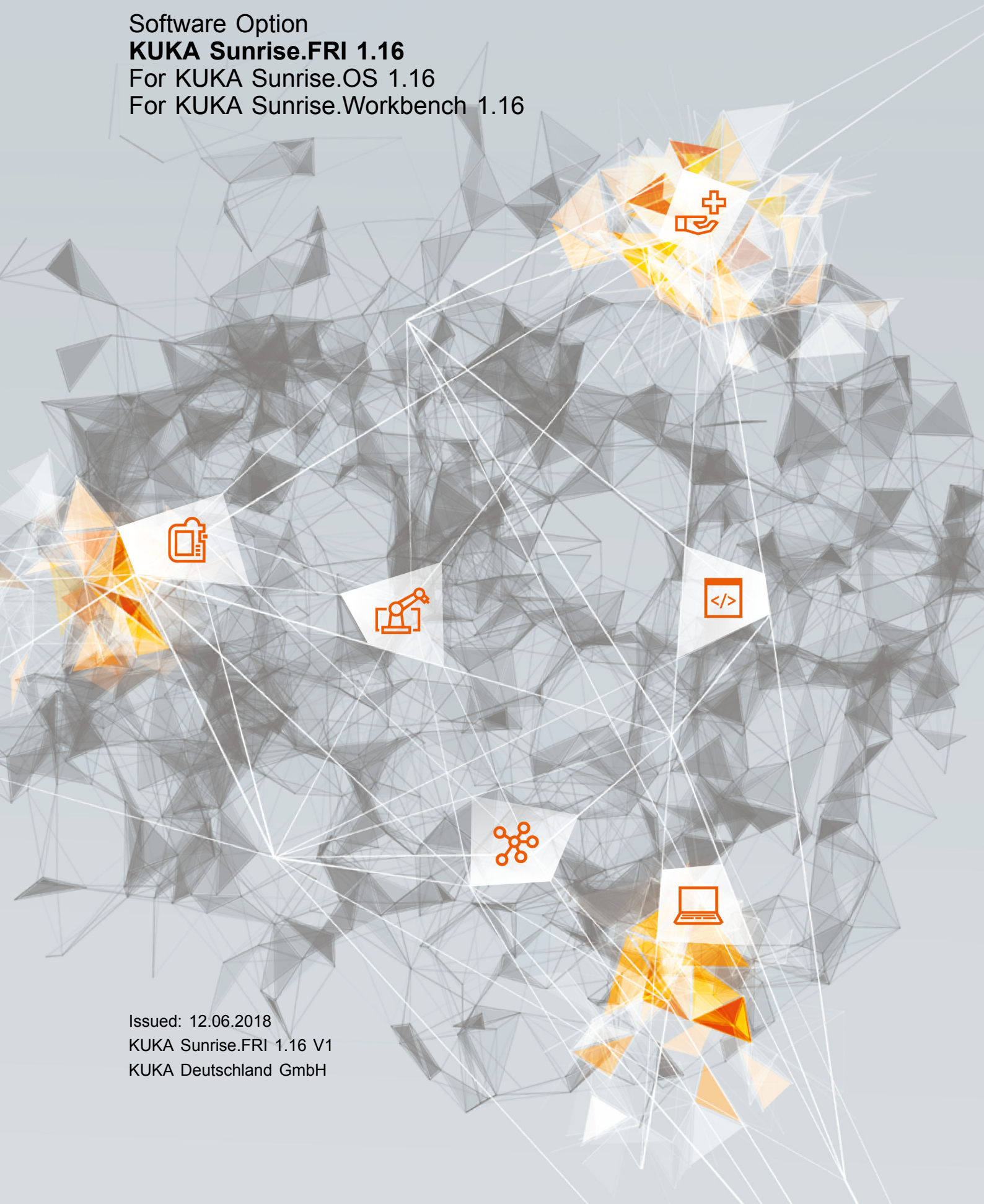
Software Option

KUKA Sunrise.FRI 1.16

For KUKA Sunrise.OS 1.16

For KUKA Sunrise.Workbench 1.16



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KUKA Sunrise.FRI 1.16 V1

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Other functions not described in this documentation may be operable in the controller. The user has no claims to these functions, however, in the case of a replacement or service work.

We have checked the content of this documentation for conformity with the hardware and software described. Nevertheless, discrepancies cannot be precluded, for which reason we are not able to guarantee total conformity. The information in this documentation is checked on a regular basis, however, and necessary corrections will be incorporated in the subsequent edition.

Subject to technical alterations without an effect on the function.

KIM-PS5-DOC

Translation of the original documentation

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Contents

1 Introduction

1.1 Target group

This documentation is aimed at users with the following knowledge and skills:

- Advanced system knowledge of robotics
- Advanced C++ programming skills
- Advanced knowledge of KUKA RoboticsAPI programming
- Basic knowledge of control technology and stability
- Advanced knowledge of real-time programming

For optimal use of our products, we recommend that our customers take part in a course of training at KUKA College. Information about the training program can be found at www.kuka.com or can be obtained directly from our subsidiaries.

1.2 Industrial robot documentation

The industrial robot documentation consists of the following parts:

- Documentation for the manipulator
- Documentation for the robot controller
- Operating and programming instructions for the System Software
- Instructions for options and accessories
- Parts catalog on storage medium

Each of these sets of instructions is a separate document.

1.3 Representation of warnings and notes

Safety

These warnings are relevant to safety and **must** be observed.

DANGER

These warnings mean that it is certain or highly probable that death or severe injuries **will** occur, if no precautions are taken.

WARNING

These warnings mean that death or severe injuries **may** occur, if no precautions are taken.

CAUTION

These warnings mean that minor injuries **may** occur, if no precautions are taken.

NOTICE

These warnings mean that damage to property **may** occur, if no precautions are taken.

These warnings contain references to safety-relevant information or general safety measures.
These warnings do not refer to individual hazards or individual precautionary measures.

This warning draws attention to procedures which serve to prevent or remedy emergencies or malfunctions:

SAFETY INSTRUCTION

The following procedure must be followed exactly!

Procedures marked with this warning **must** be followed exactly.

Notices

These notices serve to make your work easier or contain references to further information.

Tip to make your work easier or reference to further information.

1.4 Terms used

Term	Description
API	Application Programming Interface Interface for programming applications.
Exception	Exception or exceptional situation An exception describes a procedure for forwarding information about certain program statuses, mainly error states, to other program levels for further processing.
FRI	Fast Robot Interface Real-time interface which can be programmed by the user
Field bus I/O	Field bus input/output
Header file	Text file in the programming language C++ containing declarations and other components of a source code
Host	Computer in a network with an IP address and port number
Jitter	Standard deviation from the latency
KLI	KUKA Line Interface Connection to Ethernet network
KONI	KUKA Option Network Interface
KUKA LBR iiwa	KUKA Lightweight robot **i**ntelligent **i**ndustrial **w**ork **a**ssistant
KUKA RoboticsAPI	Java programming interface for KUKA robots RoboticsAPI is an object-oriented Java interface for controlling robots and peripheral devices.
KUKA Sunrise Cabinet	Control hardware for operating the LBR iiwa industrial robot
KUKA Sunrise.OS	KUKA Sunrise.Operating System System software for industrial robots which are operated with the robot controller KUKA Sunrise Cabinet
KUKA Sunrise. Workbench	Development environment for the start-up of a robot cell (station) and for the development of robot applications

Term	Description
Latency	Mean value of the response time to a signal or delay of a signal
SDK	Software Development Kit
Socket	Software module which allows the robot controller to be connected to an external system and to exchange data
UDP	User Datagram Protocol Connectionless protocol for the data exchange between the devices of a network
IP	Internet Protocol The Internet Protocol is used to define subnetworks by means of physical MAC addresses.

1.5 Trademarks

Visual Studio is a trademark of Microsoft Corporation.
Windows is a trademark of Microsoft Corporation.

2 Product description

2.1 Overview of Sunrise.FRI

FRI is an interface via which data can be exchanged continuously and in real time between a robot application on the robot controller and an FRI client application on an external system.

The real-time capability provides the FRI client application with fast cyclical access to the robot path at millisecond intervals.

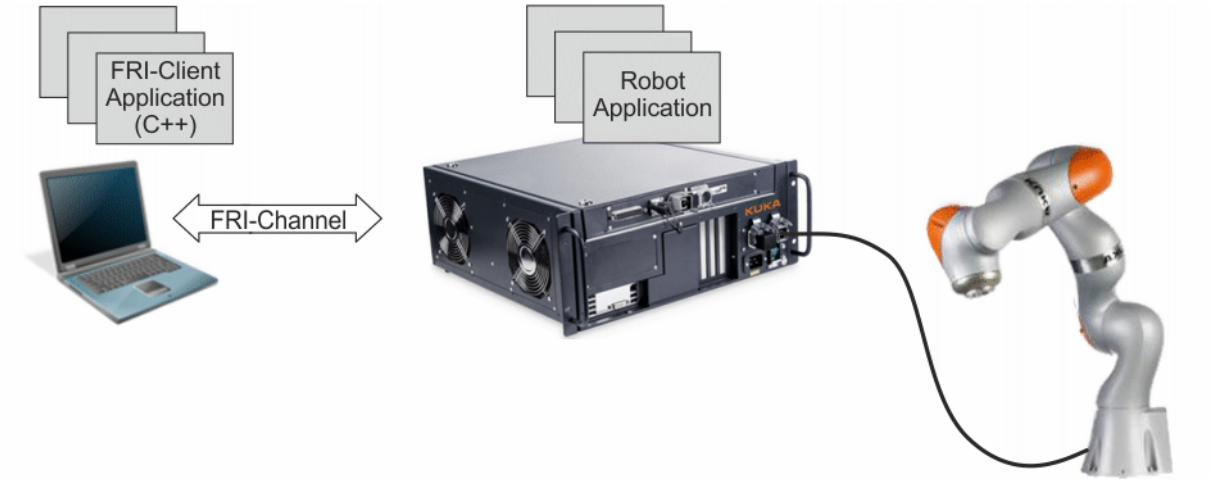

Fig. 2-1: Overview of application development with FRI

Robot application

Robot applications are programmed in Java and executed on the robot controller.

The robot application has the following functionalities:

- Sequence control for the robot
- Management of coordinate systems, objects and motions
- Programming interface for integration of external libraries and functionalities

The following functionalities are added with FRI:

- Configuration and management of various FRI channels
- Activation of access by FRI client applications to selected motion sections

FRI client application

FRI client applications can be created in the programming language C++. They are executed on an external system.

The FRI client application has the following functionalities:

- Evaluation of the robot data in real time
- Continuous evaluation of the application states in real time
- Path superposition under real-time conditions

FRI channel

The robot application and FRI client application are connected via the FRI channel. The FRI channel is an Ethernet-based UDP interface with the following functionalities:

- Binary data exchange
- Management via the robot controller
- Recording of the effective cycle time for monitoring the connection quality and real-time capability

2.1.1 Funktionality of the FRI

Description

The FRI functionality has 2 parts:

- Observing the robot state
- Influencing robot motions

Monitor mode

Monitor mode observes the robot controller and sends the current robot data to the FRI client in real time.

The following robot data can be accessed in Monitor mode:

- Connection state
- Axis-specific actual position
- Axis-specific actual torque
- Axis-specific commanded setpoint position
- Axis-specific setpoint torque
- Axis-specific external torque
- Activity of the drives (switched on/off)
- Operating mode (T1, T2, AUT)
- Status of the safety signal “Safety stop”
- Number of axes
- Time stamp of the data transmission
- Parameter for the tracking performance of the robot
- State of the FRI interface
- Setpoint position of the superposed motion
- Control type of the robot
- 10 field bus I/Os

The cycle time for data transfer can be configured: range from 1 ... 100 ms.

Command mode

In Command mode, the robot controller can also be influenced externally.

Command mode has the following tasks:

- Overlaying of axis positions
- Overlaying of additionally applied joint torques, Cartesian forces and torques
- The FRI client can react to changes on the robot controller cyclically and in real time.

2.1.2 Quality of the FRI connection

The quality of the FRI connection is classified as follows:

- POOR

- FAIR
- GOOD
- EXCELLENT

A classification can only improve in a linear fashion, from the lower quality to next best classification. It is not possible to skip one or more levels. On the other hand, it is always possible for the connection quality to be assessed with any one of the lower classifications.

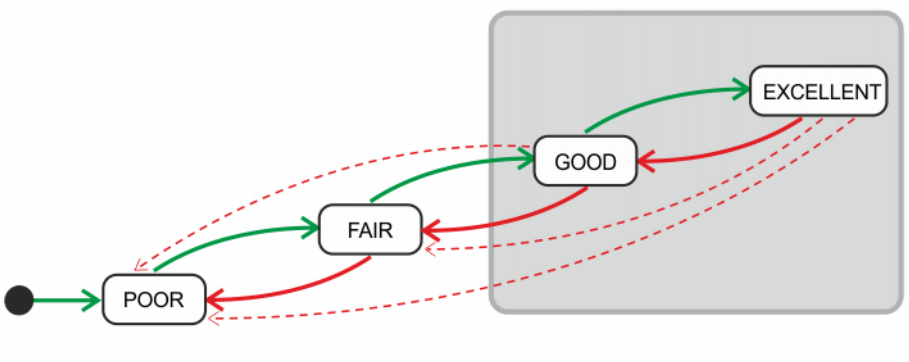

Fig. 2-2: Quality levels of the FRI connection

- Green: Improvement
- Red: Deterioration: data packet lost
- GOOD and EXCELLENT: Command mode (gray) can be used
- POOR and FAIR: only Monitor mode is available

When the FRI connection is first established, the connection quality is always classified as “POOR”. A successful handshake improves the quality of the connection quality from “POOR” to “FAIR” and then from “GOOD” to “EXCELLENT”.

Commands from the external system to the robot controller are only accepted if the connection quality is “GOOD” or “EXCELLENT”.

2.1.3 Connection quality characteristics

The following characteristics determine the quality of the FRI connection:

- Latency of the FRI connection
- Jitter of the FRI connection
- Number of lost data packets
- Answer rate (compliance with the reception rate)

The characteristics can be polled.

(>>> *6.1.4.1 "Polling connection quality and FRI state" Page 28*)

2.1.4 Interaction between Monitor mode and Command mode

Monitor mode

The following FRI states are controlled by the robot controller in Monitor mode:

- MONITORING_WAIT

  The robot controller has opened the FRI connection and is waiting for real-time-capable data exchange.

- MONITORING_READY

  The robot controller is performing real-time-capable data exchange with the FRI client application.

  It is possible to switch to Command mode in the MONITORING_READY state. The change is initiated in the robot application if a motion with path superposition is called.

Command mode

The following FRI states are controlled by the robot controller in Command mode:

- COMMANDING_WAIT

  The robot controller initializes the motion to be superposed and synchronizes itself with the FRI client.
- COMMANDING_ACTIVE

  The robot controller applies the values specified by the FRI client application for superposing the robot path.

The external system is synchronized with the robot controller during the transition phase COMMANDING_WAIT. The robot controller switches from COMMANDING_WAIT to COMMANDING_ACTIVE when the following conditions are met:

- All motions which precede the motion with path superposition have been completed.
- The robot controller has received at least one command message from the FRI client during the transition phase COMMANDING_WAIT.
- The difference between the setpoint position of the robot and the commanded setpoint position of the FRI client is less than 0.001 rad.

The figure shows the dependencies between the different FRI states and their dependency on the connection quality.

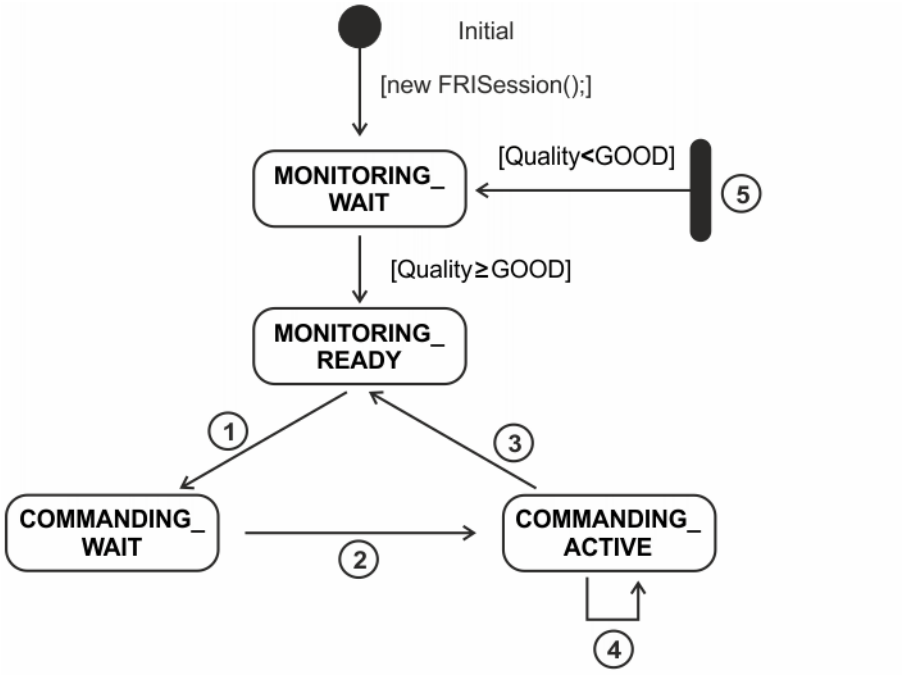

Fig. 2-3: Interaction between Monitor mode and Command mode

Item	Description of state transitions
1	Call of FRI client application

Item	Description of state transitions
	The Command mode of the FRI client application can be activated in the MONITORING_READY state with `move(addMotionOverlay(FRIJointOverlay(…));`. (>>> *6.1.3 "Path superposition with the FRI client" Page 26*) The call causes FRI to switch to the COMMANDING_WAIT state. Precondition: The connection quality is GOOD or EXCELLENT.
2	Acceptance of FRIJointOverlay Following successful synchronization in the transition phase COMMANDING_WAIT, the full command authorization COMMANDING_ACTIVE is issued.
3	End of a superposed synchronous motion Once the synchronized motion is completed, the robot stops with exact positioning. (>>> *6.3.2 "Synchronous motion programming" Page 37*) FRI switches to the MONITORING_READY state.
4	End of a superposed asynchronous motion with subsequent motion If the asynchroous motion is completed and a further superposed motion follows, the path is directly resumed. (>>> *6.3.1 "Asynchronous motion programming" Page 36*) FRI remains in the COMMANDING_ACTIVE state.
5	Connection error The connection quality switches to POOR or FAIR due to a connection error. FRI switches to the MONITORING_WAIT state.

2.1.5 FRI in the robot controller

The following classes are provided for using the FRI in the robot application:

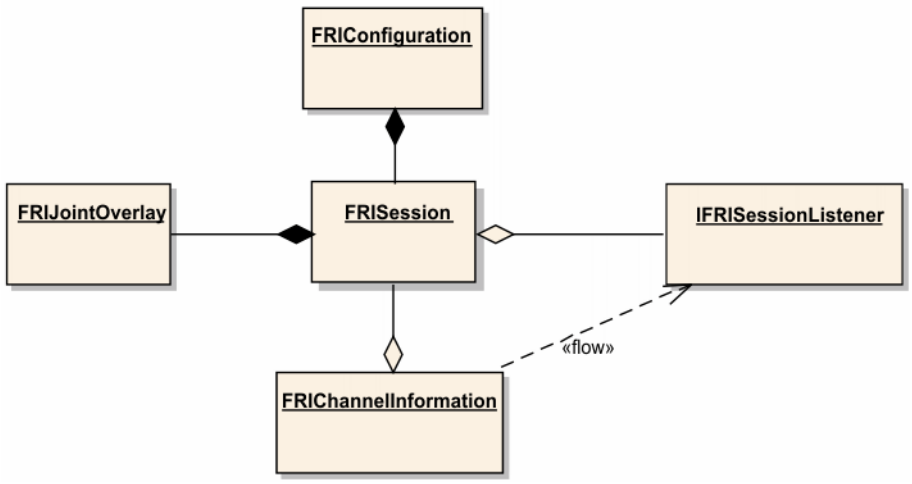

Fig. 2-4: Overview of classes

- The class FRIConfiguration enables the configuration of the FRI connection.
- The configured FRI connection is initialized and opened using the class FRISession. This causes automatic activation of Monitor mode.
- The class FRIChannelInformation can be used to poll the state of the FRI connection.
- The class IFRISessionListener provides a notification mechanism which can be used to automatically record all changes of state.
- The class FRIJointOverlay enables the activation of Command mode.

2.1.6 Application development in the FRI client

The FRI client SDK simplifies application development in the FRI client. For this reason, the network communication, state management and sequence control are encapsulated.

The following classes are provided for application development in the FRI client:

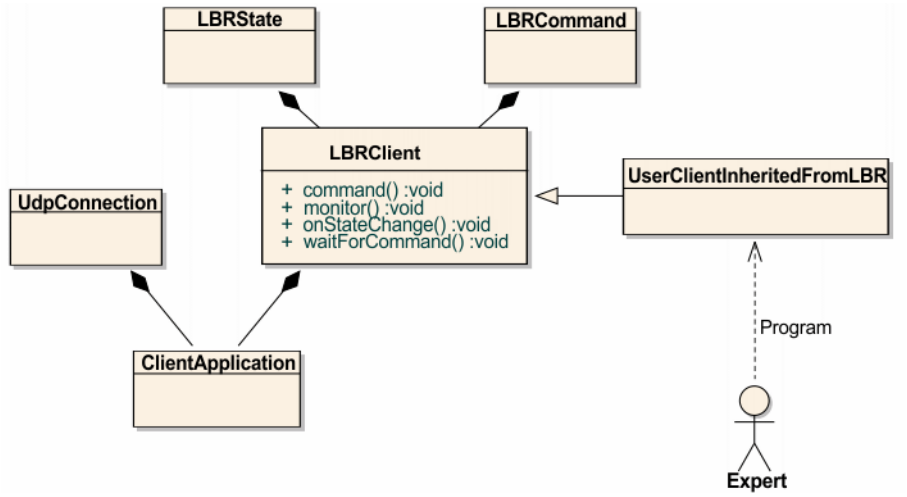

Fig. 2-5: Overview of classes

- The class LBRClient provides the interface methods for the Monitor and Command modes. Separate calculation specifications for path observation and superposition are programmed in a class derived from LBRClient.
- The class LBRState provides the current robot data.
- The class LBRCommand provides the command interface to the robot.
- The class UDPConnection encapsulates the UDP connection.
- The class ClientApplication links communication and calculation specifications.

2.1.7 Communication between the robot controller and FRI client

In the FRI client application, the FRI states are mapped directly to callback methods of the class LBRClient or classes derived from this:

- MONITORING_WAIT corresponds to `cl.monitor();`
- MONITORING_READY corresponds to `cl.monitor();`
- COMMANDING_WAIT corresponds to `cl.waitForCommand();`
- COMMANDING_ACTIVE corresponds to `cl.command();`
- State transitions are mapped with `cl.onStateChange();`.

Overview

The overview shows how the robot controller and FRI client communicate.

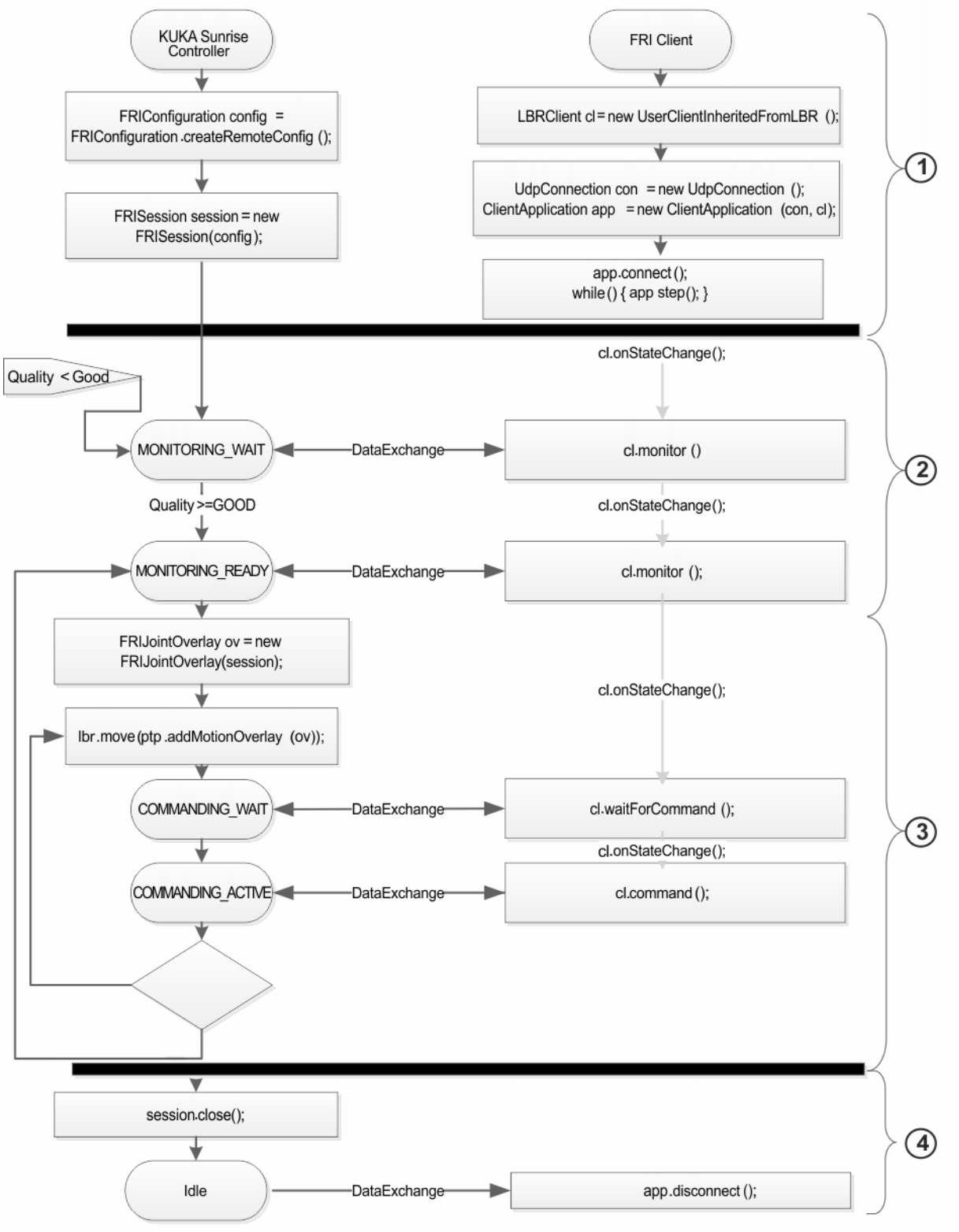

Fig. 2-6: Communication between the robot controller and FRI client

Communication can be subdivided into 4 phases:

Item	Description
1	Configuration and opening of the FRI connection

Item	Description
	(>>> *6.1.1 "Configuring the FRI connection" Page 24*) (>>> *6.1.2 "Initializing and opening the FRI connection" Page 25*) Details on the method app.step() can be found here: (>>> *2.1.8 "app.step() method" Page 15*)
2	Monitor mode Monitoring of the robot controller by the FRI client (>>> *6.2.1 "Monitor mode application phase" Page 32*)
3	Command mode Superposition of the robot path by the FRI client (>>> *6.2.2 "Command mode application phase" Page 32*)
4	Closing the FRI connection and ending the FRI client application (>>> *6.1.5 "Closing the FRI connection" Page 31*)

2.1.8 app.step() method

During communication between the FRI client and robot controller, the method app.step() is executed cyclically in the FRI client application at the configured send rate.

(>>> *6.1.1 "Configuring the FRI connection" Page 24*)

The method app.step() comprises the data exchange with the robot controller and the call of the callback methods which correspond to the current FRI state. The user can change the system behavior with these callback methods. The callback methods are implemented via derivation from the class LBRClient.

(>>> *2.1.6 "Application development in the FRI client" Page 13*)

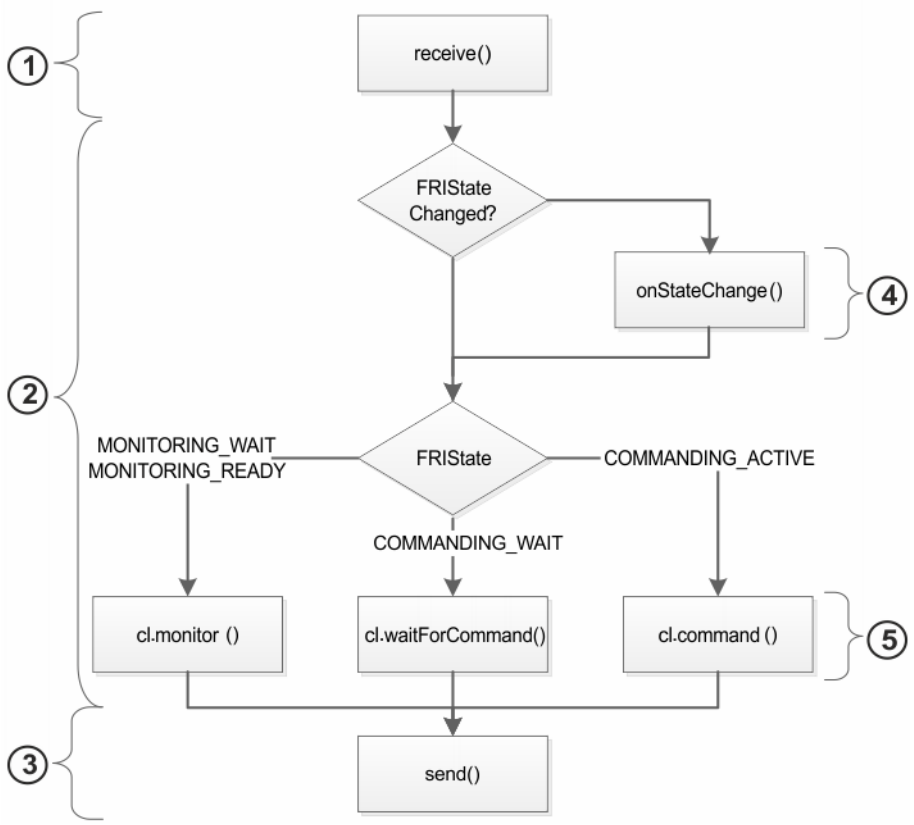

Fig. 2-7: Procedure within the method app.step()

Item	Description
1	Receipt and preparation of the message
2	Evaluation of the current FRI state and calculation of new specified values via calling of callback methods
3	Sending of message including preparation of the message
4	Callback Reaction to change of FRI state (>>> *6.2 "Programming the FRI client application" Page 31*)
5	Callback Cyclical calculations in different FRI states (>>> *6.2 "Programming the FRI client application" Page 31*)

2.2 Intended use

Use

KUKA Sunrise.FRI is used for tapping new areas of use, applications and algorithms for the LBR iiwa. FRI may only be used during development by trained personnel in supervised operation.

The user is responsible for ensuring that the provisions of monitored operation are adhered to. This particularly includes:

- Only trained personnel and personnel instructed in system use may be used.
- It must be possible at all times to bring the robot to a standstill within the reach of the operator by means of safety-oriented equipment.

The user must perform a risk analysis for use outside monitored operation.

Operation in accordance with the intended use also involves continuous observance of the following documentation:

- Assembly and operating instructions of the industrial robot
- Assembly and operating instructions of the robot controller
- Operating and programming instructions for the System Software

Misuse

Any use or application deviating from the intended use is deemed to be misuse and is not allowed. KUKA Deutschland GmbH is not liable for any damage resulting from such misuse. The risk lies entirely with the user.

3 Safety

This documentation contains safety instructions which refer specifically to the product described here. The fundamental safety information for the industrial robot can be found in the “Safety” chapter of the following documentation:

- Operating or assembly instructions of the robot
- Operating and programming instructions for the System Software

The “Safety” chapter in the robot operating or assembly instructions or in the operating and programming instructions for the system software must be observed. Death to persons, severe injuries or considerable damage to property may otherwise result.

The user is responsible for performing his own risk and hazard analysis for use of the robot. This applies in particular if personnel have to enter the robot’s workspace. We recommend having a separate supervisor with a suitable EMERGENCY STOP device. The risk analysis must give special attention to injuries caused by crushing, collision and sharp objects.

NOTICE

FRI enables closed control loops to be implemented. The user is responsible for ensuring their stability. Unstable control loops can cause the overall system to vibrate and the robot to move otherwise than expected, although the robot addresses its destination correctly. KUKA is not liable for damage to property resulting from operation of the robot with unstable control loops.

NOTICE

FRI enables the dynamic superposition of specified paths which can overload the robot. KUKA is not liable for damage resulting from operation of the robot with dynamic overloading.

NOTICE

Due to the limitation of the dynamic parameters to protect the robot, it may, under certain circumstances, not be possible to maintain the path planned by the user.

WARNING

When using the FRI, the actual system response will differ from the response specified by the manufacturer. The stopping distances and times specified in the operating and assembly instructions of the LBR iiwa are not valid. The user is responsible for determining the application-specific stopping distances and times.

Applications with the FRI in Command mode must always be carefully tested first in Manual Reduced Velocity mode (T1).

When using the FRI in T1 mode, only the velocity of the robot flange is monitored for a maximum of 250 mm/s.

4 Installation

4.1 System requirements

Hardware

- KUKA LBR iiwa
- KUKA Sunrise Cabinet
- FRI client: real-time capable computer with real-time capable operating system

  Recommended hardware: KUKA Office Programming System

Software

- KUKA Sunrise.Workbench 1.16
- KUKA Sunrise.OS 1.16

4.2 Installing FRI in Sunrise.Workbench

Description

The FRI software option must be installed in Sunrise.Workbench. Through the installation, the software catalog of Sunrise.Workbench is expanded.

- If supplied jointly with Sunrise.Workbench, the software option is automatically installed during the installation of Sunrise.Workbench.
- If Sunrise.Workbench is already installed at the time of delivery of the software option, the option must be subsequently installed in Sunrise.Workbench using the following procedure.

The following files can be selected for installation (delivered in the **options** folder):

- ZIP archive with the software option
- ZIP archive with the documentation for the software option

The archive names have the following composition:

- *Article number*;*revision number (2-digit)*;*product name*;*build version*

Precondition

- Sunrise.Workbench is installed.
- Data storage medium with the software to be installed

Procedure

1. Select the menu sequence **Help** > **Install new software ...**. The **Install** window is opened.
2. To the right of the **Work with** box, click on **Add**. The **Add repository** window is opened.
3. Click on **Archive …** and navigate to the installation file.
4. Select the file and confirm with **Open**. The **Position** box now displays the path to the file.
5. Click on **OK**.
   - In the **Install** window, the **Work with** box now displays the path to the file.
   - The window now also displays the **KUKA Connectivity** check box.

6. Activate the **KUKA Connectivity** check box.
7. Leave the other settings in the **Install** window as they are and click on **Next >**.
8. An installation details overview is displayed. Click on **Next >**.
9. A license agreement is displayed. In order to be able to install the software, the agreement must be accepted. Then click on **Finish**.

   The installation operation begins.
10. A safety warning concerning unsigned contents is displayed. Confirm with **OK**.
11. A message indicates that Sunrise.Workbench must be restarted in order to apply the changes. Click on **Restart now**.
12. Sunrise.Workbench restarts. This completes installation in Sunrise.Workbench.

4.3 Installing FRI for a station

Description

The following entries for installation can be selected in the software catalog:

- **Fast Robot Interface Extension**
  - Extension of the FRI command library
  - FRI Client SDK (C++ and Java) and examples

    The FRI client application is inserted as a ZIP file under **FastRobotInterface_Client_Source/FRI-Client-SDK_Cpp.zip**.

    (>>> *6.4 "Creating the FRI client application (C++)" Page 41*)

    (>>> *6.5 "Creating an FRI client application (Java)" Page 43*)
- **Fast Robot Interface Extension Example Applications**
  - Examples of robot applications

    The examples are inserted in the Sunrise project in the **examples** folder.
  - Examples of FRI client applications (Java)

    The examples are inserted under **FastRobotInterface_Client_Source/FRI-Client-SDK_Java/examples**.
  - Extension of the libraries

Precondition

- The FRI software option has been installed in KUKA Sunrise.Workbench.
- Sunrise project has been created.

Procedure

1. Open the station configuration of the Sunrise project and select the **Software** tab.
2. Select the desired software expansions for the installation:
   - Set the check mark for the corresponding entry in the **Install** column.
3. Save the station configuration. The system asks whether the modifications to the project should be accepted. Click on **Save and apply**.

   The selected software expansions are installed.

The software expansions installed in the Sunrise project must be transferred to the robot controller. The System Software must be reinstalled on the robot controller for this.

5 Configuration

5.1 Ethernet interfaces for the network connection

Description

The robot controller and external system must be connected via a network. The following Ethernet interfaces are available on the robot controller:

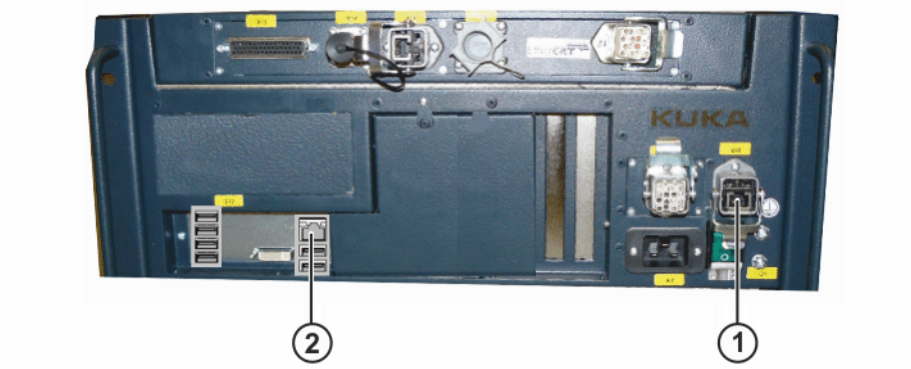

Fig. 5-1: Ethernet interfaces on the KUKA Sunrise Cabinet

Item	Description
1	X66 KUKA Line Interface (KLI) Non real-time capable Ethernet interface (possible at clock rates of >2 ms)
2	LAN Onboard – KUKA Option Network Interface (KONI) Real-time capable Ethernet interface (required at clock rates of 1…2 ms)

The following network configuration is recommended:
- Direct point-to-point connection (without switch)
- Connection via the KONI of the robot controller

The FRI client on the external system is called by the robot controller. The robot controller decides which Ethernet interface is used on the basis of the target address specified in the robot application.

(>>> *6.1.1 "Configuring the FRI connection" Page 24*)

5.2 Network settings in Sunrise.Workbench

Description

The network settings can be changed in the station configuration of the Sunrise project.

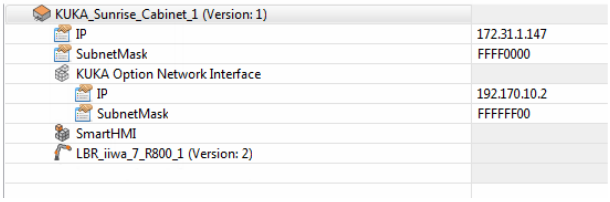

Fig. 5-2: Example network settings

The IP addresses of the KLI and KONI must be in different subnets. If the IP addresses are in the same subnet, the external system and robot controller cannot communicate with each other.

Procedure

1. Open the station configuration and select the **Configuration** tab.
2. Make the desired network settings:
   - IP address and subnet of the KLI under **KUKA_Sunrise_Cabinet_1...** > **IP** / **SubnetMask**
   - IP address and subnet of the KONI under **KUKA_Sunrise_Cabinet_1...** > **KUKA Option Network Interface** > **IP** / **SubnetMask**
3. Save the station configuration. The system asks whether the modifications to the project should be accepted. Click on **Save and apply**.
4. Install the system software on the robot controller. Changes to the station configuration do not take effect until the software is installed on the robot controller.

6 Programming

6.1 Programming the robot application

The FRI connection is configured and managed in the robot application.

6.1.1 Configuring the FRI connection

Description

The FRI connection to an external system is configured via the static method createRemoteConfiguration(…). The method belongs to the class FRIConfiguration.

When the method is called, the name of the robot and the IP address of the external system (FRI client) must be transferred.

Syntax

```
FRIConfiguration configuration =
FRIConfiguration.createRemoteConfiguration (robot,
IP address);
```

Explanation of the syntax

Element	Description
configuration	Type: FRIConfiguration Name of the FRI configuration
robot	Type: com.kuka.roboticsAPI.deviceModel.Device Robot instance in the application
IP address	Type: String IP address of the external system

Overview

The class FRIConfiguration provides the following “set” methods:

Method	Description
setPortOnController(…)	Defines the port number on the robot controller (type: int) • **30200 … 30209** • **-1** (default) If the port number **-1** is used, the same port which is configured via setPortOnRemote(…) is set on the robot controller. **Note**: Only change the port number on the robot controller if the application requires different port numbers on both sides of the FRI channel.
setPortOnRemote(…)	Defines the port number on the external system (type: int) • **30200 … 30209** Default: **30200** The port number **30200** is the default on both sides of the FRI channel.

Method	Description
	Note: The firewall and network services must ensure that transfer of data via the FRI channel is available.
setReceiveMultiplier(…)	Defines the answer rate factor (type: int) Default: **1** The answer rate factor defines the rate at which the external system is to send data to the robot controller: Answer rate = answer rate factor*send rate
setSendPeriodMilliSec(…)	Defines the send rate (type: int, unit: ms) • **1 … 100** Default: **10**

The class FRIConfiguration provides the following “get” methods:

Method	Description
getDevice()	Return value type: String Polls the device to be connected with the FRI (here LBR ii-wa)
getHostName()	Return value type: String Polls the IP address of the external system
getPortOnController()	Return value type: int Polls the port number of the robot controller
getPortOnRemote()	Return value type: int Polls the port number on the external system
getReceiveMultiplier()	Return value type: int Polls the answer rate factor
getSendPeriodMilliSec()	Return value type: int Polls the send rate of the robot controller

6.1.2 Initializing and opening the FRI connection

Description

Using an instance of the class FRISession, the FRI connection between the robot controller and external system is opened and Monitor mode is automatically activated.

If Monitor mode is activated, the connection quality is continuously determined and evaluated.

Syntax

```
FRISession session = new FRISession(configuration);
```

Explanation of the syntax

Element	Description
configuration	Type: FRIConfiguration Name of the FRI configuration
session	Type: FRISession

Element	Description
	Name of the FRI connection

6.1.3 Path superposition with the FRI client

Description

The robot path can be superposed by the FRI client. For this, an instance of the class FRIJointOverlay must be created in the robot application.

This instance must be transferred to every motion to be superposed. The method addMotionOverlay(…) is used for this purpose.

If a linked motion is called with addMotionOverlay(…), the robot controller switches to Command mode.

(>>> *2.1.7 "Communication between the robot controller and FRI client" Page 13*)

Once the motion is completed, the robot controller automatically switches to Monitor mode. If a switch back to Monitor mode is not desired, a further motion must be programmed.

(>>> *6.3 "Motion programming" Page 35*)

Syntax

`FRIJointOverlay` ***overlay*** `= new FRIJointOverlay (`***session, <clientCommandMode>***`);`

object`.move|moveAsync(`***motion***`.addMotionOverlay(`***overlay***`));`

Explanation of the syntax

Element	Description
overlay	Type: FRIJointOverlay Name of the superposition
session	Type: FRISession Name of the FRI connection to be used for the superposition
object	Object to be moved (robot, tool or workpiece) The object variable name which was declared and initialized in the robot application must be specified.
motion	Type: PTP, LIN, SPLINE or PositionHold Synchronously or asynchronously executed motion to be superposed
clientCommandMode	Type: Enum of type ClientCommandMode Optional parameter: defines which commands must be sent by the FRI client to the robot. Default: ClientCommandMode.POSITION

Example

```
FRIJointOverlay ov = new FRIJointOverlay(session);
lbr_iiwa_7_R800_1.moveAsync(ptp(jp1).addMotionOverlay(ov));
lbr_iiwa_7_R800_1.move(ptp(jp2).addMotionOverlay(ov));
```

ClientCommandMode

The optional parameter ClientCommandMode defines the commands with which the FRI client influences the robot path during path superposition. Depending on the parameter selected, specific requirements are made on the control type of the robot and the answer rate of the FRI connection.

Type	Description
ClientCommandMode. POSITION	The FRI client must cyclically command axis positions. • Answer rate ≤ 10 ms • Supported control types: – Position control – Axis-specific impedance control – Cartesian impedance control • Default value if the ClientCommandMode is not explicitly specified on creation of the FRIJointOverlay object.
ClientCommandMode. WRENCH	The FRI client must cyclically command axis positions as well as Cartesian forces and torques. • Answer rate ≤ 5 ms • Supported control types: – Cartesian impedance control
ClientCommandMode. TORQUE	The FRI client must cyclically command axis positions as well as axis-specific torques. Commanded joint torques are superposed with the internally calculated model torques and the torques resulting from the impedance control. • Answer rate ≤ 5 ms • Supported control types: – Axis-specific impedance control • The commanded, superposed joint torques can result in a discrepancy between actual position and commanded setpoint position. If this deviation is greater than ±10°, the motion is terminated with a CommandInvalidException.

Example

```
FRIJointOverlay overlay = new FRIJointOverlay (session, Cli-
entCommandMode.WRENCH);
CartesianImpedanceControlMode ctrMode = new CartesianImpedan-
ceControlMode();
PositionHold posHold = new PositionHold(ctrMode, 20, TimeU-
nit.SECONDS);
object.move(posHold.addMotionOverlay(overlay));
```

6.1.4 Synchronization with the FRI client

Description

FRI serves as an interface between the robot application and the FRI client application. The FRI connection quality is used for the synchronization of the two application components. Motion commands with FRI superposition may only be sent if the connection quality is sufficient (≥ GOOD).

The robot application and FRI client application can be synchronized in different ways:

- By polling the connection quality and the FRI state
- By monitoring the connection quality and the FRI state
- Using the method await(…)

6.1.4.1 Polling connection quality and FRI state

Description

The method getFRIChannelInformation() can be used to poll the following information and save it in a variable of type FRIChannelInformation:

- Jitter, latency and quality of the FRI connection
- Time stamp of the poll
- Polling of the current FRI state FRISessionState (>>> *2.1.4 "Interaction between Monitor mode and Command mode" Page 10*)

Syntax

```
FRIChannelInformation chanInfo =
session.getFRIChannelInformation();
```

Explanation of the syntax

Element	Description
chanInfo	Type: FRIChannelInformation Variable in which the data for the FRI connection and FRI state are saved
session	Type: FRISession Name of the FRI connection and the FRI state from which the data are polled

Overview

The class FRIChannelInformation provides the following “get” methods:

Method	Description
getJitter()	Return value type: double; unit: ms Poll of the jitter
getLatency()	Return value type: double; unit: ms Poll of the latency
getQuality()	Return value type: Enum of type FRIConnectionQuality Poll of the connection quality • FRIConnectionQuality.POOR • FRIConnectionQuality.FAIR • FRIConnectionQuality.GOOD • FRIConnectionQuality.EXCELLENT
getTimeStampMillis()	Return value type: long; unit: ms Poll of the time stamp
getFRISessionState()	Return value type: Enum of type FRISessionState Polling of the current FRI state

Method	Description
	• FRISessionState.IDLE • FRISessionState.MONITORING_WAIT • FRISessionState.MONITORING_READY • FRISessionState.COMMANDING_WAIT • FRISessionState.COMMANDING_ACTIVE

6.1.4.2 Monitoring connection quality and FRI state

Description

A listener of type IFRISessionListener can be used to monitor the connection quality and the FRI state. If the connection quality and FRI state change, the methods onFRIConnectionQualityChanged(…) and onFRISessionStateChanged(…) are called.

The listener must be registered with addFRISessionListener(…). It can be deactivated with removeFRISessionListener(…).

Syntax

```
IFRISessionListener listener = new IFRISessionListener() {
@Override
public void onFRIConnectionQualityChanged(
FRIChannelInformation friChannelInformation) {
// Reaction to change in connection quality
}
@Override
public void onFRISessionStateChanged(
FRIChannelInformation friChannelInformation) {
// Reaction to change in FRI state
}
};
session.addFRISessionListener(listener);
```

Explanation of the syntax

Element	Description
listener	Type: IFRISessionListener Name of the listener object
session	Type: FRISession Name of the FRI connection for which the listener is registered
Input parameter of the listener method:	
`friChannelInformation`	Type: FRIChannelInformation Contains the following information about the FRI connection: • Jitter, latency and quality of the FRI connection • Time stamp at which the quality change occurred • Current FRI state

Example

```
IFRISessionListener listener = new IFRISessionListener(){
@Override
public void onFRIConnectionQualityChanged(
    FRIChannelInformation friChannelInformation){
        getLogger().info("QualityChangedEvent - quality:" +
friChannelInformation.getQuality());
    }
@Override
public void onFRISessionStateChanged(
    FRIChannelInformation friChannelInformation){
        getLogger().info("SessionStateChangedEvent - session
state:" + friChannelInformation.getFRISessionState());
    }
};
session.addFRISessionListener(listener);
```

6.1.4.3 Wait function for switching to Command mode

Description

With await(…), the robot application is stopped until it is possible to switch to Command mode (connection quality ≥ GOOD) or a specified wait time has expired.

The method belongs to the class FRISession. If the defined wait time expires without the robot controller changing to Command mode, the exception java.util.concurrent.TimeoutException is triggered.

Using a try-catch block, the exception can be executed without the application being aborted.

Syntax

```
try{
session.await( timeout, timeUnit)
}
catch(TimeoutException toe){
// Code for handling the timeout
}
finally{
// Final treatment (optional)
}
```

Explanation of the syntax

Element	Description
session	Type: FRISession Name of the FRI connection
timeout	Type: long Maximum wait time
timeUnit	Type: Enum of type TimeUnit Unit of the given wait time. The Enum is contained by default in the Java libraries.

Element	Description
`TimeoutException toe`	The error data type `TimeoutException` is handled in the catch block. The parameter `toe` can be used to poll information about the error which occurred.

Example

```
FRISession session = new FRISession(config);
try {
    session.await(1000, TimeUnit.SECONDS);
        FRIJointOverlay ov = new FRIJointOverlay(session);
        lbr_iiwa_7_R800_1.moveAsync(ptp(jp1).addMotionOver-
lay(ov));
        lbr_iiwa_7_R800_1.move(ptp(jp2).addMotionOverlay(ov));
}
catch(TimeoutException toe){
    FRIChannelInformation channelInfo = session.getFRIChanne-
lInformation();
        getLogger().error("Timeout occured - quality: " +
channelInfo.getQuality() +
        " - session state: " + channelInfo.getFRISession-
State());
}
finally{
    session.close();
}
```

6.1.5 Closing the FRI connection

Description

The FRI connection is closed with close(). The method belongs to the class FRISession.

Syntax

`FRISession` *session*`.close();`

Explanation of the syntax

Element	Description
session	Type: FRISession Name of the FRI connection

6.2 Programming the FRI client application

In the FRI client application, Monitor mode and Command mode are implemented on an external system. For this, class methods corresponding to the different FRI states and state transitions are implemented.

(>>> *2.1.4 "Interaction between Monitor mode and Command mode" Page 10*)

The class methods are automatically called during program execution as a function of the current FRI state.

A template is provided for the development of user-specific robot applications.

6.2.1 Monitor mode application phase

In Monitor mode, the robot controller sends information about the current state of the robot in real time. This information can be used for process evaluation, for example.

Overview

The following methods are available in Monitor mode (class LBRClient):

Method	Description
virtual void onStateChange (ESessionState oldState, ESessionState newState)	Callback method for displaying FRI state changes
virtual void monitor()	Cyclical callback method in the states MONITORING_WAIT and MONITORING_READY
const LBRState & robotState()	Read access to the current runtime data of the robot

6.2.2 Command mode application phase

In Command mode, the robot path can be changed from the FRI client.

The switch to Command mode is initiated in the robot application.

(>>> *6.1.3 "Path superposition with the FRI client" Page 26*)

In both of the states COMMANDING_WAIT and COMMANDING_ACTIVE, the FRI client must continuously send command values to the robot. If commands are not received, this results in the motion being aborted.

Precondition

- In order to be able to switch from Monitor mode to Command mode, the connection quality must be GOOD or EXCELLENT.

Overview

The following methods are available in Command mode (class LBRClient):

Method	Description
virtual void onStateChange (ESessionState oldState, ESessionState newState)	Callback method for displaying FRI state changes
virtual void waitForCommand()	Cyclical callback method in the state COMMANDING_WAIT
virtual void command()	Cyclical callback method in the state COMMANDING_ACTIVE
const LBRState & robotState()	Read access to the current runtime data of the robot
LBRCommand & robotCommand()	Write access for changing the commandable runtime data

6.2.3 Methods of the class LBRState (polling runtime data)

The class LBRState provides the following methods for polling runtime data from the robot controller:

Method	Description	Robot controller
double getSampleTime() const	Cycle time in seconds	FRIConfiguration. getSendPeriodMilliSec() / 1000.0
ESessionState getSessionState() const	State of the FRI connection	———
EConnectionQuality getConnectionQuality() const	Quality of the FRI connection	FRISession. getFRIChannelInformation(). getQuality()
ESafetyState getSafetyState() const	Status of the safety signal “Safety stop”	LBR.getSafetyState()
EOperationMode getOperationMode() const	Operating mode (T1, T2, AUT)	LBR.getOperationMode()
EDriveState getDriveState() const	Activity of the drives (switched on/off)	LBR.hasActiveMotion Command()
unsigned int getTimestamp Sec() const	Time stamp of the data transmission in [s] (time of registration of the measured value)	———
unsigned int getTimestamp NanoSec() const	Fine fraction of the time stamp of the data transmission in [s] (time of registration of the measured value)	———
const double* getMeasured JointPosition() const	Axis-specific actual position [rad]	LBR.getCurrentJointPosition()
const double* getCommanded JointPosition() const	Axis-specific setpoint position in [rad]	LBR.getCommanded JointPosition()
const double* getMeasured Torque() const	Axis-specific actual torque in [Nm]	———
const double* getCommanded Torque() const	Axis-specific setpoint torque in [Nm]	———
const double getExternal Torque() const	Axis-specific external actual torque in [Nm]	———
const double* getIpo JointPosition() const	Interpolated setpoint position as basis for path superposition in [rad]	———
double get TrackingPerformance() const	Tracking performance parameter (Tracking Performance)	———
EClientCommandMode getClientCommandMode() const	Currently required command mode	———
EOverlayType getControlMode() const	Current control type of the robot	———
static int getNumberOf-Joints() (static variable)	Number of axes	LBR.getJointCount()

6.2.4 Methods of the class LBRCommand (modifying runtime data)

The class LBRCommand provides the following methods for modifying runtime data on the robot controller:

Method	Description	Robot controller
void setJointPosition (const double* values)	Setpoint position in [rad]	———
void setWrench (const double* wrench)	For a Wrench array, 6 elements must always be specified. Additional translational force in the x, y and z directions in [N]: • F_x, F_y, F_z Additional rotational torque about the orientation angle in [Nm]: • tau_A, tau_B, tau_C	———
void setTorque (const double* torques)	Commanded joint torques in [Nm]: • A1, A2, … An The number of elements of a joint torque array depends on the number of axes of the manipulator.	———

Both the maximum value and the modification rate of the commanded Cartesian forces and torques and the commanded axis torques are limited internally to a machine-specific maximum value.

6.2.5 Methods of the class LBRClient (creating real-time functionalities)

In order to create a real-time application, a new class must be derived from the class LBRClient:

```
class LBRJointSineOverlayClient:public LBRClient
```

The following methods can be implemented in order to realize the real-time functionalities:

Method	Description	Default behavior
virtual void onStateChange (ESessionState oldState, ESessionState newState)	Display of the FRI state change	———
virtual void monitor()	Observation in Monitor mode State MONITORING_WAIT and MONITORING_READY	Mirroring of the commanded position
virtual void waitForCommand()	Coordination with the robot controller for activating the state COMMANDING_WAIT	Mirroring of the interpolated position
virtual void command()	Path superposing in the COMMANDING_ACTIVE state	Mirroring of the interpolated position

6.2.5.1 Integrating real-time functionalities into the FRI client application

In order to integrate the newly implemented real-time functionalities into the FRI client application, an instance of the new class must be transferred to the constructor of the class ClientApplication.

Example

```
UDPConnection conn;
LBRJointSineOverlayClient cl;
ClientApplication app(conn, cl);
```

6.3 Motion programming

Description

The FRI client application can directly influence the robot motion in Command mode. This can lead to an intentional deviation of the robot motion from the originally programmed path. The path deviation also influences subsequent motion sections and the pause behavior.

A programmed path consisting of several motion commands (`moveAsync` with FRIJointOverlay) is represented as a single continuous motion sequence in the FRI client application. It is advisable to complete such motion sequences with a synchronous motion command (`move` with FRIJointOverlay).

If the controller loses the connection to the FRI client during a superposed motion, the motion is aborted with an error message.

During a superposed motion, the FRI client application must continuously send to the robot controller all command values requested by the ClientCommandMode. If one or more values are omitted, the motion is aborted with an error message.

The figure shows the geometric effects on the programmed path when approximated asynchronous or synchronous motion commands with FRIJointOverlay are used:

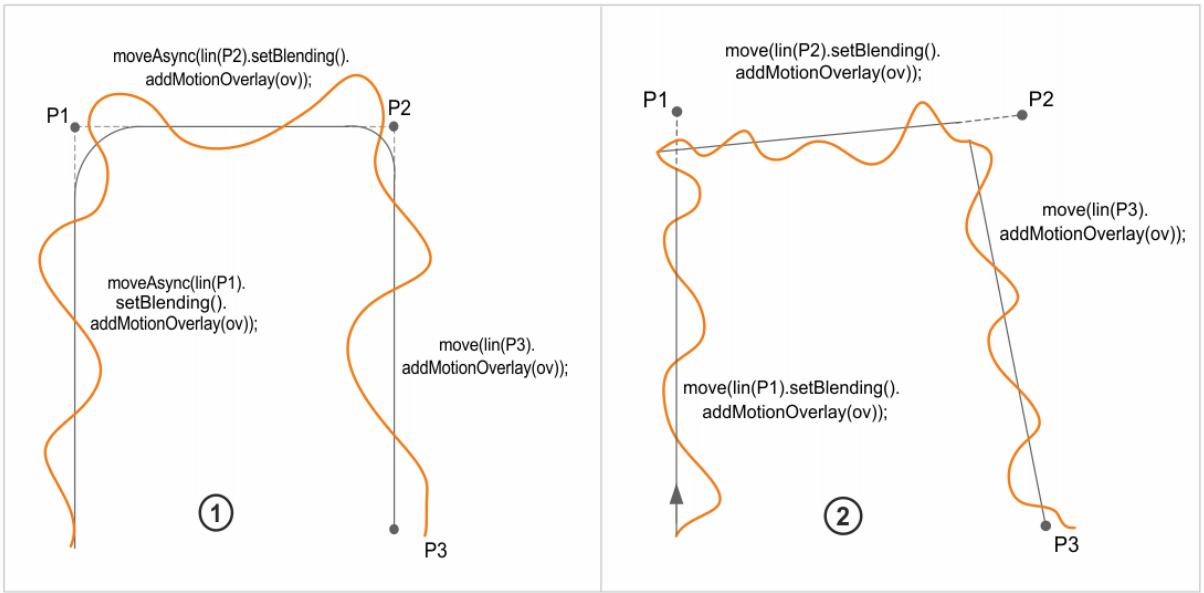

Fig. 6-1: Comparison of the geometric effects of the motions

Item	Description
1	FRIJointOverlay when using the commands `moveAsync` and `move`: • The motion is continuously executed and approximated. • Command mode is not interrupted.
2	FRIJointOverlay without `moveAsync`: • In each case, the programmed motion stops at the approximation point with exact positioning. • The subsequent motion starts from the last commanded position. • Command mode is ended after each motion section and reinitialized for the subsequent motion.

6.3.1 Asynchronous motion programming

Description

If an asynchronous motion command with FRIJointOverlay is replaced by a further motion command with FRIJointOverlay, the command flow in the FRI client application is not interrupted. The motion commands are regarded as one motion sequence. FRI remains in the state COMMANDING_ACTIVE during the entire motion.

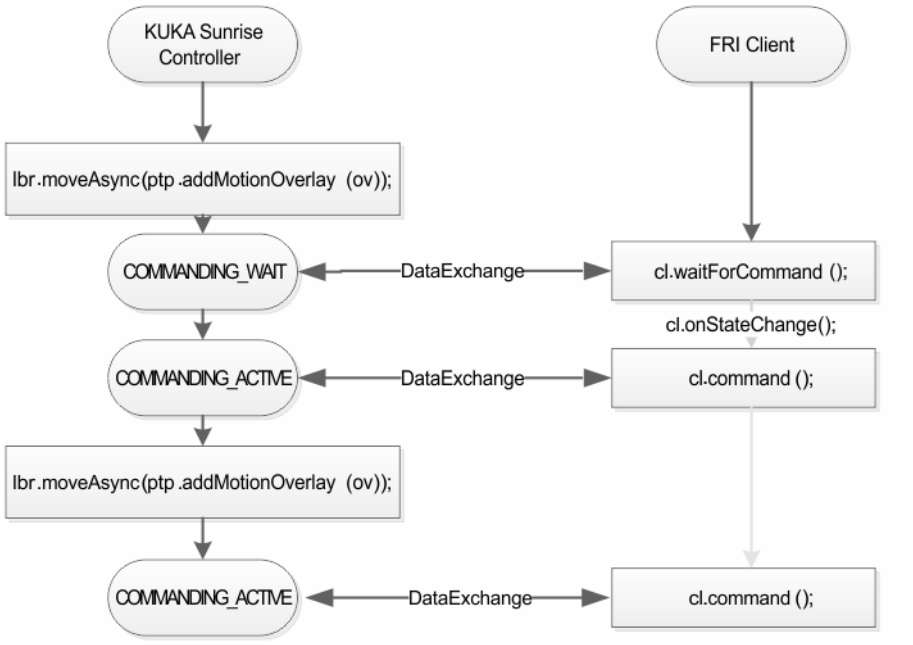

Fig. 6-2: State sequence with asynchronous motion programming

Path

The figure (>>> *Fig. 6-3*) shows the fundamental path in the case of approximation between 2 asynchronous motions. The gray line shows the path of the interpolator and the orange line shows a possible path due to the FRI superposition by the external system.

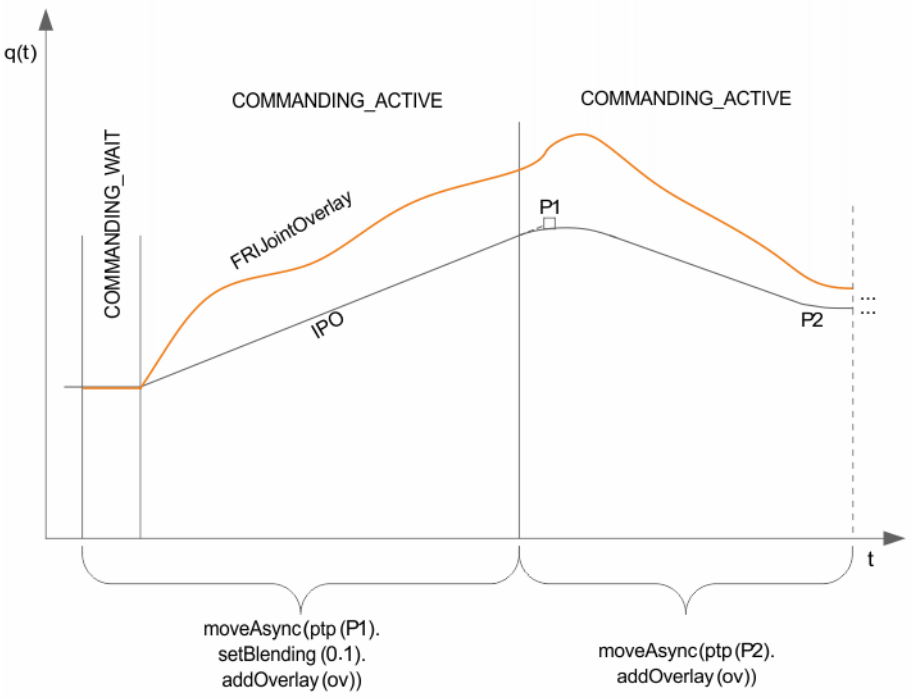

Fig. 6-3: Path with asynchronous motion programming

Approximate positioning

Asynchronous motions can be approximated such that a continuous motion is performed without exact positioning. Approximate positioning also works in Command mode (>>> *Fig. 6-3*).

Command mode can be activated in the middle of an approximated motion sequence without the need for exact positioning. However, leaving Command mode always results in exact positioning, even if the programmed path would permit approximation.

6.3.2 Synchronous motion programming

Description

A synchronous motion command with FRIJointOverlay is always followed by exact positioning and a switch from Command mode to Monitor mode (regardless of the subsequent motion type). The following motions start from the last position commanded by the FRI client and not from the programmed end point of the previous motion.

If a further motion command with FRIJointOverlay follows, the COMMANDING_WAIT state is executed again. The FRI client application must synchronize with the programmed path once again. Only after the synchronization has been performed is it possible to switch to COMMANDING_ACTIVE.

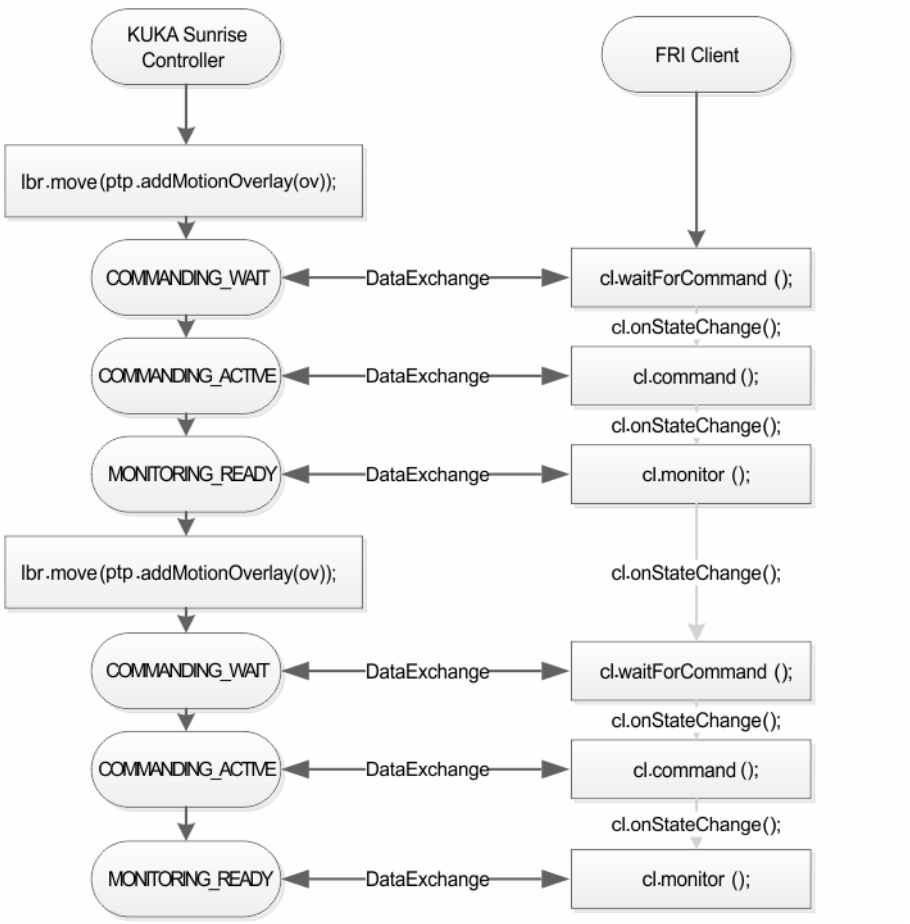

Fig. 6-4: State sequence with synchronous motion programming

Path

The figure (>>> *Fig. 6-5*) shows the fundamental path between 2 synchronous motions. The gray line shows the path of the interpolator and the orange line shows a possible path due to the FRI superposition by the external system. Exact positioning is executed between the motions.

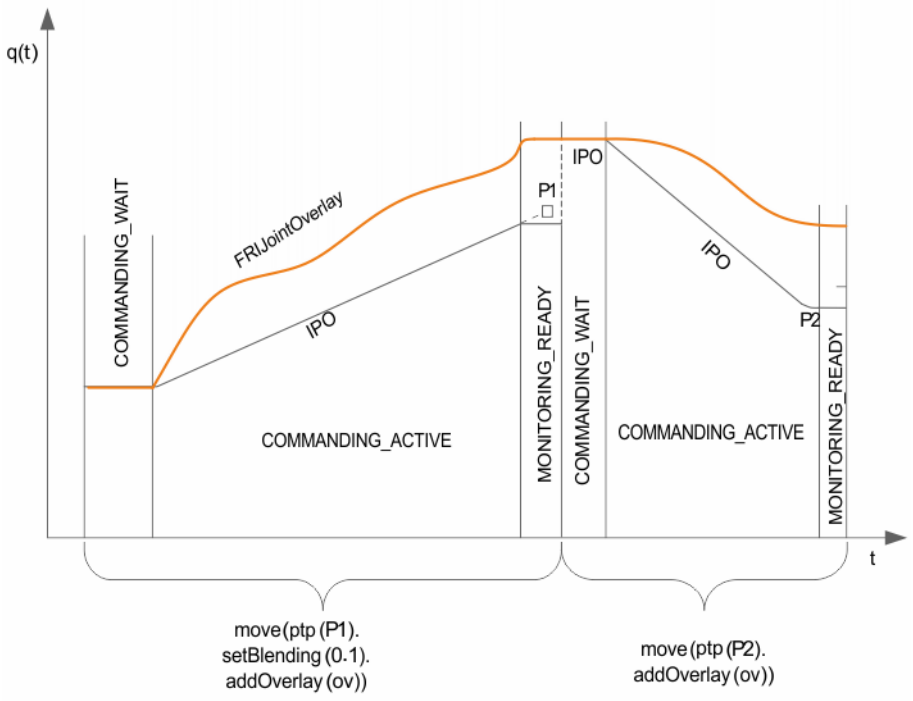

Fig. 6-5: Path with synchronous motion programming

6.3.3 Pause behavior in Command mode

Description

If the robot application is paused while Command mode is active (for example by pressing the STOP key), the FRI client will not accept any further command specifications. The motion is stopped with path-oriented braking and FRI switches to the state MONITORING_READY.

Pressing the Start key causes the robot to be automatically repositioned on the originally programmed path. The motion then restarts from the programmed path. The state COMMANDING_WAIT is executed again and the FRI client application must synchronize with the programmed path. Only then is it possible to switch to the state COMMANDING_ACTIVE and resume the motion.

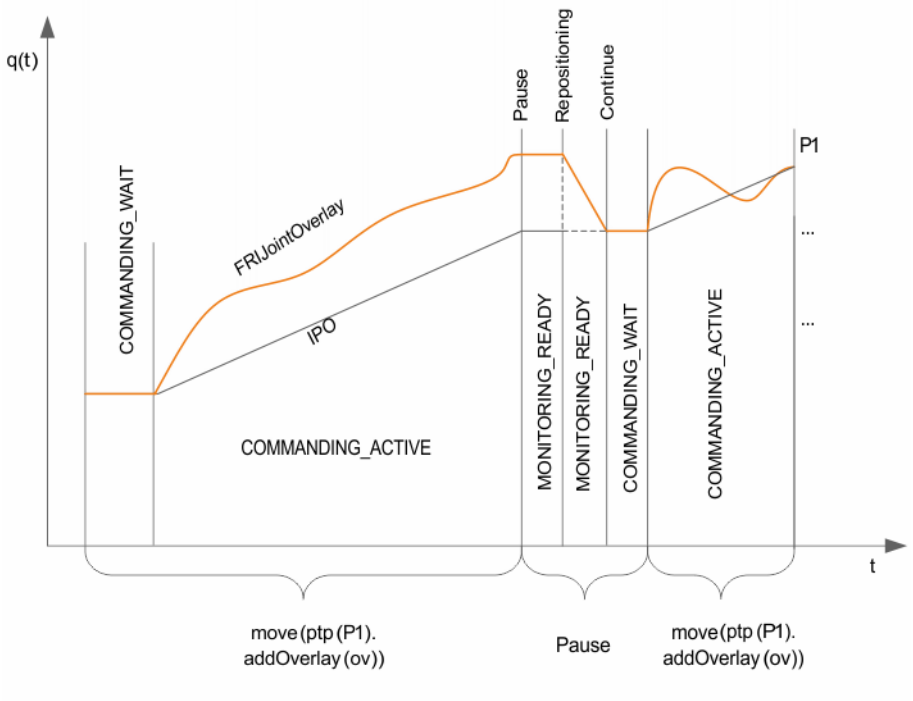

Fig. 6-6: Pause behavior in Command mode

6.3.4 Machine protection and tracking performance

Description

The tracking performance specifies how precisely the robot can track the setpoint values of the commanded path specified by the FRI client.

To protect the robot, the dynamic characteristic of the robot motion is limited. This machine protection is preset to minimize damage to the robot due to possible command errors by the FRI client.

The machine protection is no substitute for the user checking the commanded path for plausibility.

The machine protection function checks whether the axis-specific setpoint positions exceed the machine-specific dynamic parameters (maximum velocity, acceleration and jerk).

If a violation occurs, the robot attempts to execute the path commanded by the FRI client without exceeding the limit values. It is possible that the commanded path cannot be executed precisely and that the robot leaves the path.

The tracking performance defines how precisely the robot can track the specified values. The value for tracking performance lies between 0.0 and 1.0. The maximum value (= 1.0) corresponds to optimal tracking.

Example

Using the tracking performance, the user can tell if the machine protection filter has modified the commanded path:

```
void MyLBRClient::command(){
double performance = robotState().getTrackingPerformance()
}
```

The preset dynamic parameters refer to a full load in the extended position.

In order to fully exploit the performance reserves of the robot, the acceleration can optionally be increased. The overrideJointAcceleration(…) method is used for this. The performance reserves are directly dependent on application-specific parameters, e.g. the load and the robot configuration.

```
FRIJointOverlay jointOverlay = new FRIJointOverlay(friSes-
sion);
jointOverlay.overrideJointAcceleration(5.0);
```

6.4 Creating the FRI client application (C++)

Description

To create an FRI client application, the C++ Software Development Kit (SDK) is required.

The C++ SDK is located in the Sunrise project as a ZIP file under **FastRobotInterface_Client_Source/FRI-Client-SDK_Cpp.zip**. Unzip the C++ SDK and save it in the C++ development environment (C++ development environment is not included in the scope of suppy).

The following directories are created during unzipping:

- **build**: Build environments for the SDK and example programs
- **doc**: Documentation for the programming interface
- **example**: FRI client application examples
  - LBRJointSineOverlay: overlaying of a sinusoidal oscillation on the individual axis angles
  - LBRWrenchSineOverlay: overlaying of a sinusoidal force in the X and Y directions
  - LBRTorqueSineOverlay: commanding of joint torques (amplitude of the torques has a sinusoidal oscillation)
  - LBRClientTemplate: empty client implementation for user-specific applications
- **src**: Source code required for building the SDK library

In order to ensure that the SDK has the greatest possible platform independence, KUKA supplies the library sources as source code. The library must be compiled once for the desired target platform before the application is created. The SDK provides sample build environments for Windows and Linux.

It is advisable to always use the supplied SDK programming interface for FRI client applications. Only those FRI client applications created in this way will remain compatible with future FRI developments.

A detailed description of the programming interface is stored in the HTML documentation **doc/html/index.html**.

6.4.1 Build process with Visual Studio (Windows)

Description

The SDK library and sample applications exist as independent projects and can be opened in Visual Studio.

Precondition

- Windows operating system
- Microsoft Visual Studio 2010 SP1

Procedure

1. Open the Visual Studio solution **build/MSVisualStudio2010/FRIClientSDK.sln**.
2. Build the SDK library as a binary for Win32 in the solution (project **libFRIClient**).

6.4.2 Build process with GNUMake (Linux)

Description

Generic makefiles for building the SDK library are located in the directory **build/GNUMake**. The build process is initiated using the program `make`.

New applications can be added to the automatic build process by expanding the variable EXAMPLE_DIRS in the file **build/GNUMake/Makefile**. Alternatively, the applications can be compiled directly from their source directories by calling `make`.

Precondition

- Linux operating system

Procedure

- Call `make` in the directory **build/GNUMake**.

  The SDK library and the sample applications are built one after the other. Once the build process has been successfully completed, the compiled sample applications can be found in the directory **bin**.

6.4.3 Build process for further platforms

Description

The supplied GNU makefiles are optimized for Linux. In order to build on other platforms, the file **build/GNUMake/tools.mak** can be adapted.

Procedure

1. Enter the build tools belonging to the platform, e.g. compiler, linker, etc., in the file "tools.mak".
2. Set the required compiler and linker options.

Platform-dependent adaptations

The source code of the SDK is as C++-compliant as possible. Depending on the platform, it may be necessary to make adaptations in certain files.

UdpConnection.h, UdpConnection.cpp:

If UDP sockets are used for the FRI channel, it may be necessary to use platform-specific headers. Furthermore, depending on the platform, the compiler option **–DHAVE_SOCKLEN_T** must be set or removed in the file **build/GNUMake/tools.mak**.

pb_syshdr.h:

The header files from nanopb sources are not available on all platforms:

- stdint.h
- stddef.h
- stdlib.h
- stdbool.h

- string.h

For this reason, the nanopb sourcs contain the file "pb_syshdr.h". This file provides the appropriate functionalities for platforms which do not recognize these headers. The availability of the headers is configured via compiler options.

By setting or removing the following compiler options in the file **build/GNUMake/tools.mak**, it is possible to determine which header files are available on the platform used:

- -DHAVE_STDINT_H (stdint.h)
- -DHAVE_STDDEF_H (stddef.h)
- -DHAVE_STDLIB_H (stdlib.h)
- -DHAVE_STDBOOL_H (stdbool.h)
- -DHAVE_STRING_H (string.h)

6.5 Creating an FRI client application (Java)

Description

A Java project must be created for the FRI client project. The corresponding libraries must be inserted into this project.

FRI client application examples can additionally be integrated.

Procedure

1. Create a Java project for the FRI client project.
2. Create a new folder in the Java project into which the required libraries will be inserted, e.g. with the folder name **Libraries**.
3. Open the **FastRobotInterface_Client_source\FRI-Client-SDK_Java** folder in the Sunrise project and select the existing JAR files.
4. Store these JAR files in the **Libraries** folder in the Java project.
5. In the **Libraries** folder, select the client SDK and the Protobuf file that are to be added to the build path.
6. Right-click and select **Build Path** > **Add to Build Path** from the context menu. The **Referenced Libraries** folder is created in the project with the selected files.
7. In the **Referenced Libraries** folder, right-click on the JAR file with the client SDK.
8. Select **Build Path** > **Configure Build Path …** from the context menu. The **Properties for Project** window opens.
9. Select the **Libraries** tab in the **Java Build Path**. Open the Java archive with the SDK client and select the entry **Javadoc position: (none)**.
10. Click on the **Edit ...** button. The **Javadoc for Project** window opens. Select the option **Javadoc in Archive**.
11. Select the option **Workspace file**. Click on the **Browse ...** button. The **Javadoc archive selection dialog** opens. All the projects in the workspace are displayed in a list.
12. In the Java project, open the **Libraries** folder and select the Javadoc file. Confirm with **OK**.
13. In the **Javadoc for Project** window, confirm the archive path with **OK**.
14. The specified path is displayed in the entry **Java Build Path**. Confirm with **OK**.
15. To integrate the FRI client application examples:

    In the Java project, rename the source folder **src** as **examples**.

16. In the Sunrise project, open the folder **FastRobotInterface_Client_source/FRI-Client-SDK_Java/examples**. Select and copy the **connectivity** folder.
17. Store this folder in the **examples** folder in the Java project.

6.6 Field buses

Description

The FRI interface enables access to field bus inputs/outputs during the runtime of FRISession. Read and write access is possible at all times, independently of Command or Monitor mode.

The following options are available:

- (>>> *6.6.1 "Field bus in the robot application" Page 44*)
- (>>> *6.6.2 "Field bus in the FRI client application" Page 44*)

Information about configuration of the field bus I/Os is contained in the **WorkVisual** documentation.

6.6.1 Field bus in the robot application

Description

The field bus I/Os for the FRI client are registered in the robot application.

Precondition

- The inputs and outputs have been configured with WorkVisual.
- When exporting an I/O configuration from WorkVisual, the Java classes were created in the corresponding Sunrise project.

Method	Description
FRIConfiguration.registerIO(…)	Type: com.kuka.roboticsAPI.ioModel.AbstractIO Registers a field bus I/O for the FRI connection.

- A maximum of 10 inputs and outputs can be registered for an FRI connection.
- FRI client SDK can exclusively access registered inputs/outputs.

6.6.2 Field bus in the FRI client application

Description

Read access

Access to inputs/outputs in the FRI client SDK is controlled using the name of the inputs/outputs. The inputs/outputs are created in WorkVisual. The name consists of the field bus group name and the name of the inputs/outputs.

General rule:

- The method used must correspond to the data type used (e.g. Bool, Digital, Analog).
- When reading the current value, no distinction is made between inputs and outputs.

The class LBRState provides the following methods for reading the field bus inputs/outputs:

Method	Description
bool getBooleanIOValue(const char* name) const	Return value type: Boolean Returns the status of a field bus I/O in the created path (char* name) of the element.
unsigned long long getDigitalIOValue(const char* name) const	Return value type: Bit array with a length of 64 bits Returns the status of a digital field bus I/O in the created path (char* name) of the element.
double getAnalogIOValue(const char* name) const	Return value type: double Returns the status of an analog field bus I/O in the created path (char* name) of the element.

Description

Write access

If required, a registered field bus output can be set by the FRI client.

To prevent unintentional overwriting of the output values by other program sections, the field bus output is reserved when it is set by the FRI client for the first time. The reservation is automatically cleared at the end of the FRISession.

The class LBRCommand provides the following methods for write access to the the field bus:

Method	Description
void setBooleanIOValue(const char* name, const bool value)	Type: Boolean Sets the status of a Boolean field bus I/O.
void setDigitalIOValue(const char* name, const unsigned long long value);	Type: Bit array with a length of 64 bits Sets the status of a digital field bus I/O in the bit array.
void setAnalogIOValue(const char* name, const double value);	Type: double Sets the status of an analog field bus I/O.

Example

In a Sunrise.Workbench project with an LBR and the media flange IO electrical, field bus I/Os are to be read and written in the FRI client.

The field bus I/Os are registered in the robot application:

```
@Inject
private LBR robot;
@Inject
protected MediaFlangeIOGroup myMediaFlange;
@Override
public void run() {
    FRIConfiguration friConfig = FRIConfiguration
        .createRemoteConfiguration(robot, "192.168.42.42");
    friConfig.registerIO(myMediaFlange.getOutput("Output3"));
    friConfig.registerIO(myMediaFlange.getInput("Input1"));
...
```

The registered field bus I/Os can be accessed as follows in the FRI client:

```
//Field bus I/O is read
       bool myVal = robotCommand().getBooleanValue("Media-
Flange.Input1");
//Field bus I/O is written
       robotState().setBooleanValue("MediaFlange.Out-
put3",true);
```

7 Troubleshooting

7.1 Problems with connection quality and real-time capability

Error	Cause	Remedy
The quality of the FRI connection is consistently POOR (state MONITORING_WAIT).	The network is incorrectly configured.	• Check the network configuration. • Check the connection between the robot controller and the external system (ping function).
	Plug connection of the KLI or KONI does not match the assigned IP address.	• Check the plug connection. • Check the network configuration.
	The firewall is blocking the connection.	Check the firewall and set it correctly.
	The real-time capability of the network driver of the operating system is disrupted by the installed programs (e.g. VPN services, virus scanners, safety suites and virtualization software).	Configure or remove disruptive programs.
The quality of the FRI connection is consistently FAIR (state MONITORING_WAIT).	Send/receive timing is not complied with.	Check the timing on the FRI client and use slower clock rates if necessary.
The quality of the FRI connection changes constantly between FAIR, GOOD and EXCELLENT.	The switch used is not real-time capable.	Use a direct point-to-point connection with a Cat6 cable.
	FRI client application is not real-time capable.	• Check the FRI client application. • Relocate processing-intensive operations to the background task. • Use slower clock rates.
	The external computer used is not real-time capable.	• Check BIOS settings. • Use a real-time capable computer (recommended hardware: KUKA Office Programming System).
	The operating system on the external computer used is not real-time capable.	Use a real-time capable operating system.
	The network driver of the operating system on the external computer used is not real-time capable.	Use a real-time capable network driver.
	The network connection via the KLI is not real-time capable.	Network connection via the KONI

Error	Cause	Remedy
The robot controller is no longer available in the network following installation of the system software.	The KLI and KONI are in the same subnet.	Contact KUKA Service. (>>> *8 "KUKA Service" Page 53*)

7.2 Runtime problems in Command mode

Error	Cause	Remedy
The robot makes jerky motions or sags during the transition to COMMANDING_ACTIVE.	The FRI client application is not correctly installed.	Check the implementation of the following methods in the FRI client application: • onStateChange() • waitForCommand()
Runtime Exception CK_COMPOUND_RETURN_ERROR: • Connection quality switches to POOR. • State switches from COMMANDING_ACTIVE to MONITORING_WAIT.	Computing time of the FRI client in `command()` is too long.	It is advisable to call the calculations performed in the COMMANDING_ACTIVE phase while still in the MONITORING_READY phase. This ensures that an increased computing time requirement is already recognized in Monitor mode. 1. Estimate the computing time requirement via FRIChannelInformation.getLatency(). 2. Reduce the send timing accordingly. 3. Reduce the computing time requirement.
	The computing time in the FRI client is temporarily too long.	In the FRI client application, check the following methods for potential deadlocks (e.g. new, malloc, semaphores): • onStateChange() • command()
	The quality of the FRI connection is insufficient or unstable.	(>>> *7.1 "Problems with connection quality and real-time capability" Page 47*)
Runtime Exception CK_COMPOUND_RETURN_ERROR: • The connection quality is GOOD or EXCELLENT. • State MONITORING_READY	The specified value is outside the allowed axis range or the allowed velocity and acceleration.	Check the specified value.
The robot stops abruptly, FRI connection is no longer available.	FRI connection was closed prematurely.	• Check the program sequence. • Wait for asynchronous motions.

Error	Cause	Remedy
		• Complete the motion sequence with a synchronous motion command.
Runtime Exception CK_COMPOUND_RETURN_ERROR: • The connection quality is GOOD or EXCELLENT. • State switches from COMMANDING_ACTIVE or COMMANDING_WAIT to MONITORING_READY.	A required command value is missing in the specified values (e.g. no joint angles are commanded by the FRI client in ClientCommandMode.WRENCH)	Check the specified value.

7.3 Runtime problems in the field bus

Runtime errors in the robot application: Runtime Exception CK_COMPOUND_RETURN_ERROR

Error	Cause	Remedy
• `Unable to read IO from IOManager` • `Unable to write output via IOManager`	• Hardware defective • Field bus I/O defective	Eliminate defect
`Unable to get output lock via IOManager`	Competing write access to the field bus output.	Check the application and put write access into the correct order.
`Write on unknown field bus output`	Write access is carried out to an unregistered field bus output.	Register output: FRIConfiguration.registerIO()
`Write on field bus output with wrong type`	There is an incorrect data type in the write access of the FRI client.	Correct the FRI client application.
`Write on field bus input`	Write access is not supported by the field bus input.	Correct the FRI client application.

Runtime error in the FRI client application: Runtime Exception FRIException

Error	Cause	Remedy
`Could not locate IO <name> in monitor message.`	Field bus I/O is not known to the FRI client.	Register field bus I/O using the FRIConfiguration.
`Exceeded maximum number of IOs that can be set.`	An output has been set more than once during a cycle.	Only set the output a maximum of once per cycle.
`IO <name> is not an output value.`	A field bus input was treated as a field bus output.	Correct the FRI client application.
• `IO <name> is not of type analog value.`	Incorrect I/O type	Use a function that matches the data type.

Error	Cause	Remedy
• `IO <name> is not of type digital value.` • `IO <name> is not of type Boolean.`		
The value of the field bus output deviates from the set value.	The range of values of the corresponding field bus I/Os is limited.	Take the value ranges of the field bus output into consideration.

7.4 Exceptions

Java exception	Method	Cause / remedy
IllegalArgumentException	FRIConfiguration.createRemoteConfiguration(…)	Invalid parameterization (>>> *6.1.1 "Configuring the FRI connection" Page 24*)
	• FRIConfiguration.setPortOnController(…) • FRIConfiguration.setPortOnRemote(…) • FRIConfiguration.setReceiveMultiplier(…) • FRIConfiguration.setSendPeriodMilliSec(…)	Invalid parameterization (>>> *6.1.1 "Configuring the FRI connection" Page 24*)
	FRISession.await(…)	Invalid parameterization
	FRISession.FRISession(…)	FRI configuration invalid (>>> *6.1.2 "Initializing and opening the FRI connection" Page 25*)
	• FRISession.addFRISessionListener(…) • FRISession.removeFRISessionListener(…)	Invalid listener
	FRISession.close()	FRI connection has already been closed. Remedy: Check the program sequence.
IllegalStateException	FRISession.await(…)	FRI connection is closed. Remedy: Check the program sequence.
	FRISession.FRISession(…)	FRI connection could not be opened. Remedy: Check the network connection (IP address, port) (>>> *7.1 "Problems with connection quality and real-time capability" Page 47*)
TimeoutException	FRISession.await(…)	Wait time has expired before the state MONITORING_READY was reached.

Java exception	Method	Cause / remedy
		• Extend the wait time. • Start the FRI client. (>>> *7.1 "Problems with connection quality and real-time capability" Page 47*)
NotSupportedException	addMotionOverlay(FRIJointOverlay)	The motion contains more than one FRIJointOverlay.
		A control type not supported by the FRI has been used, e.g. a Cartesian impedance controller with overlaid force oscillation. Only motions with the following control types can be superposed: • Position control • Axis-specific impedance control • Cartesian impedance control
		A motion type not supported by the FRI has been used, e.g. CIRC or MotionBatch. The following motion types are supported: PTP, LIN, SPLINE, PositionHold.
IllegalArgumentException	addMotionOverlay(FRIJointOverlay)	The FRI connection used does not match the robot being moved. Remedy: When configuring the FRI connection, select the appropriate robot instance. (>>> *6.1.1 "Configuring the FRI connection" Page 24*)
IllegalArgumentException	FRIConfiguration.registerIO(…)	I/O parameterization invalid: • The number of registered I/Os is too high. Remedy: Check the number of registered I/Os (≤ 10) • Name of the I/Os is identical. Remedy: Check name • Name of the I/Os is invalid. Remedy: Check mapping in WorkVisual.

7.5 Errors in the FRI client C++ application

Fault	Cause	Remedy
The FRI client application library does not compile.	The compiler settings (defines) do not match the environment.	Determine and set the compiler settings for "nanopb".

Fault	Cause	Remedy
		See also C++ SDK "src/nanopb-0.2.8/pb_syshdr.h".
The FRI client cannot open the connection.	The network is incorrectly configured.	Check the network configuration. (>>> *7.1 "Problems with connection quality and real-time capability" Page 47*)
	The firewall is preventing the connection.	Modify the firewall settings.
	The port is already assigned.	Enable the port, e.g. by ending the running application.
The user-specific FRI client application does not work, but the supplied FRI client sample application **example/LBRSineOverlay** does.	There is a real-time violation.	Check the user-specific FRI client application.
	The specified value is outside the permitted axis range.	
	The specified value is outside the permitted velocity or acceleration.	

8 KUKA Service

8.1 Requesting support

Introduction

This documentation provides information on operation and operator control, and provides assistance with troubleshooting. For further assistance, please contact your local KUKA subsidiary.

Information

The following information is required for processing a support request:

- Description of the problem, including information about the duration and frequency of the fault
- As comprehensive information as possible about the hardware and software components of the overall system

  The following list gives an indication of the information which is relevant in many cases:

  – Model and serial number of the kinematic system, e.g. the manipulator
  – Model and serial number of the controller
  – Model and serial number of the energy supply system
  – Designation and version of the system software
  – Designations and versions of other software components or modifications
  – Diagnostic package KRCDiag

    Additionally for KUKA Sunrise: Existing projects including applications

    For versions of KUKA System Software older than V8: Archive of the software (KRCDiag is not yet available here.)
  – Application used
  – External axes used

8.2 KUKA Customer Support

Availability

KUKA Customer Support is available in many countries. Please do not hesitate to contact us if you have any questions.

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