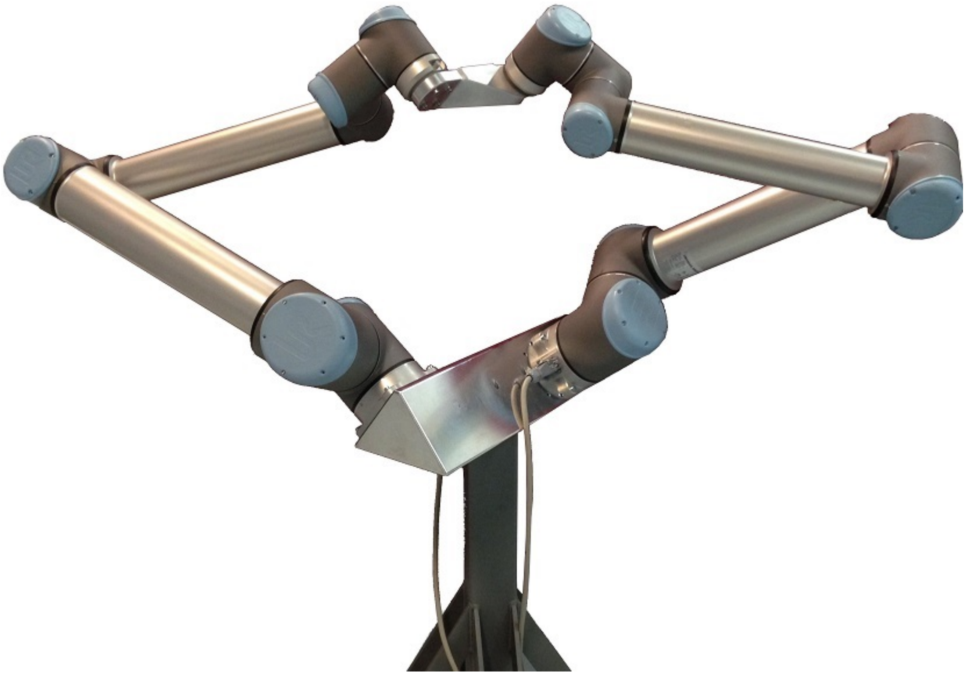
UNIVERSAL ROBOTS



Kinematic Calibration

User Manual

Compatible robots: UR3e, UR5e, UR10e, UR16e

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1. Introduction

1.1. About this document

This document describes how to set up and do Dual Robot Calibration on Universal Robots e-Series robots with the e-Series Control Box. 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.

1.2. What's in the box

The box contains the following parts:

- The Dual Robot Calibration kit
    - Calibration Horse with alignment pins
    - Calibration Tool Connector with alignment pins
    - Four M8-1.25x70 screws with washers
    - Eight M8-1.25x25 screws with washers
    - Eight M6-1.0x25 screws
    - Eight M6-1.0x25 screws
    - *Go* / *NoGo* tools
- This document

1.3. Terminology and abbreviations

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

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

1.4. Company Details

Universal Robots A/S

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https://www.universal-robots.com

2. Safety

2.1. Safety Message Types

2.2. General safety precautions

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

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.

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.

2.3. Dual Calibration safety precautions

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.

3. Dual robot calibration: Preparation

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

3.1. Required items

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

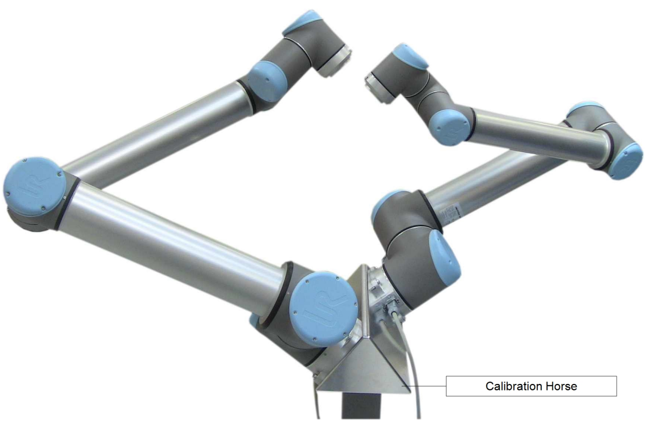
- Two Universal Robots e-Series robots of the same type and software version
- A Calibration Horse
- A 0.5 m stand for the Calibration Horse
- A network cable
- A Dual Robot Calibration kit (purchase number: 185500)

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.

3.2. The Calibration Horse

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.



3.3. How to mount robot arms to the Calibration Horse

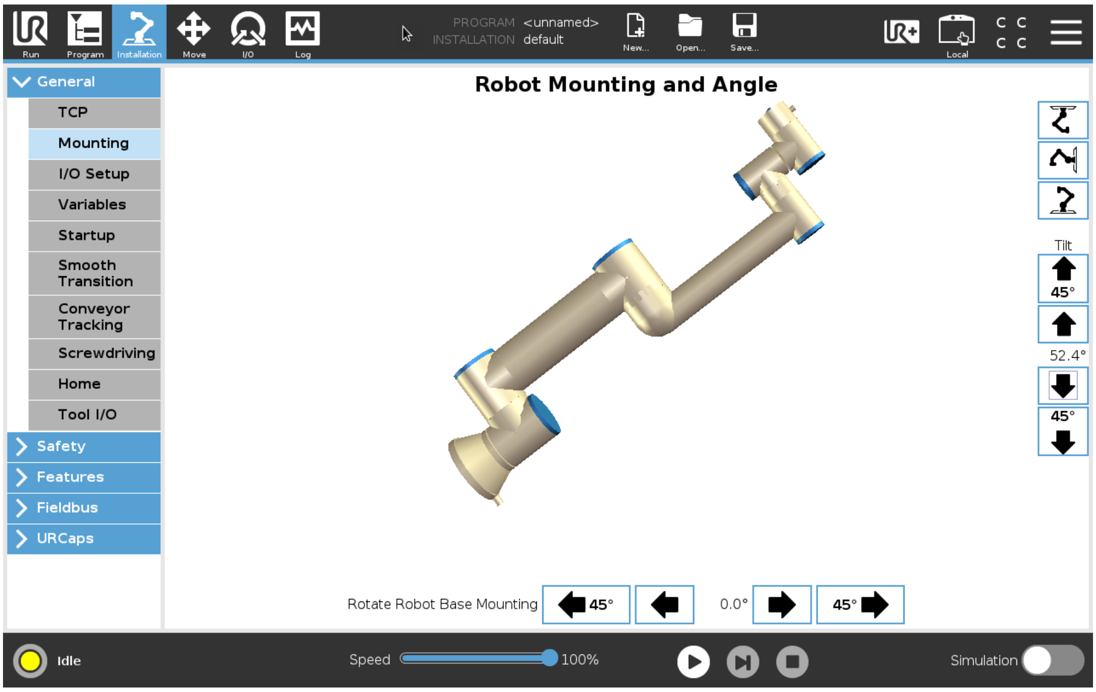
This procedure requires the following criteria for success:

- Mount the robots at approximately 52.5°
- Use a custom installation before activating the robots.

To mount each robot arm

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.



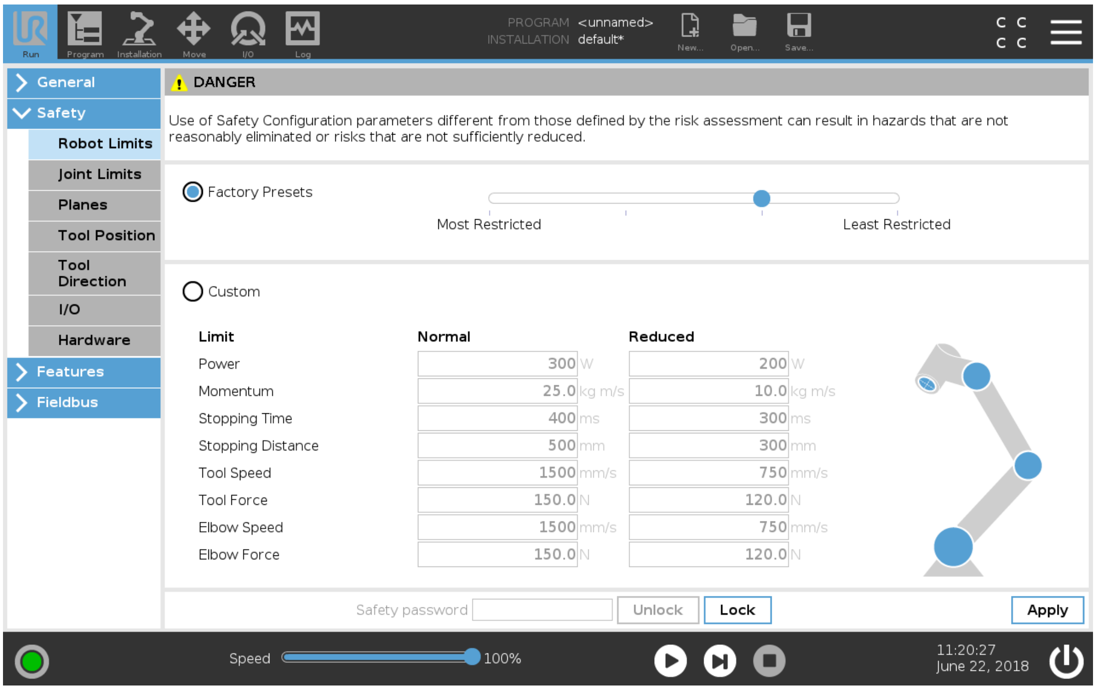
To configure the mounting software

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.

Robot size	Tilt	Rotate Robot Base Mounting
UR3e	52.5°	270°
UR5e	52.5°	90°
UR10e	52.5°	90°
UR16e	52.5°	90°

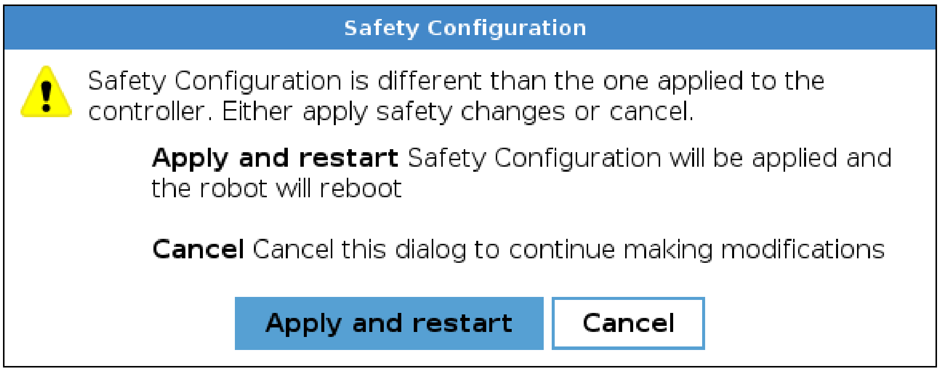
3.4. How to prepare robot safety settings

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



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

Select a method, based on your connection type.

- Method 1 Manual: hen 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

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.

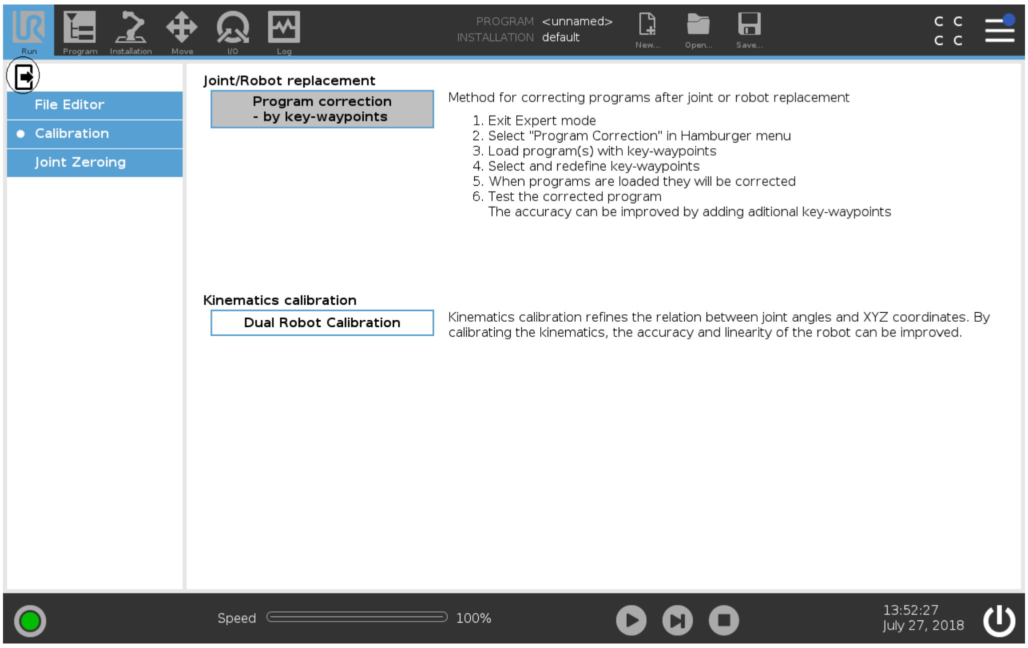
Connecting the Manual network (Method 1)

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

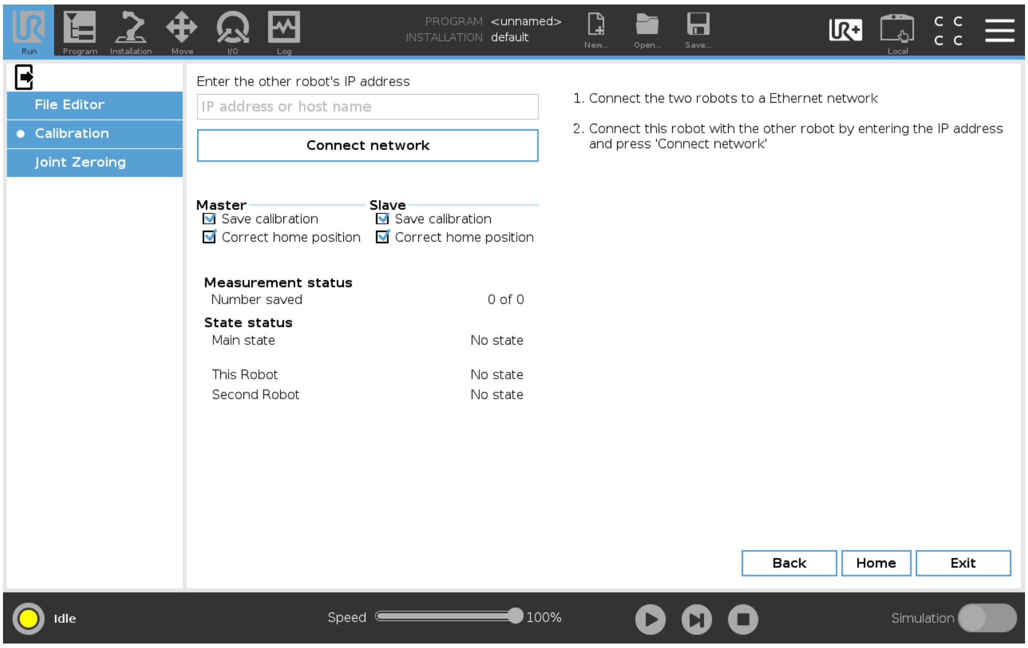
Network connection type	Definition
Master	The main robot in the calibration process. Uses a single cable.
Slave	The subordinate robot in the calibration process.
Manual	A Master robot is selected and a Slave robot selected by a user supplied IP-address.

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.



3.5.2. Method 2: Master/Slave connection

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.

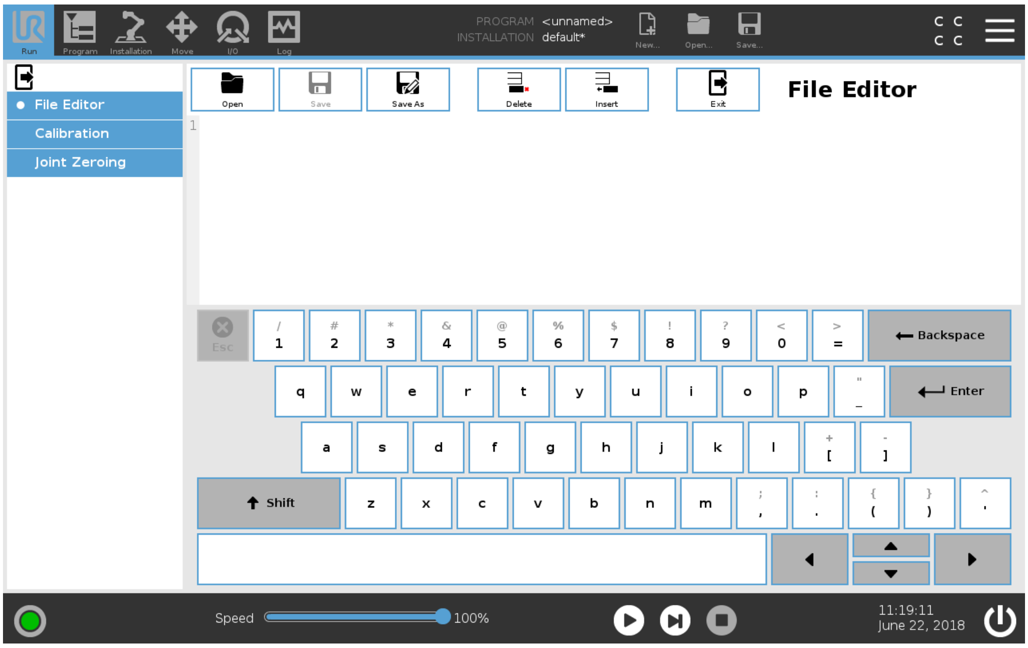
Connecting the Master / Slave network (Method 2)

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

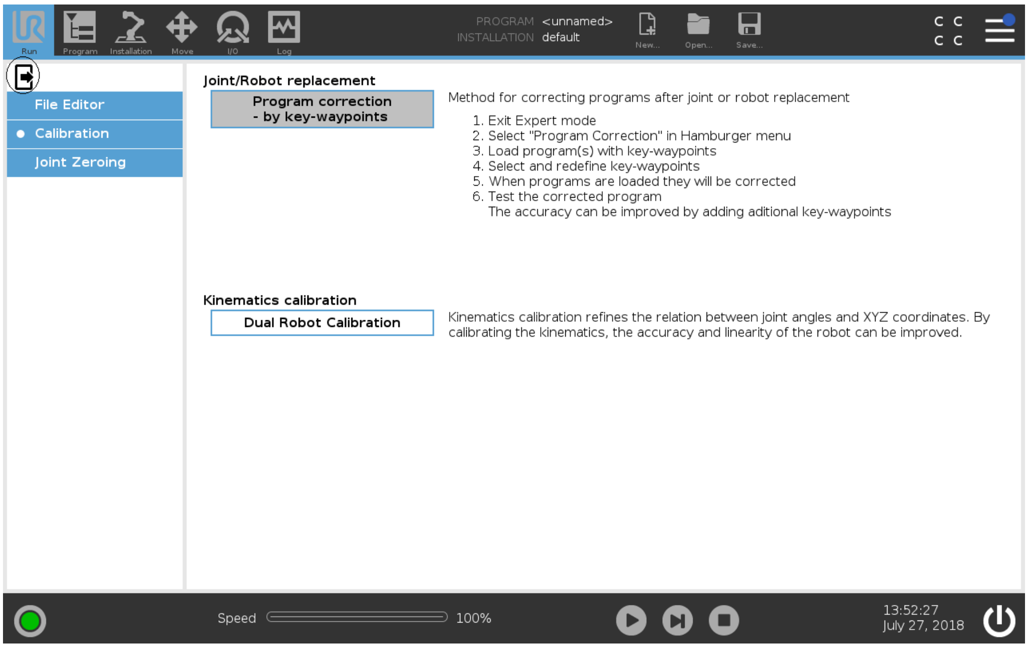
Network connection type	IP Address
Master	10.17.17.18
Slave	10.17.17.19

To connect the Master / Slave network

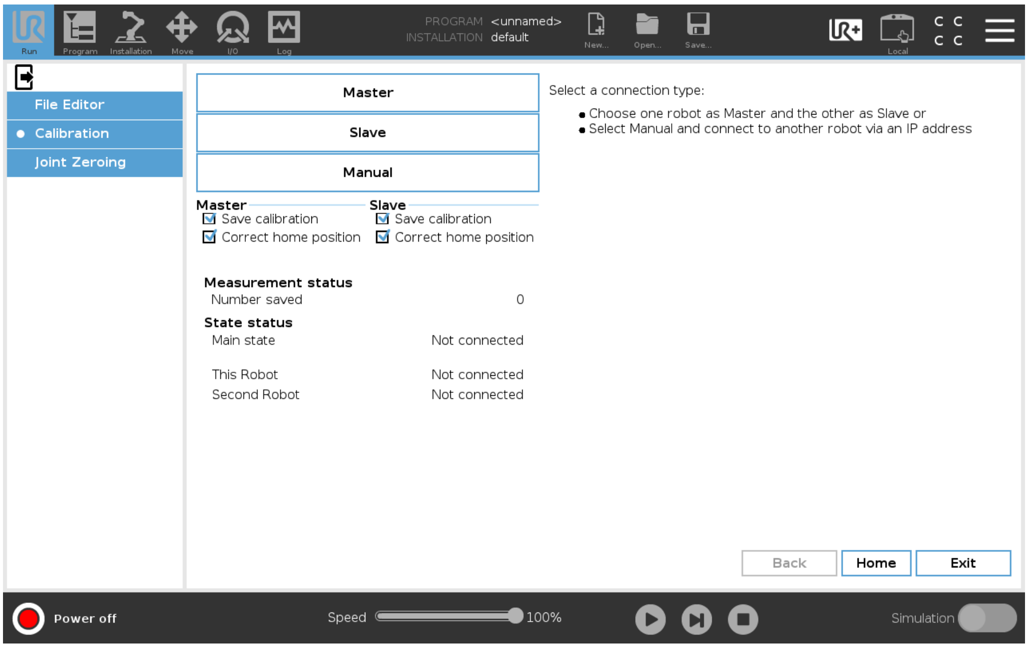
1. Use a network cable to connect the Ethernet ports of the two robot Control Boxes.
2. On PolyScope, in the Header, hold down **Run** to access Expert Mode.
3. Enter the password: `lightbot` and tap **OK**.



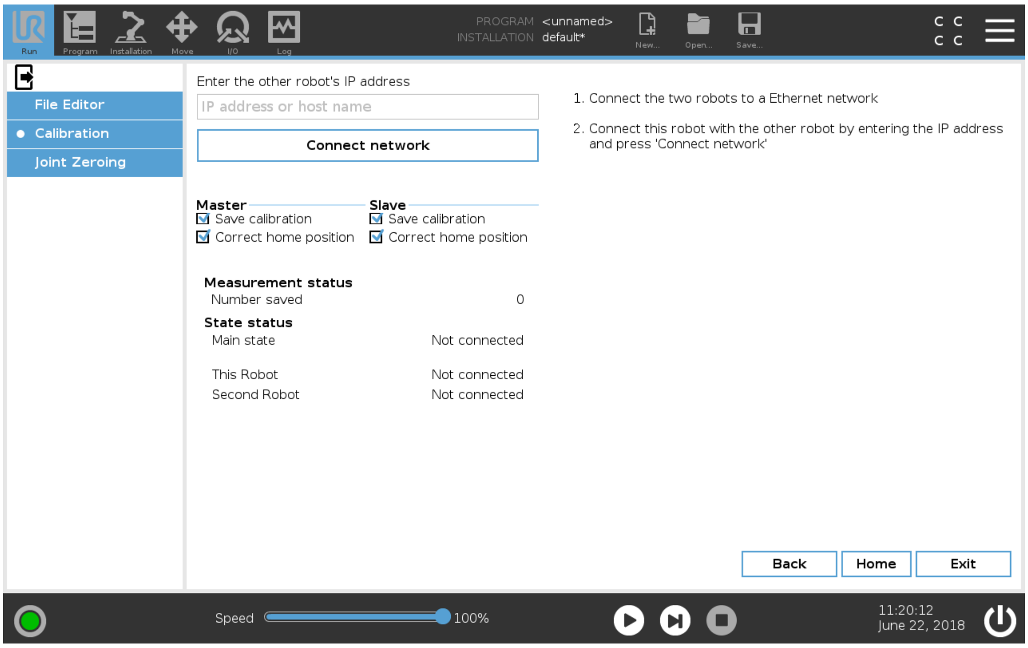
4. Under **Kinematics calibration**, select **Dual Robot Calibration**.



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.



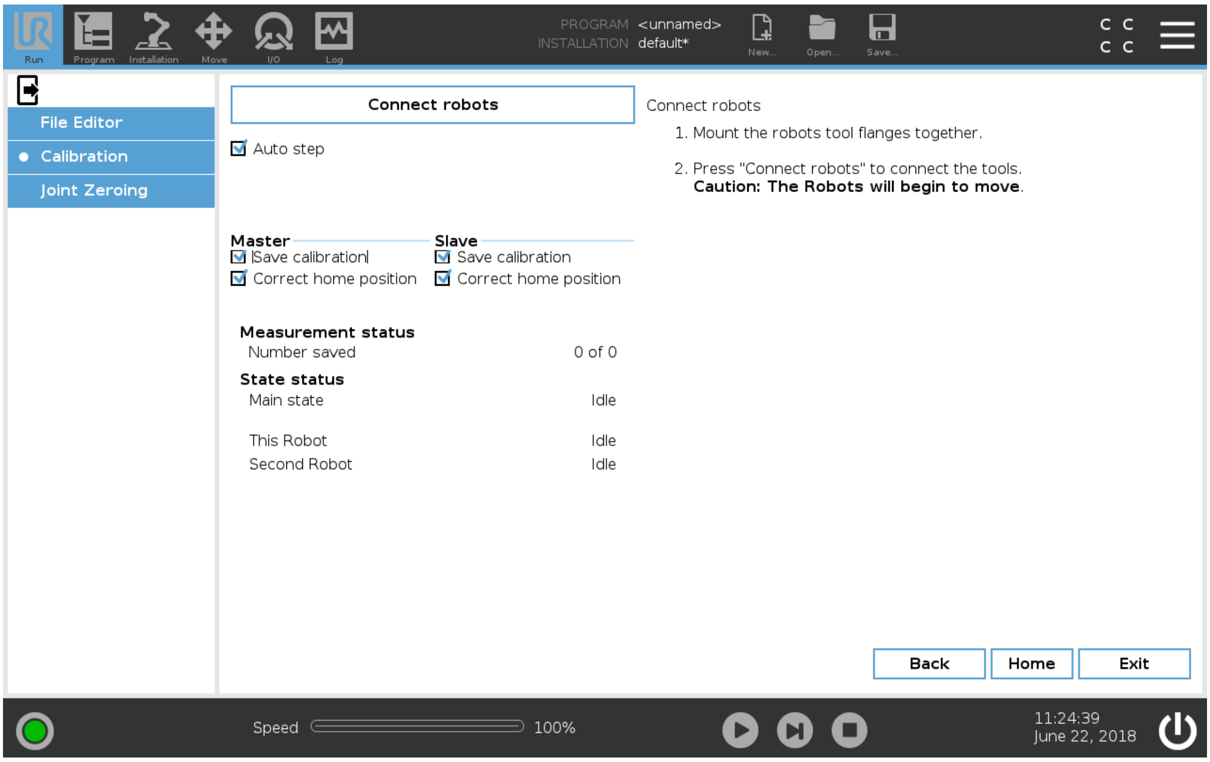
3.6. How to attach the Calibration Connector

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

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.

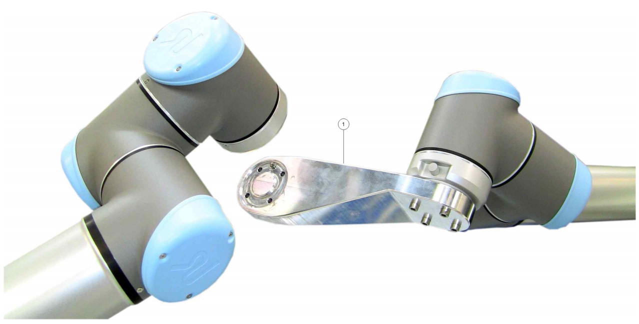
3. When the robots return to home position, attach the Calibration Connector to the designated Master robot.
4. Tap **Proceed** in the pop-up.
5. Tap **Connect Robots**.



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:



1	Calibration Connector attached to the Master robot's tool flange (step 2).	2	Calibration Connector attached to the Master robot's tool flange and the Slave robot's tool flange (step 5).

4. Dual robot calibration: Application

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

4.1. How to calibrate the robots

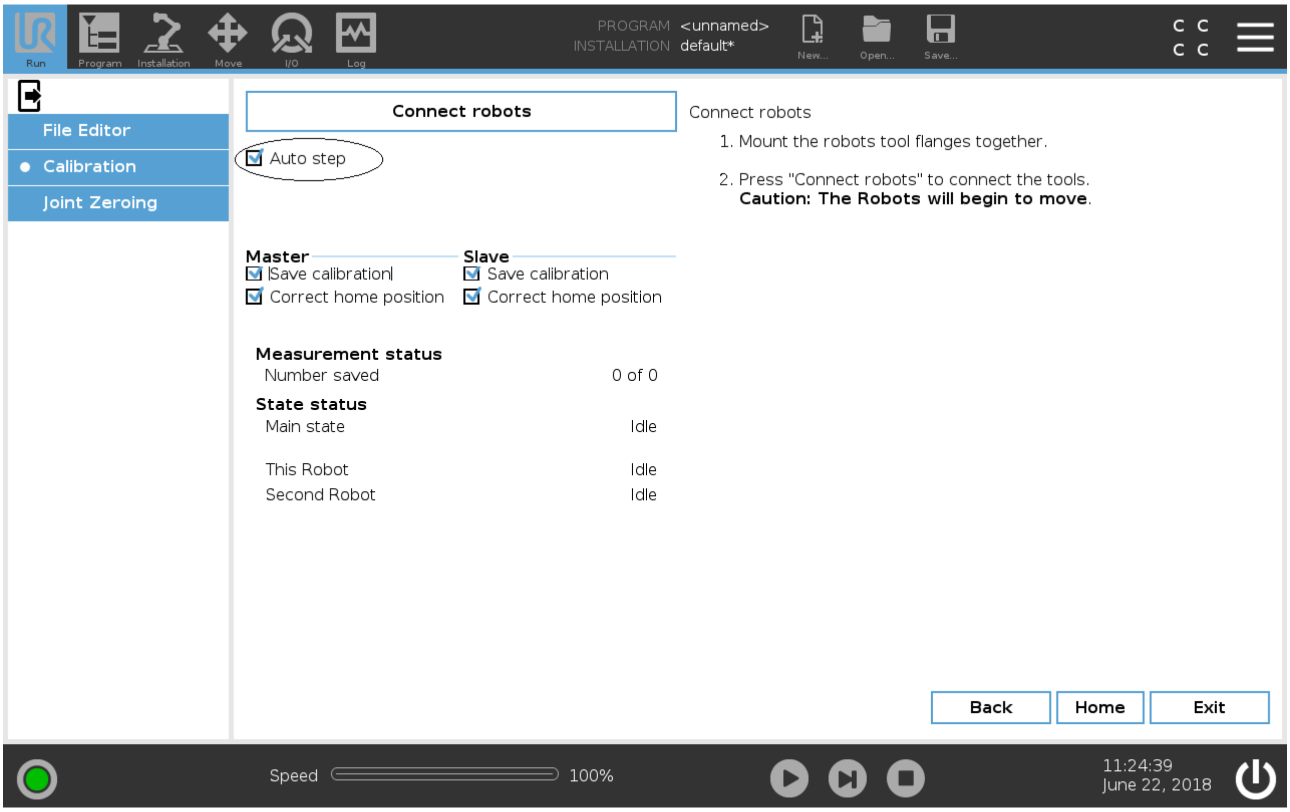
Dual calibration is performed automatically, so you only need to start the process.

You can select the following options, for each robot before the calibration starts:

- **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).

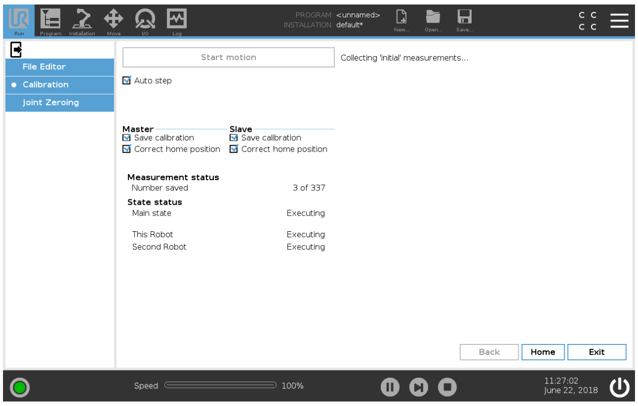
To start the calibration

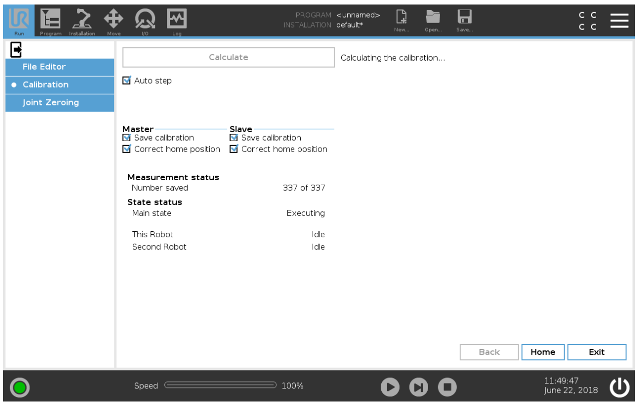
1. Ensure the Calibration Conector securely attaches both tool flanges.
2. If operator intervention is required during the calibration, you can disable the **Auto step** checkbox.
3. Tap **Proceed** and stand clear of the robots, as they start moving around.



4.2. Measuring positions and calibration statistics

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.





1	Collecting the measurements	2	Calculating the calibration

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.

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

Calibration Results

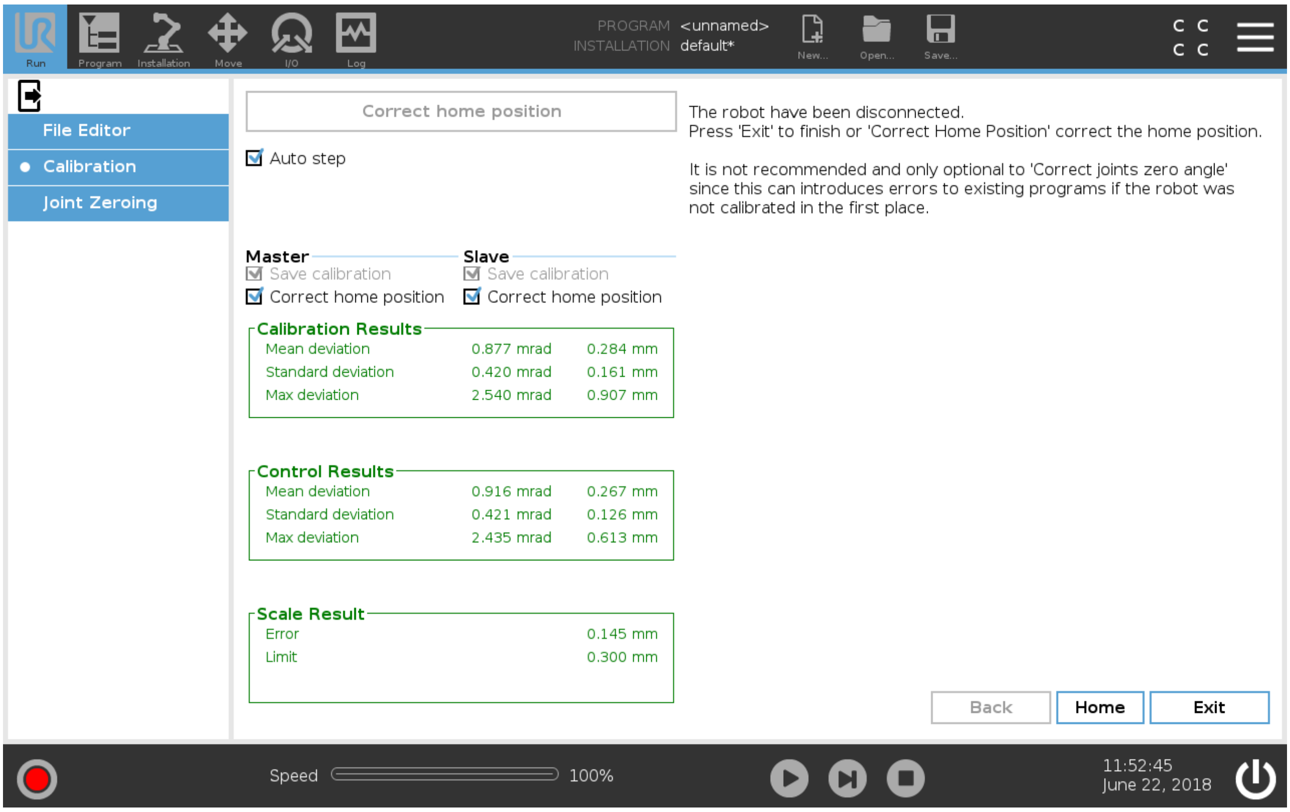
Mean deviation	0.877 mrad	0.284 mm
Standard deviation	0.420 mrad	0.161 mm
Max deviation	2.540 mrad	0.907 mm

- **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.

4.2.1. Verifying a successful calibration

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 mmand 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.



4.2.2. Troubleshooting a failed calibration

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.

4.3. Separating calibrated robots

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.

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.

4.3.1. To separate the calibrated robots

1.
2.

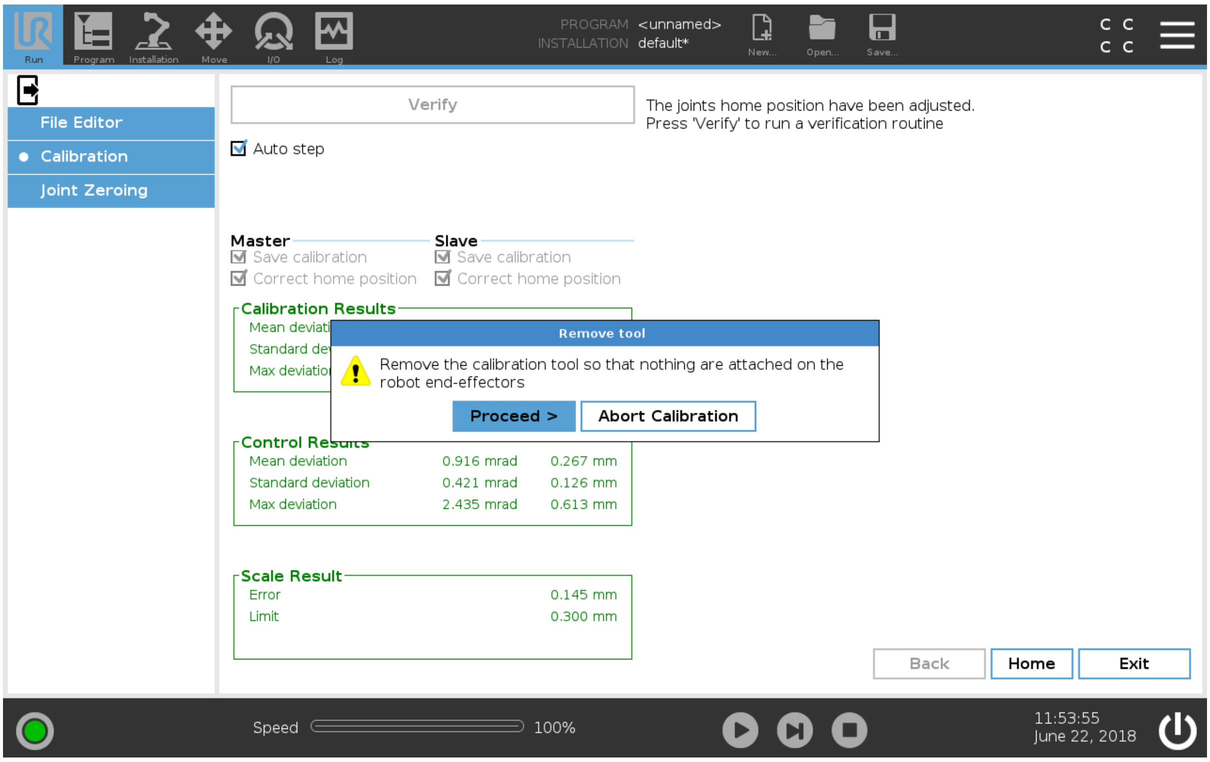
> **NOTICE**
>
> Tapping Proceed before removing all of the screws from the Tool Connector on the Slave robot, can lead to protective stops.
>
> - Verify all screws are removed and clear the Protective Stop/s. Once this is done, try tapping Proceed again.

4.4. Validating calibration results

The results of the dual robot calibration are permanently saved after a successful validation.

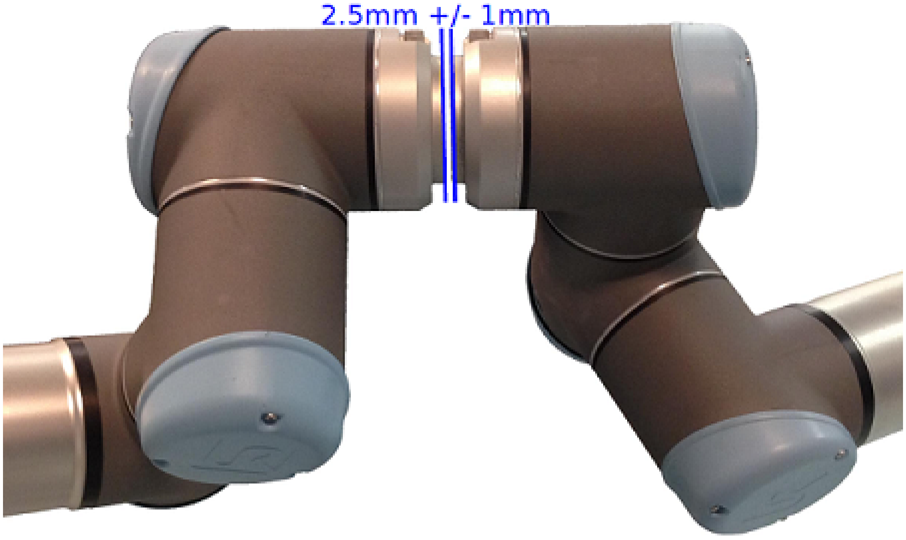
To validate a calibration

1. When the Remove tool box appears, the validation is successful. Tap **Proceed** and remove the Calibration Connector.

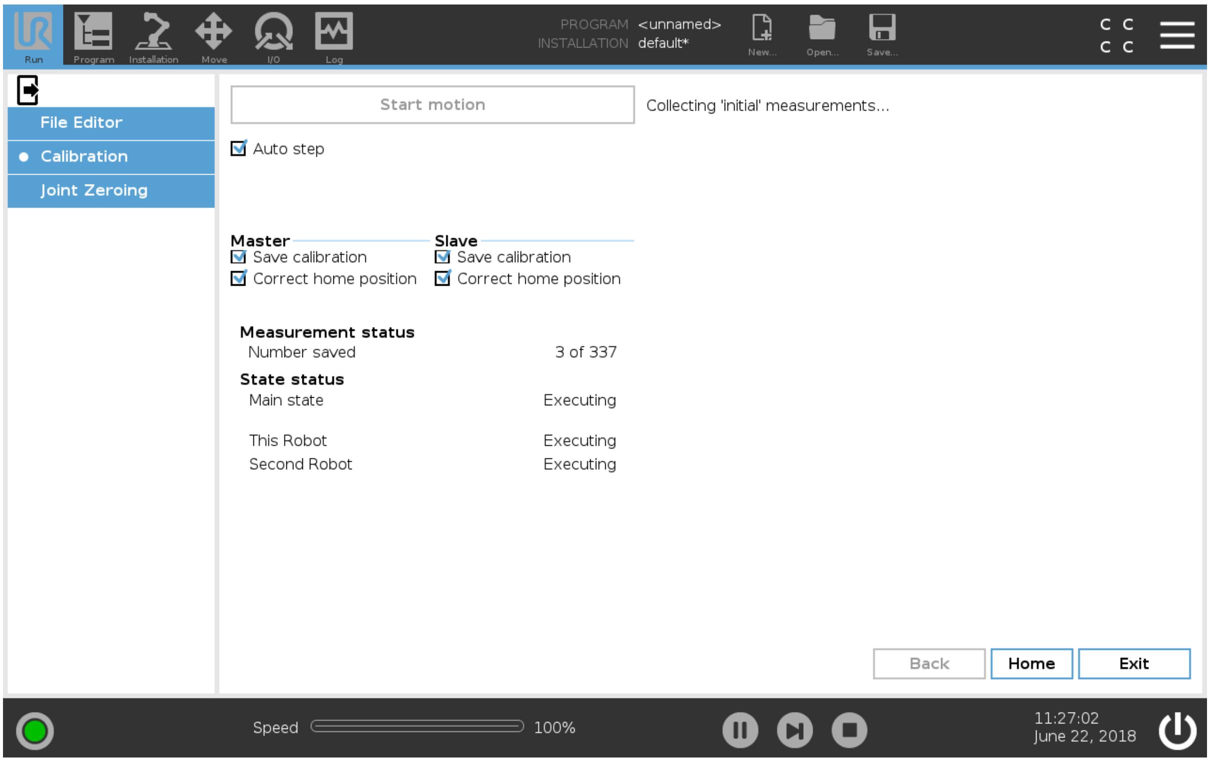


2. Remove the Calibration Connector and all alignment pins and screws.
3. Use the *Go / NoGo* tool to verify the distance between the tool flanges are within a distance of 2.5 mm.

- 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.

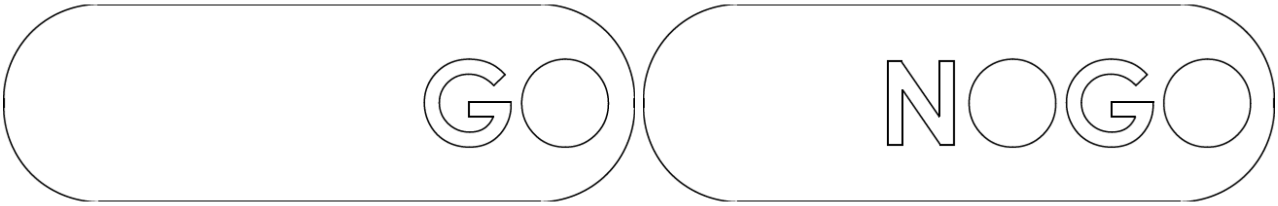


4. When the Verify position dialog appears, tap **Proceed** to verify the robots home position.
5. Save the calibration and tap **Exit**.
6. In the Header under Run, tap the **Exit** icon to exit Expert Mode.



4.4.1. The *Go / NoGo* tools

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.

4.5. Resetting a calibration

You can manually reset or adjust a calibration by editing the following file:

root/.urcontrol/calibration.conf

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
```

5. Automatic program correction

This section describes how to correct a program automatically. Program correction uses key waypoints to allow a single program to work when moved from one uncalibrated robot to another.

Key waypoints make up a model that corrects the loaded program on a new robot. The model is specific to each installation file on the robot.

The quality of the model is detemined by the following:

- The number of key waypoints.
- The accuracy of the key waypoints.
- The distance betweeen each key waypoint.

You can also use program correction after a robot joint replacement.

> **NOTICE**
> Automatic program correction currently only supports fixed waypoints. Other waypoints types are not supported.

> **NOTICE**
> You can manually correct any unsupported program nodes when the automatic program correction is complete.
> Automatic program correction currently does not support:
> - Move nodes with Use Joint Angles selected
> - Palletizing

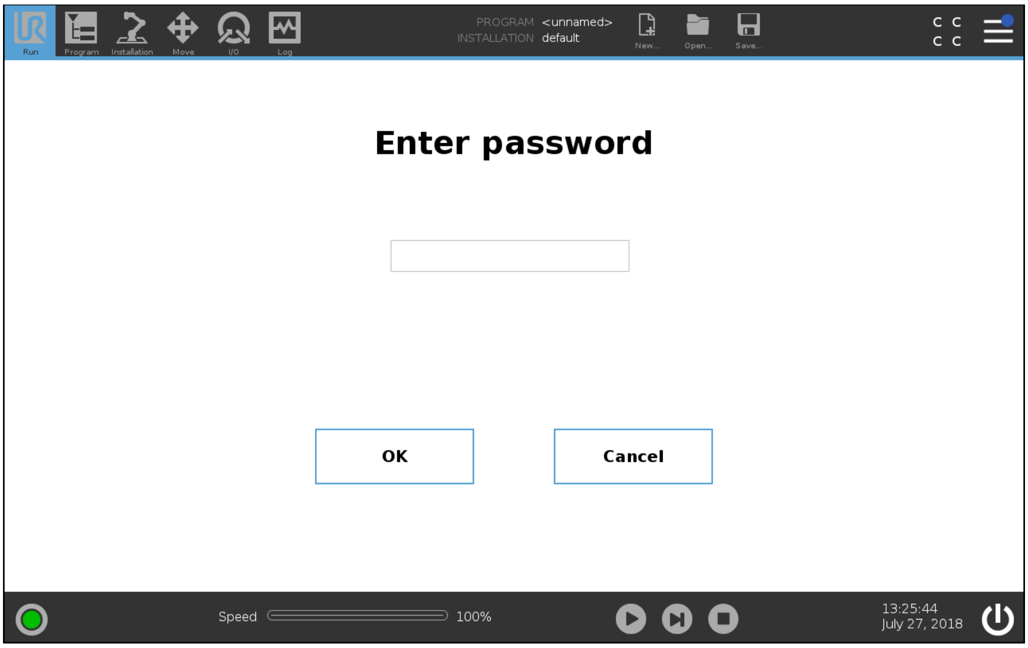
5.1. Accessing the Correction model

This section describes how to access the Correction model by enabling Program Correction.

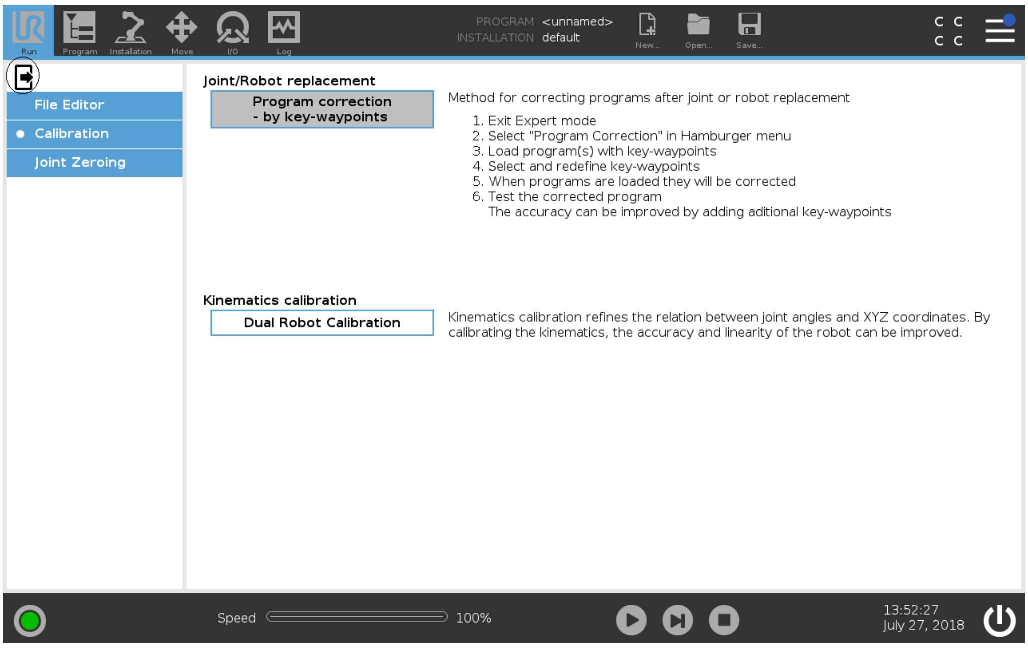
> **NOTICE**
> A saved, corrected program cannot be edited or re-corrected.
> - Backup and save your original program.

To access the Correction model

1. On PolyScope, in the Header, press and hold **Run** to access Expert Mode.
2. Enter the password: *lightbot* and tap **OK**.



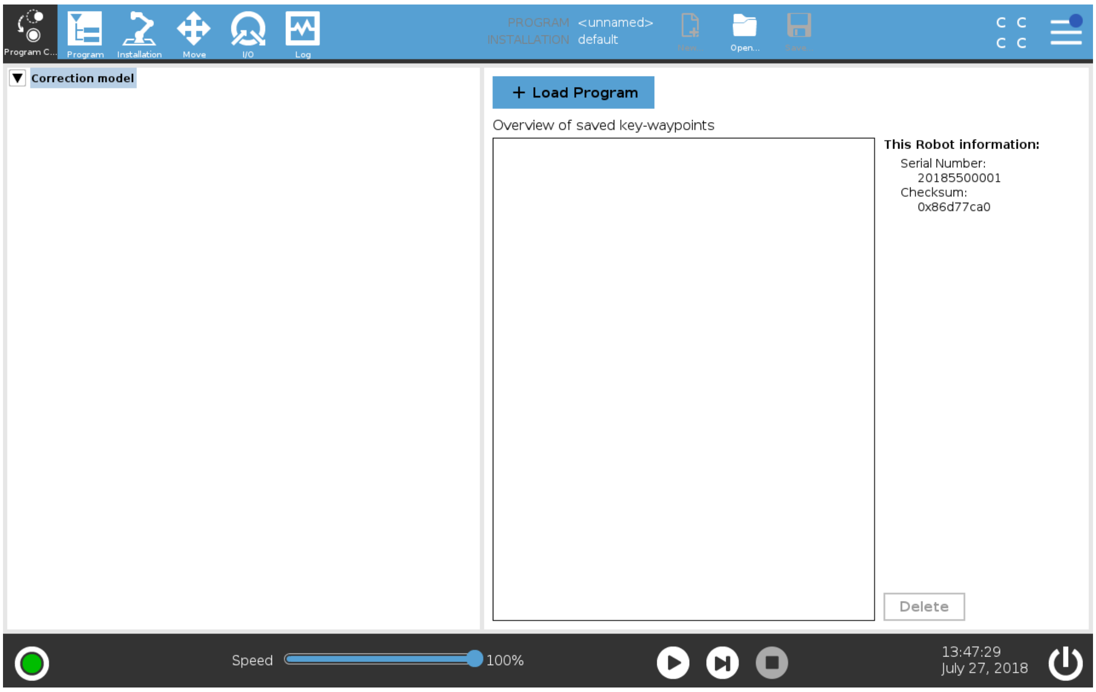
3. In the side menu, select **Calibration** and, under Joint/Robot replacement, tap **Program correction by key-waypoints**.
4. Tap the exit button under Run to exit Expert Mode.



5. In the Header, tap the **Hamburger Menu** and select **Program Correction**.
6. Enter the password: *lightbot* again to access the Correction model node on the **Program Correction** screen.

5.2. Redefining key waypoints

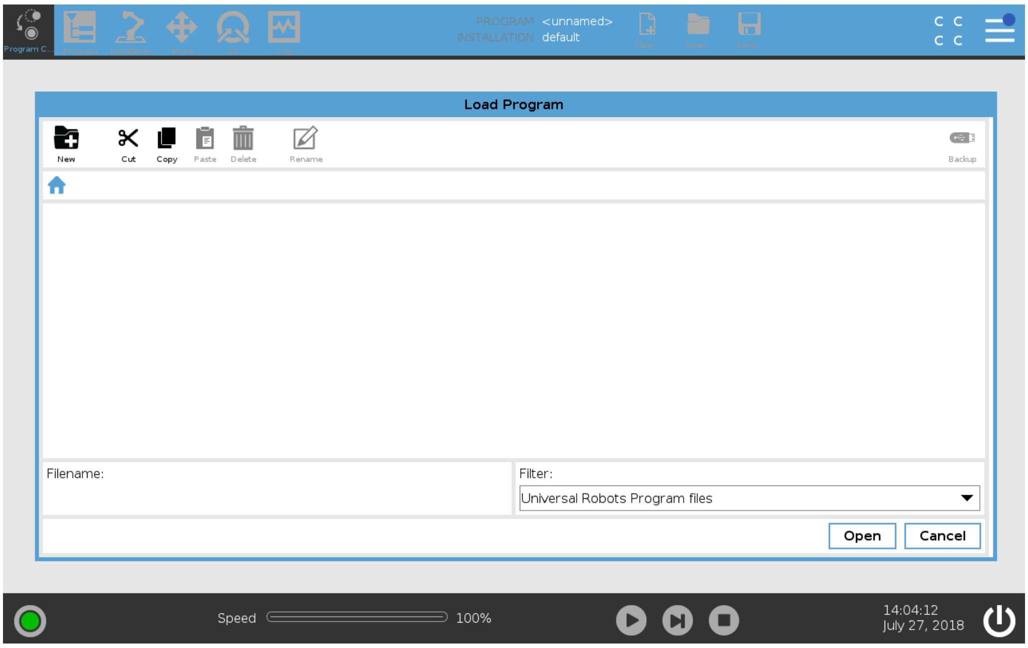
This subsection illustrates an example of a simple Pick and Place program, to describe how to redefine a key waypoint.



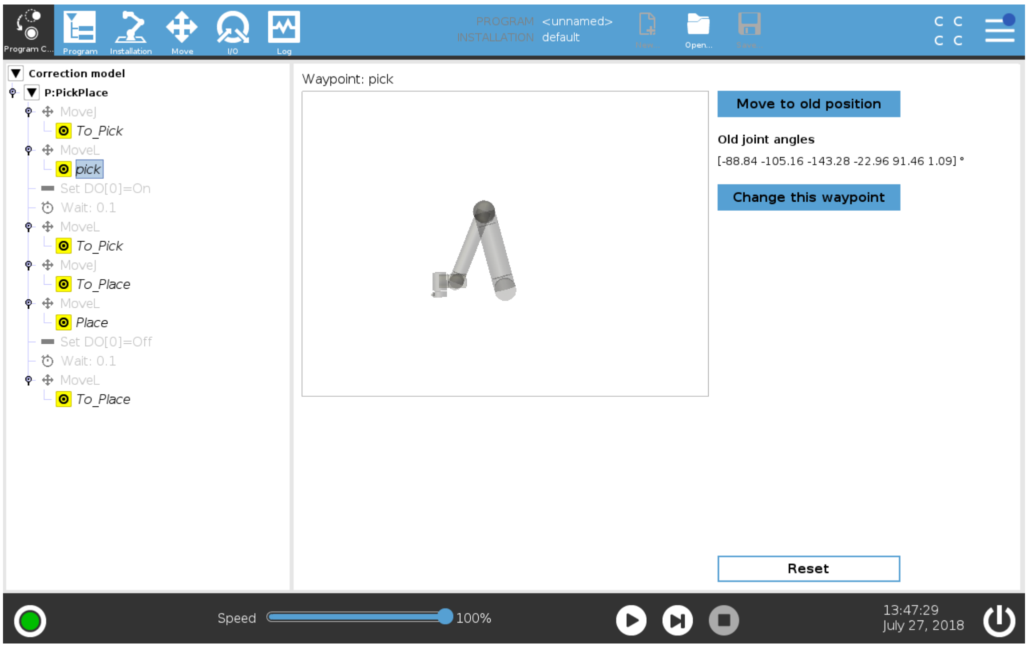
To redefine a key waypoint

1. Tap **Load Program** and select a program to load into the **Correction Model**, to create a correction model program tree.
2. In the new correction model program tree, select one of the key waypoints.

   The waypoints in the Correction Model tree that are not re-taught are displayed in italics with the undefined waypoint icon.



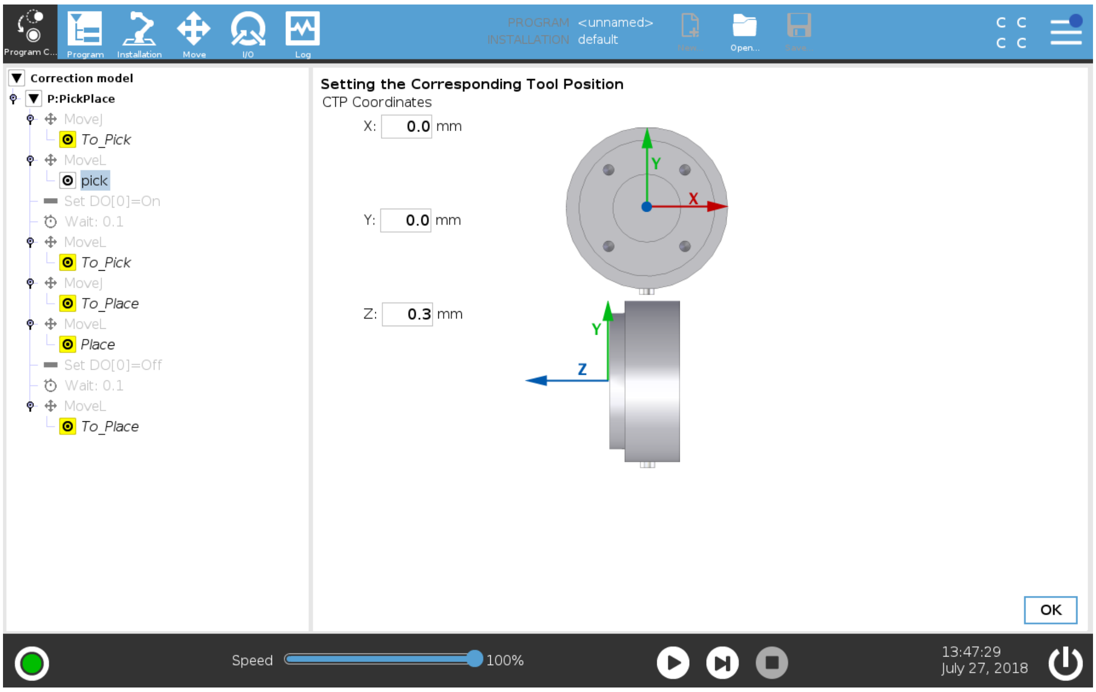
3. Tap **Change this waypoint** to redefine the configuration for the selected waypoint.
4. When the Move Tab is activated, teach the robot a new position and tap **OK**.



5.2.1. Using the Corresponding Tool Position (CTP)

The CTP is the endpoint of the robot with, or without, picked objects. The CTP improves the accuracy of the correction by redefining the waypoint and defining individual key waypoints.

Typical CTP locations include: The Tool Center Point (TCP) where the object is picked and the end point where the object is placed.

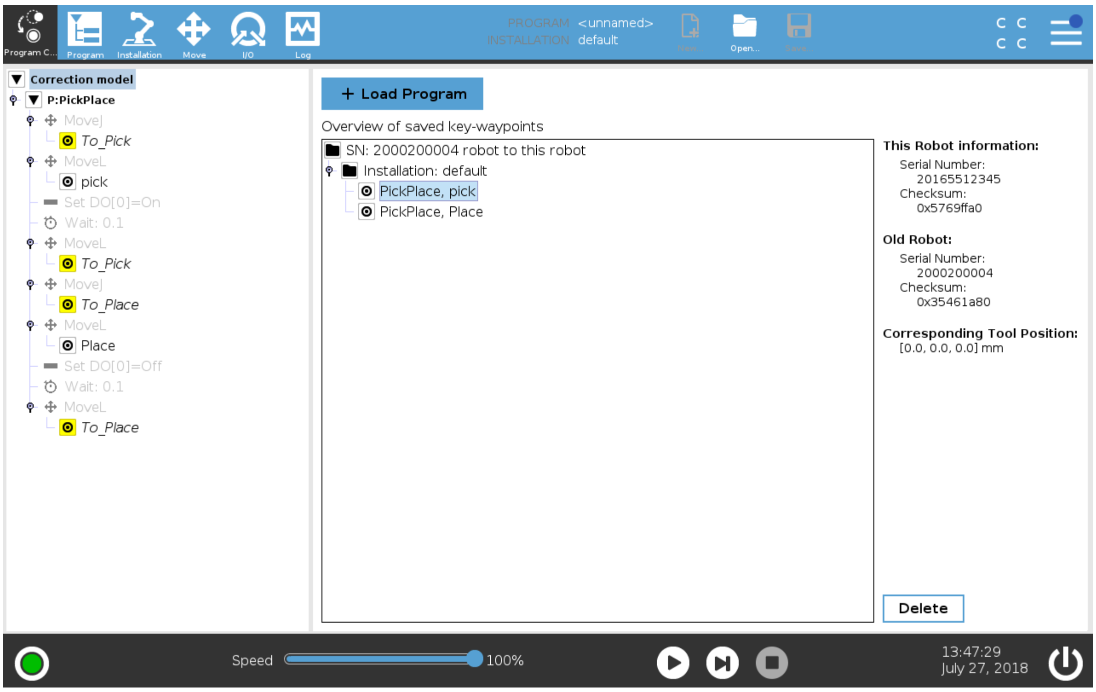


To use the CTP

1. Tap **Change CTP** to specify the CTP location.
2. Change the CTP coordinates and tap **OK** to redefine the "pick" key waypoints.
3. Continue to redefine waypoints until all key waypoint are redefined.

5.2.2. Using waypoints from multiple programs

Add key waypoints from multiple programs, if the key waypoints are distributed over multiple programs.

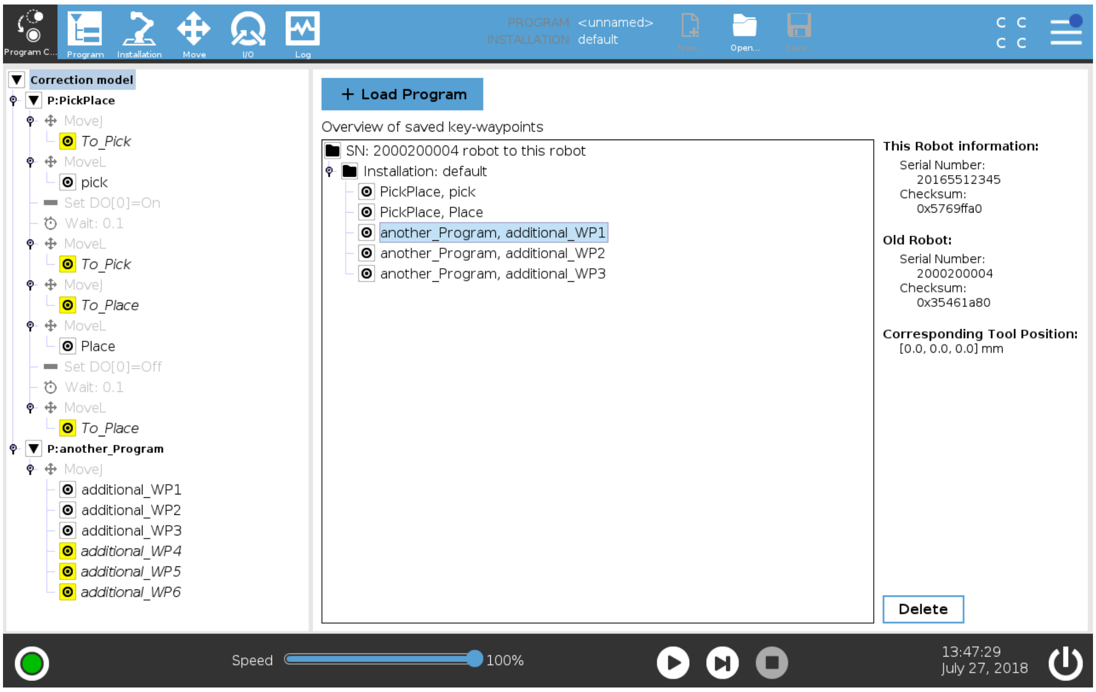


To use waypoints from multiple programs

1. Select the root node of the Correction Model tree and tap **Load Program**.

5.2.3. Using key waypoint groups

The key waypoints are grouped according to the source robot's relationship to new robot's installation. Each key waypoint is named and refers to the source source program.



- You can expand the **Correction Model** node for an overview in the **Correction Model** tree.
- You can select a waypoint, or a group of waypoints, and tap **Delete** to remove selected key waypoints from the **Correction Model** tree.

5.3. Correcting a program

NOTICE

Saving an untested program overwrites any previous programs.

- Test and correct the unsaved program before saving it.

To correct a program

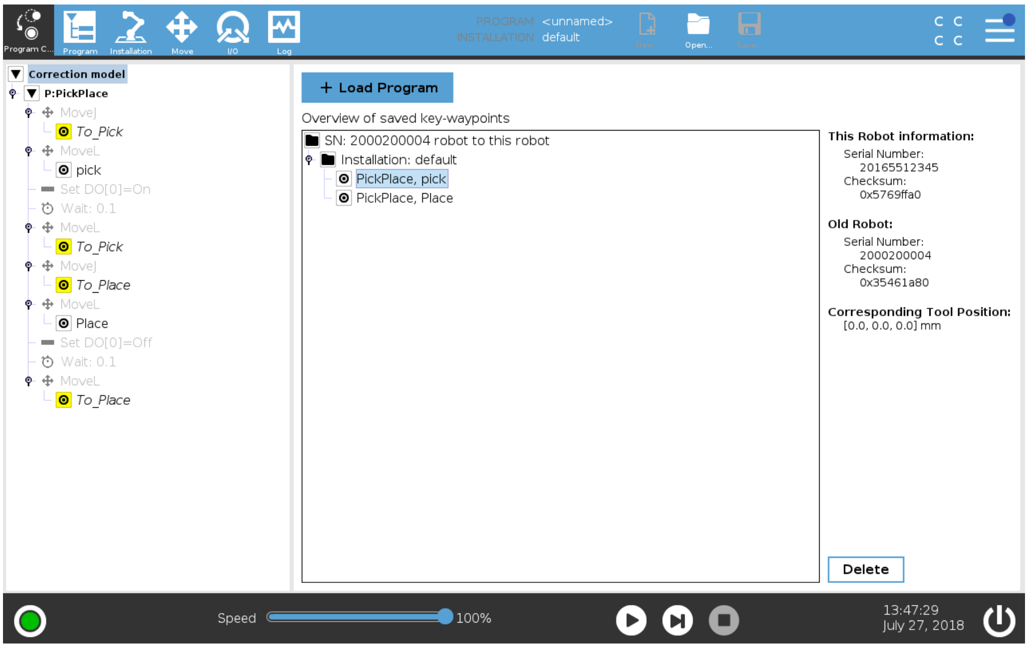
1. In the Program Correction screen, tap **Load Program** and select the program to correct.

   The robot controller software detects if a correction is applicable.
2. Once the Correct Program Waypoint pop-up appears, select **Correct Waypoints**.

   Another pop-up indicates when the correction is done.

- If the correction failed, verify and improve the key waypoints.
- If better accuracy is required, you can add additional key waypoints to the Correction Model and start the program correction again.

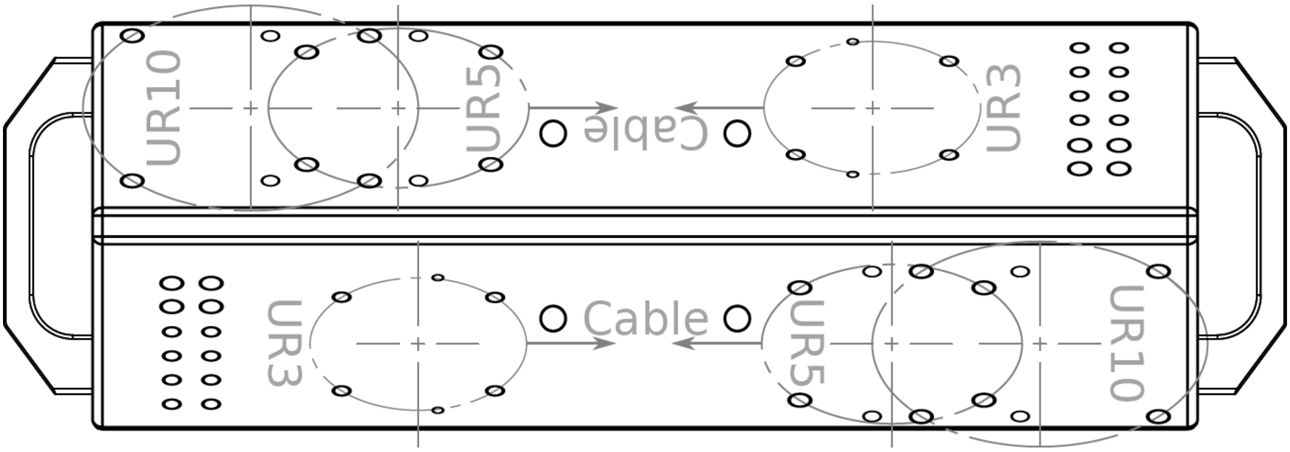
3. Once the program is successfully corrected, tap the play button and allow the robot to move through the waypoints. You can also select individual waypoints and use the **Move Robot Here** functionality.
4. Save the corrected program under a new name.



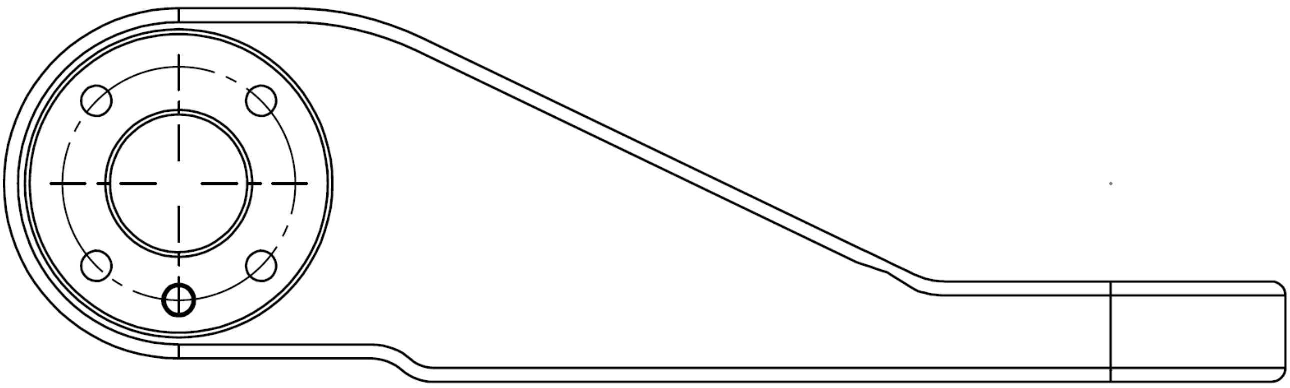
6. Tool drawings

6.1. Calibration Horse

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



6.2. Calibration Connector



7. Copyright and disclaimers

NOTICE

Universal Robots continues to improve reliability and performance of its products, and therefore reserves the right to upgrade the product without prior warning. Universal Robots takes care that the content of this document is precise and correct, but takes no responsibility for any errors or missing information.

NOTICE

Universal Robots disclaims any liability, even if all guidelines in this document are followed.

7.1. Calibration and programming of robots patent

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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