

NOTICE

Incorrect dual calibration can cause the robot to become inaccurate. Before saving the results:

- Pay attention to the generated statistics of the dual calibration.

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5. Dual Robot Calibration: Application

Description This section describes how to calibrate two robots of the same size.

5.1. How To Calibrate The Robots

Description Dual calibration is performed automatically, so you only need to start the process.

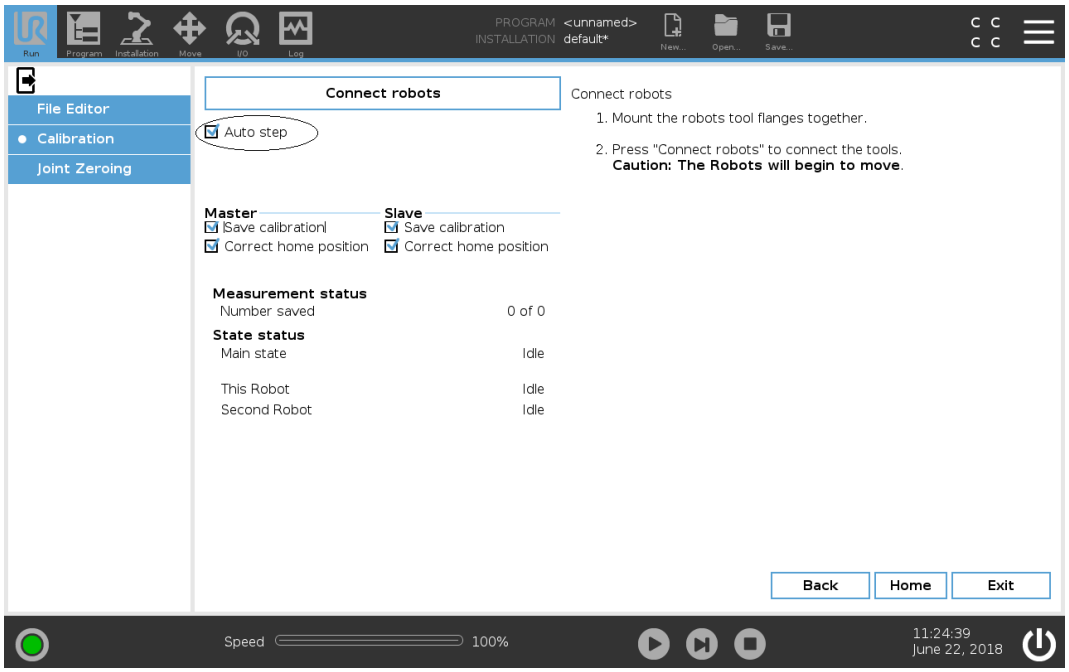
Do not disable the Save Calibration and Correct home positions options.

- **Save calibration**: The calculated kinematic calibration is applied and saved on the robot.
- **Correct home position**: Estimates and sets the Home Position using the calibration (define new joint offset angles).

These options are used by Universal Robots Service Engineers in specific scenarios.

To start the calibration

1. Ensure the Calibration Connector securely attaches both tool flanges.
2. If operator intervention is required during the calibration, you can disable the **Auto step** checkbox.
   a. This auto step only applies to non-3PE TP.
   b. If you robot is connected to a 3PE TP, it is impossible to disable auto step.
3. Tap **Proceed** and stand clear of the robots, as they start moving around.



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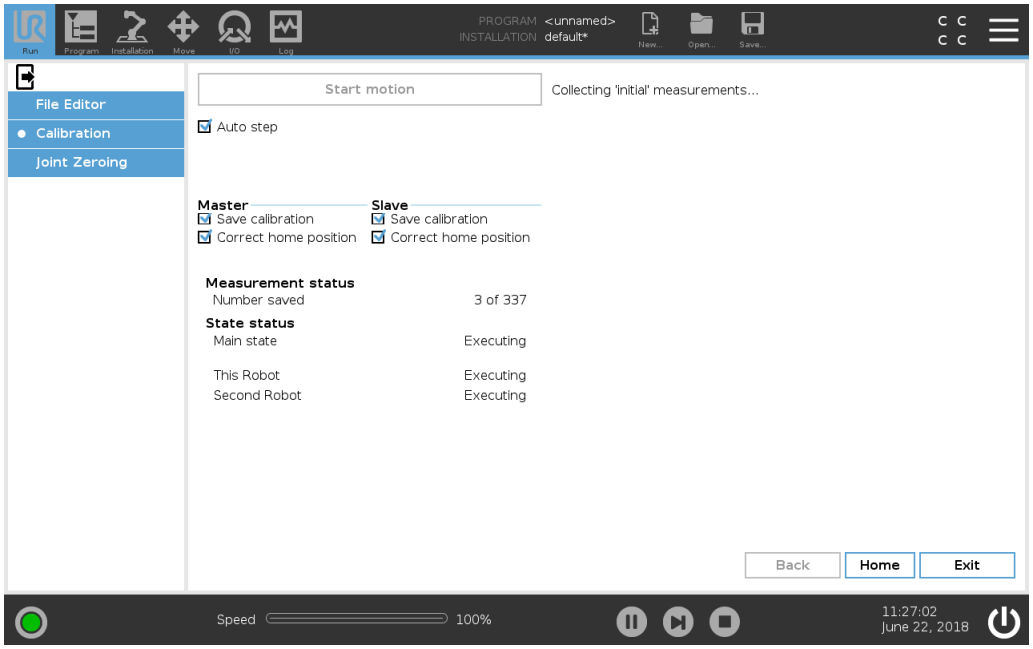
5.2. Measuring Positions and Calibration Statistics

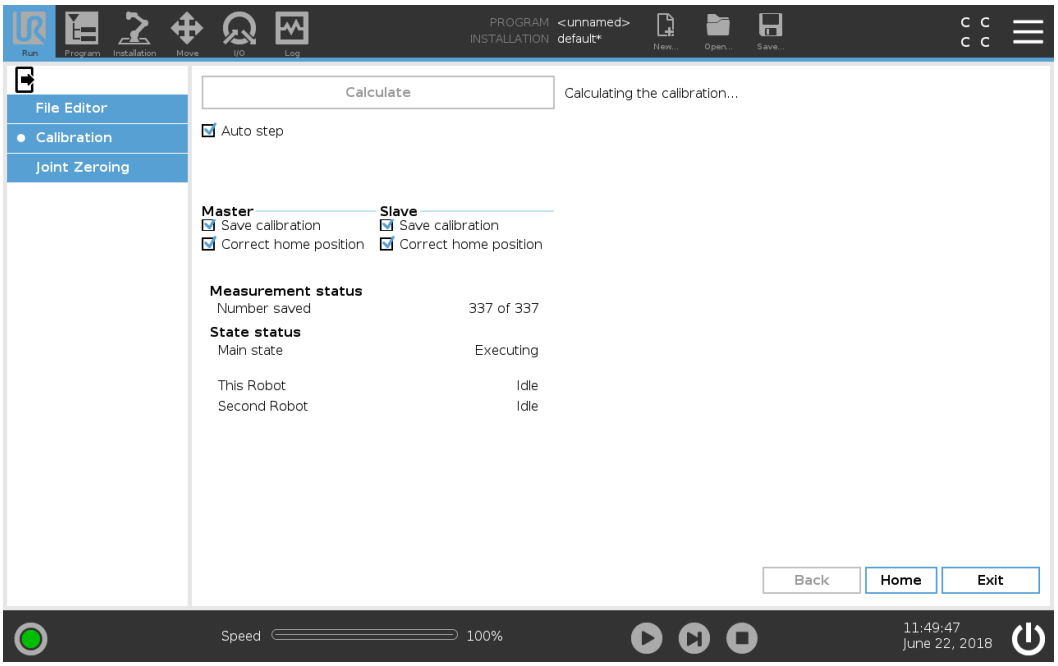
Description

Measurements are collected during dual calibration, as the robots continue to move around. A preliminary calibration is calculated, then replaced by the final calibration calculation.

Collecting the measurements



Calculating the calibration



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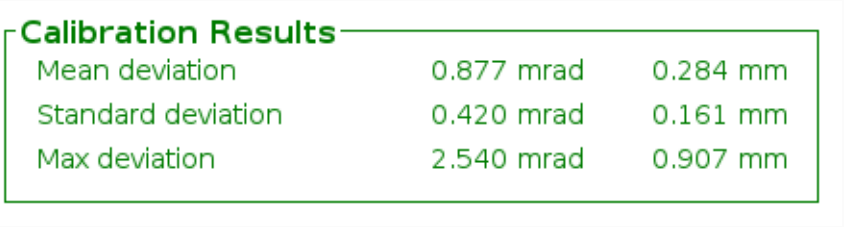
Calibration Results

At the end of the dual calibration, a Calibration Results box provides a report on the success of the calibration. If the Calibration Results box appears as green text, then the calibration was successful. If the calibration Results box appears as red text, then the calibration was unsuccessful, and the procedure continues.

NOTICE

This is an example.
The Calibration Results provide statistics in millimeters (mm) and milliradians (mrad) which refer to the RMS deviation in Cartesian Space, as follows:



- **Mean deviation**: The average deviation in millimeters and in milliradians between the positions measured by the first and second robot.
- **Standard deviation**: The standard deviation calculated on the basis of the above.
- **Max deviation**: The maximal measured deviation.

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5.3. Validating Calibrated Robots

Description

This procedure has the following success criteria:

- Both robot tool flanges are disconnected from the Calibration Connector and completely free from screws and alignment pins etc.
- The robot moves to home position.
- The robot moves to GO/noGO position.
- Go/noGO is correct and validated with tool.

NOTICE

Tapping Proceed before removing all of the screws from the Tool Connector on the Slave robot, can lead to protective stops.

- Verify all screws are removed and clear the Protective Stop/s. Once this is done, try tapping Proceed again.

CAUTION

Either robot can enter a Protective Stop while disconnecting.

- Remove the Tool Connector and jog the robots to separate the robots manually.
- When the robots are separate and the Protective Stop is cleared, the disconnection dialog box reappears on PolyScope and you can retry the step.

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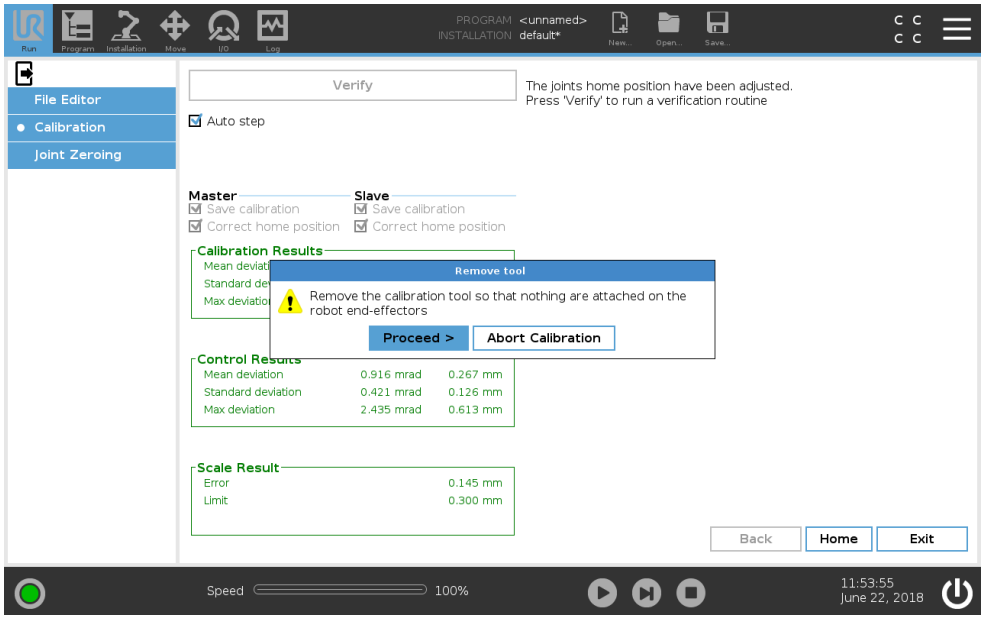
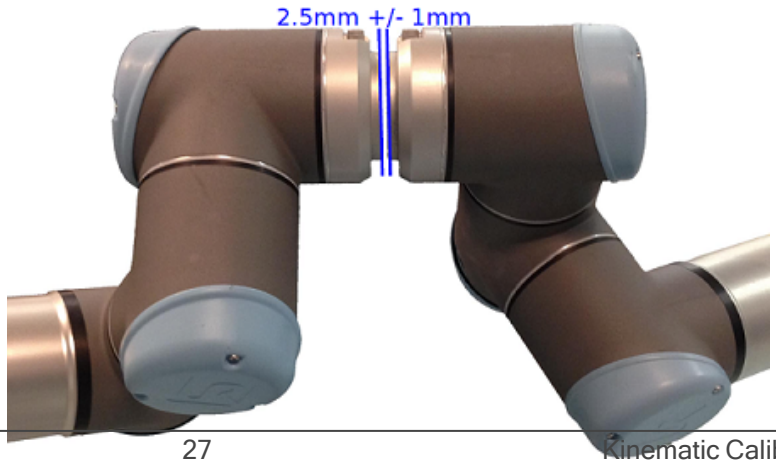
Validating Calibration Results

The results of the dual robot calibration are permanently saved after a successful validation.
When then the calibration is completed, you have to remove the connector to continue the validation.
PolyScope will prompt you to remove the screws from the slave's tool.

1. Remove the screws from the slave's tool.
2. Hit Proceed.
3. The slave robot will enter freedrive.
4. Move the robot away, so that it cannot collide with the tool.
5. Hit Proceed.
6. Remove the tool from the master's tool.



7. Hit Proceed.
8. The robots will move to home position.
9. Verify that the robots are in home position.
10. The robots will move into the *Go / NoGo* position.
11. Use the *Go / NoGo* tool to verify the distance between the tool flanges are within a distance of 2.5 mm.
    - Verify the 1.5 mm *Go* tool can pass between the robots tool flanges.
    - Verify the 3.5 mm *NoGo* tool cannot pass between the two robots tool flanges.



12. When the Verify position dialog appears, tap **Proceed** to verify the robots home position.

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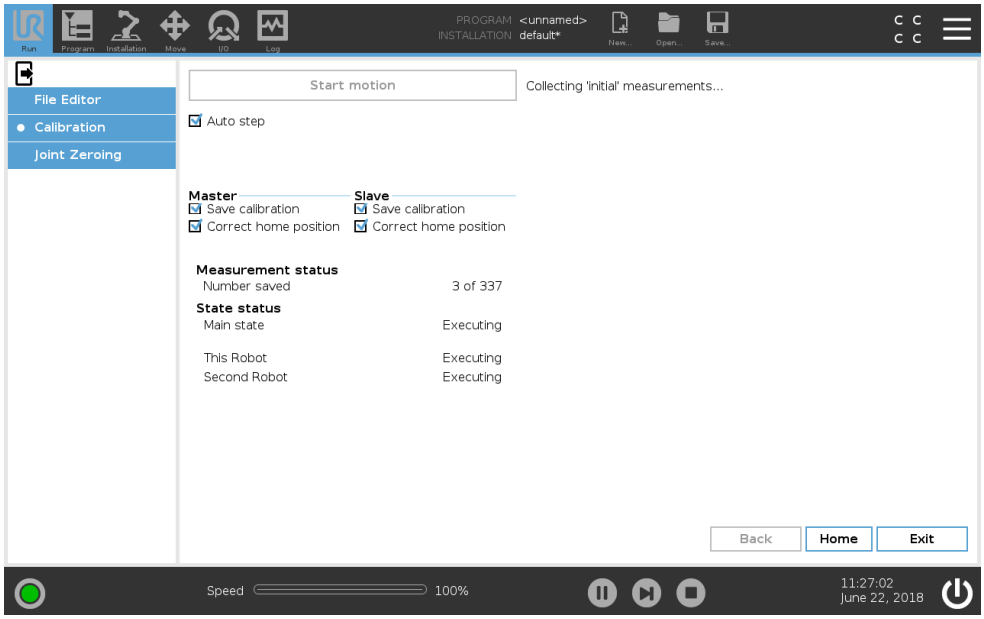
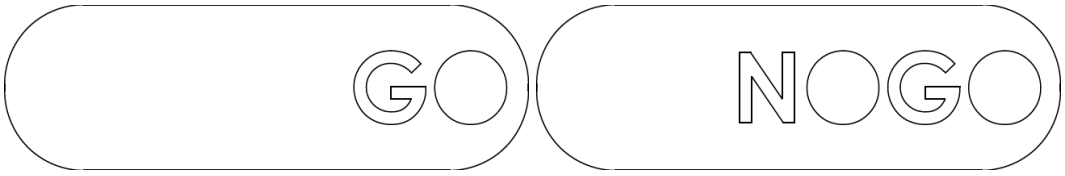
13. Save the calibration and tap **Exit**.
14. In the Header under Run, tap the **Exit** icon to exit Expert Mode.



5.4. The *Go / NoGo* Tools

Description

The *Go / NoGo* tools are two pieces of cardboard, of different thicknesses, that verify the success of the calibration. The *Go* tool passes through the space between a pair of correctly calibrated tool flanges. The *NoGo* tool cannot pass between that space.



After calibration, when the Calibration Connector is removed and the tool flanges approach each other, use the *Go / NoGo* tools to verify the distance between the tool flanges.

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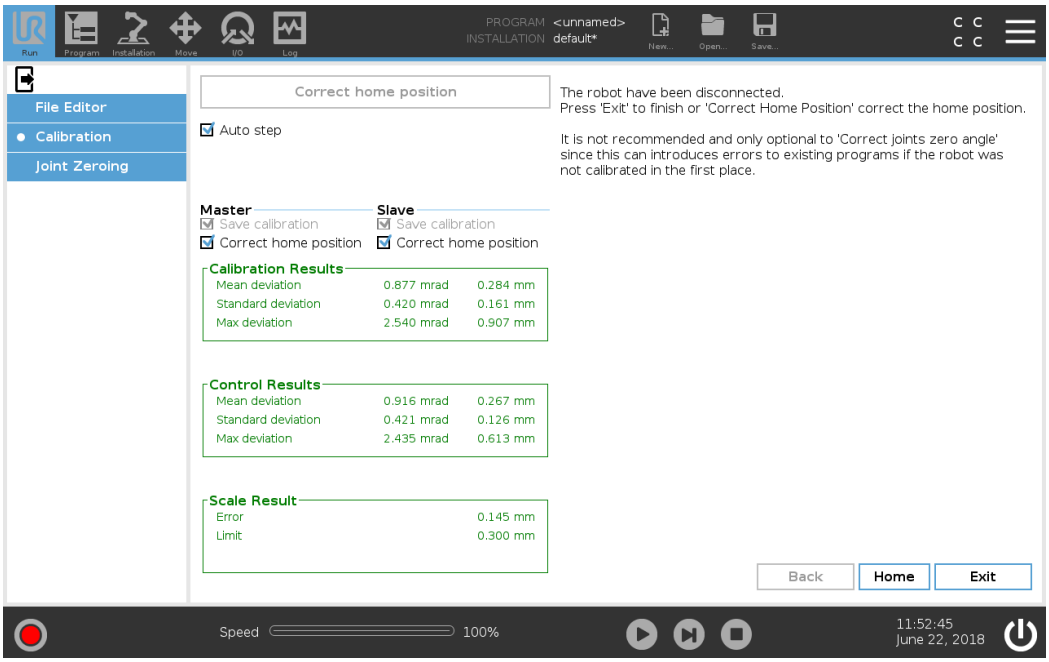
5.5. Verifying a Successful Calibration

Description

The calibration is successful if the criteria listed below are met.

- The mean deviation is less than 1 mm and 2 mrad.
- The standard deviation is less than 0.5 mm and 1 mrad.
- The difference between the Calibration Results and Control Results is no more than 50%.
- In the Scale Result, the Error value is less than the Limit value.



5.6. Troubleshooting a Failed Calibration

Description

To find solution/s for a failed calibration, you can use one or more of the troubleshooting methods listed below.

- Check security settings are set to least restricted.
- Remove the tool connector and unmount the robots from the Calibration Horse. Clean all surfaces on the robots, the Calibration Horse and the tool connector. Remount the robots while making sure that nothing is stuck between the parts.
- If one or more joints have been replaced, check that they are mounted correctly. For example, check the screw washers are on the correct side of the output flange.
- If one or more joints have been replaced, adjust the joint's zero position (see the Service Manual).

Start a new calibration when you finish the troubleshooting method/s.

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5.7. Resetting a Calibration

Description

You can manually reset or adjust a calibration by editing the following file: root/.urcontrol/calibration.conf

1. You can go to the console by pressing CTRL+ALT+F1.
2. Navigate to the folder with the calibration file.

Edit file

Before editing the file, backup your original calibration file by saving it under a different name.
To reset the calibration

1. Set all numbers in delta arrays to zero and increase file_save_count by one.
2. Then reboot the robot to apply the changes.

The example below illustrates a case where all numbers in the delta arrays to zero.

```
[mounting]
delta_theta = [ 0, 0, 0, 0, 0, 0]
delta_a = [ 0, 0, 0, 0, 0, 0]
delta_d = [ 0, 0, 0, 0, 0, 0]
delta_alpha = [ 0, 0, 0, 0, 0, 0]
joint_checksum = [ 0xb86d04a5, 0x8d29526e, 0x21a274b7, 0x5134a655, 0xc44d7e89,
    0x1be4dbeb]
calibration_status = 2 # 0 == notInitialized / 1 == notLinearised / 2 == Linearised
joint_raw_offset = [ 0.1, -.81973522672052201e-05, 3.81973522672052201e-05,
    .81973522672052201e-04, 0, 1.3]
joint_selftest_data_crc = [ 0xfd8c0ed6, 0x9c3bef33, 0xfcca0113, 0x3ddc1b38, 0xad3f2781,
    0x848b8665]
file_save_count = 2
```

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6. Tool Drawings

Description

There are two different mounts for calibration.

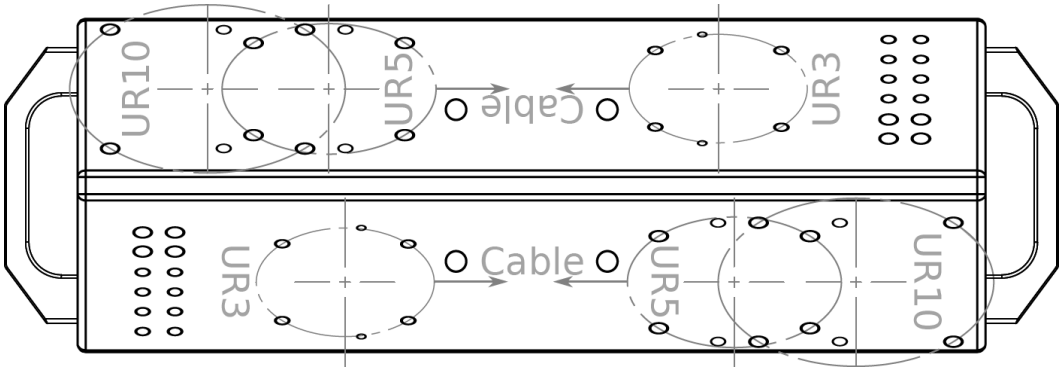
- purchase number: 185500
- purchase number: 200977

Calibration kit (185500) is with a smaller calibration horse and can be used with the following robots:
All e-Series robots.

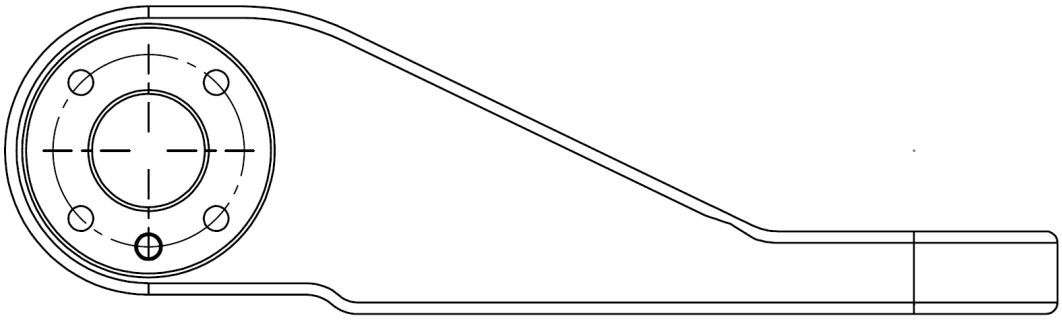
Calibration kit (number: 200977) is with a larger calibration horse and can be used with the following robots:
UR10e, UR16e and UR Series robots.

Calibration Horse (185500) Only e-Series

The UR3e and the UR10e robot arms are mounted in different positions.



Calibration Connector (185500) Only e-Series



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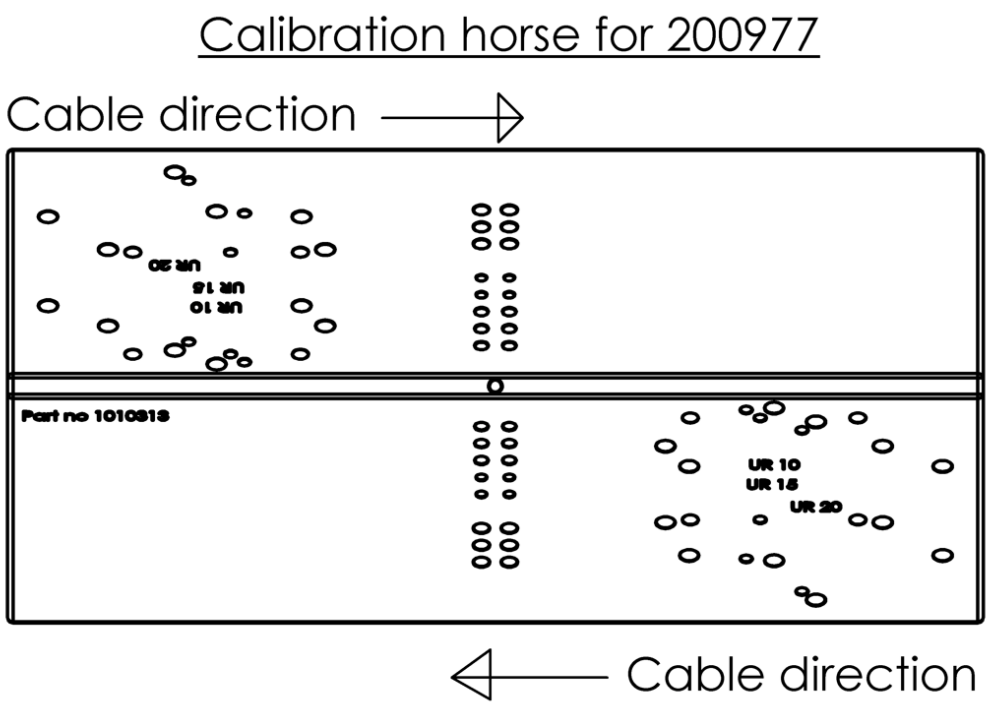
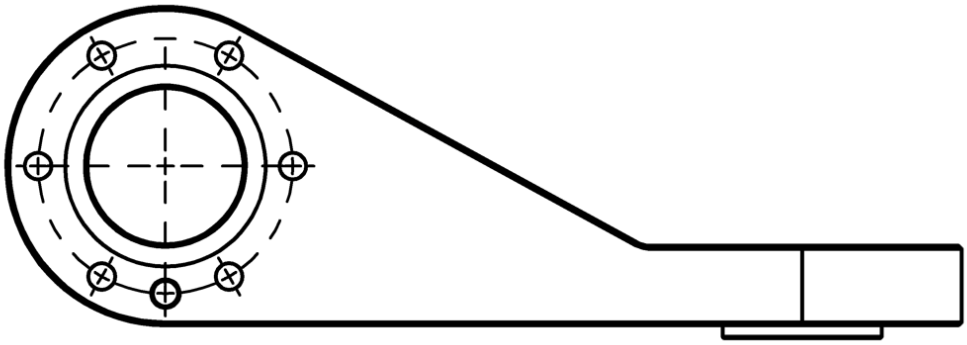
Calibration Horse (200977) UR10e, UR16e and UR Series



Calibration Connector (200977) UR10e, UR16e and UR Series



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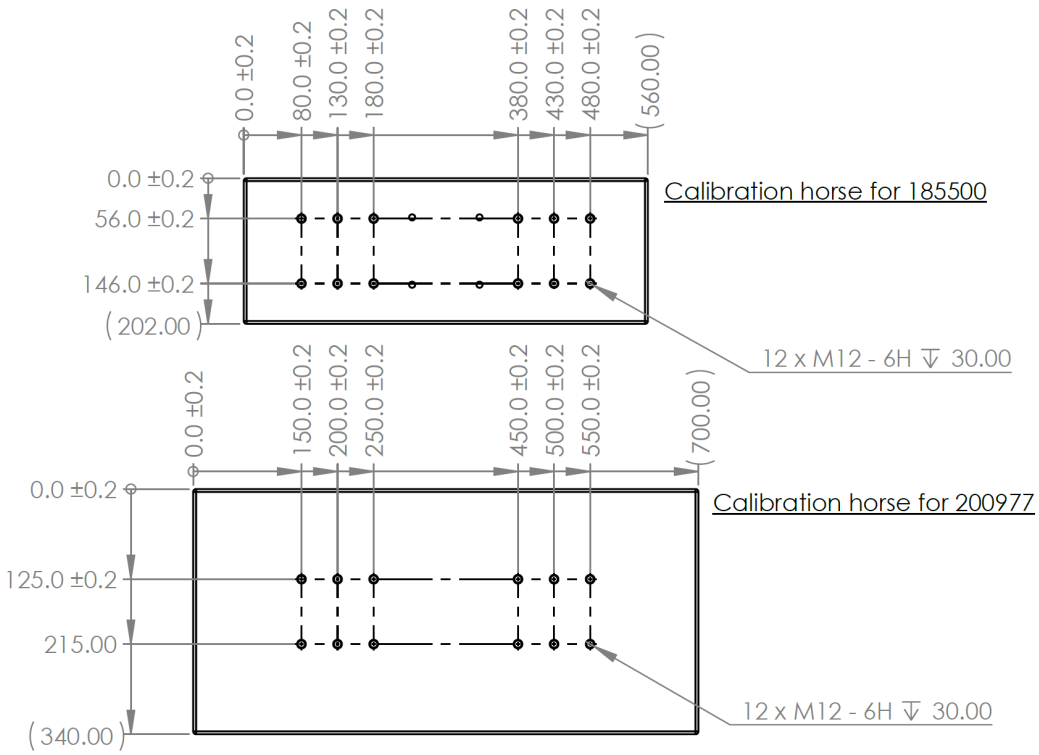
7. Drill Holes for Horse Mounting

Drawing



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8.1. Calibration And Programming of Robots Patent

Description

The Dual Robot Calibration method is covered by one, or more, of the following patents:

- CN103889663 B
- CN104991518 B
- EP2760642 B1
- EP2796249 B1
- JP6182143 B2
- MX343142 B
- RU2605393 C2
- US9248573 BB
- US9833897 BB

The Dual Robot Calibration method is also covered by one, or more, of the following patent applications:

- BR112014007077 A2
- SG10201502615Q A1
- SG11201400923Q A1
- TH141798 A

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