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Wayne Glettig :: Group Leader MX Instrumentation :: Paul Scherrer Institute

SmarGon MCS2: An Enhanced Multi-Axis Goniometer With a New Control System

09.11.2023 MEDSI, Beijing

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Overview

- Introduction of Smargon
- Problems with the previous version, and solutions
- New control system ‘smargopolo’, system architecture
- Calibration
- Results and Outlook

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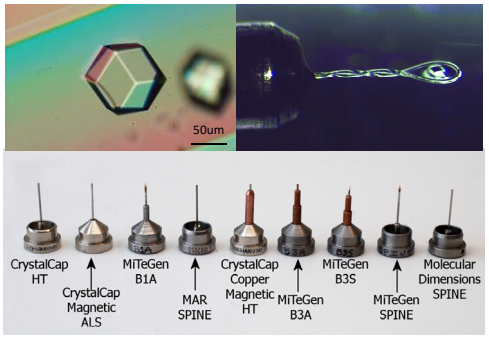
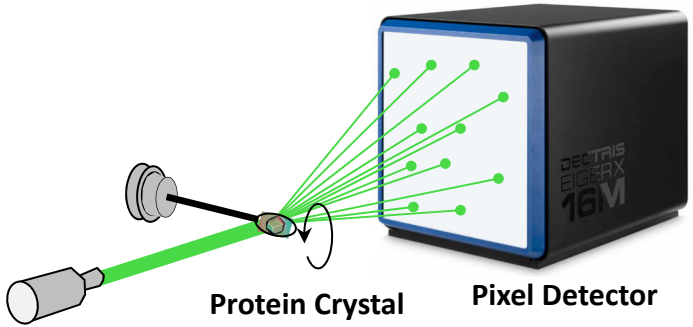
What is SmarGon?

- SmarGon is a Goniometer for the use at a Protein Crystallography Beamline



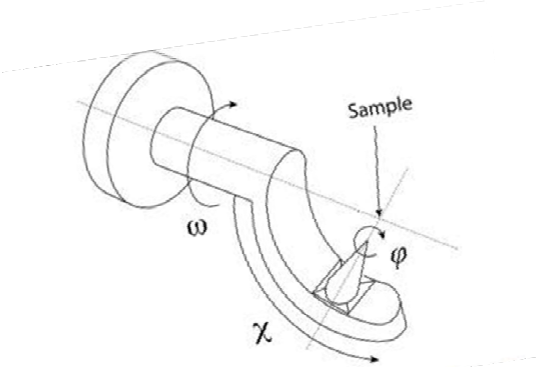


X-Ray Source + Optics

Protein Crystal

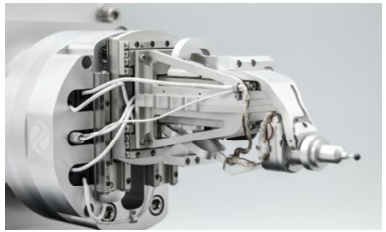
Pixel Detector

Sample size: ~5um – 100um
Beam Size: 5um – 75um
Beam size is chosen to match sample size



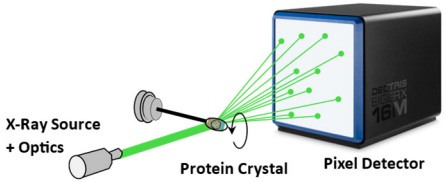
Mini-Kappa (Arinax/EMBL/ESRF)
And other Kappa Goniometers

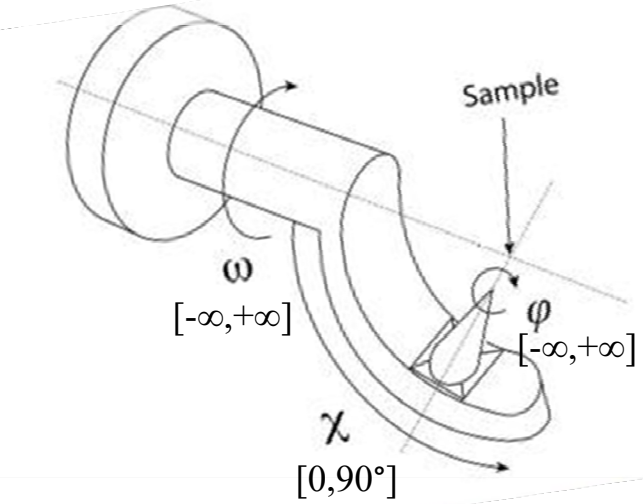
PRIGo (Swiss Light Source)

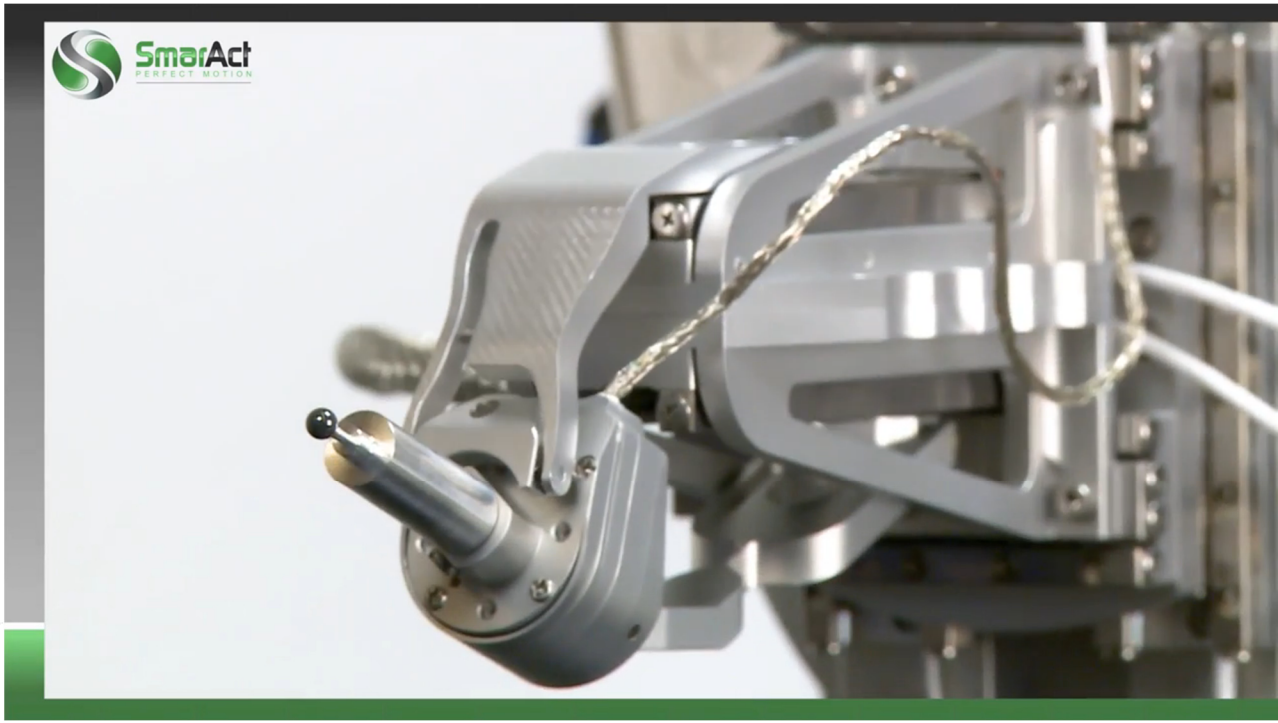


SmarGon (SmarAct GmbH)

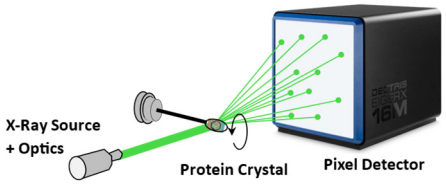
Motion

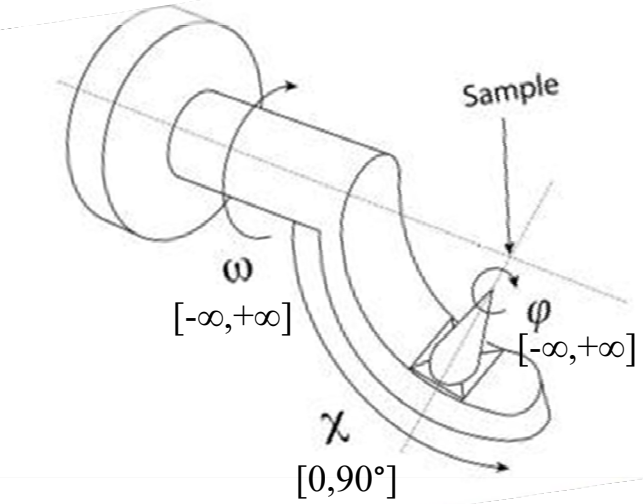

X-Ray Source
+ Optics
Protein Crystal
Pixel Detector


Sample
ω
[-∞,+∞]
φ
[-∞,+∞]
χ
[0,90°]


SmarAct
PERFECT MOTION

Motion


X-Ray Source
+ Optics
Protein Crystal
Pixel Detector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[-∞,+∞]
φ
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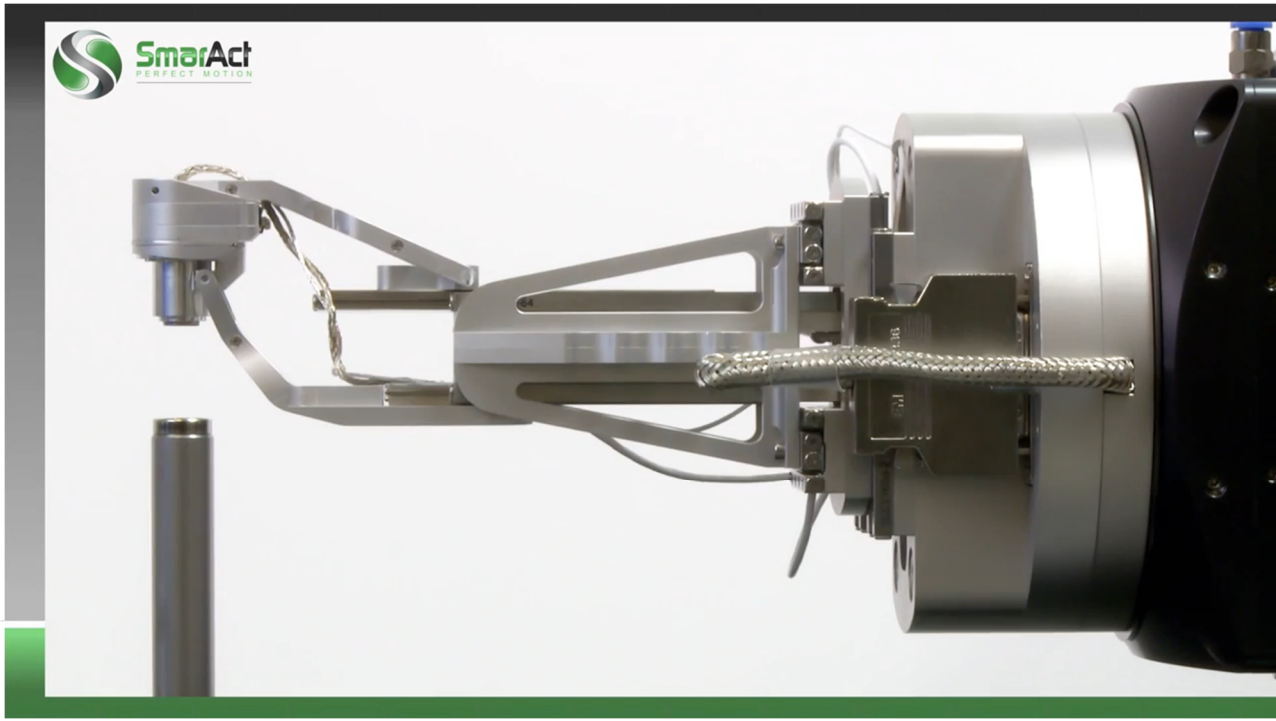
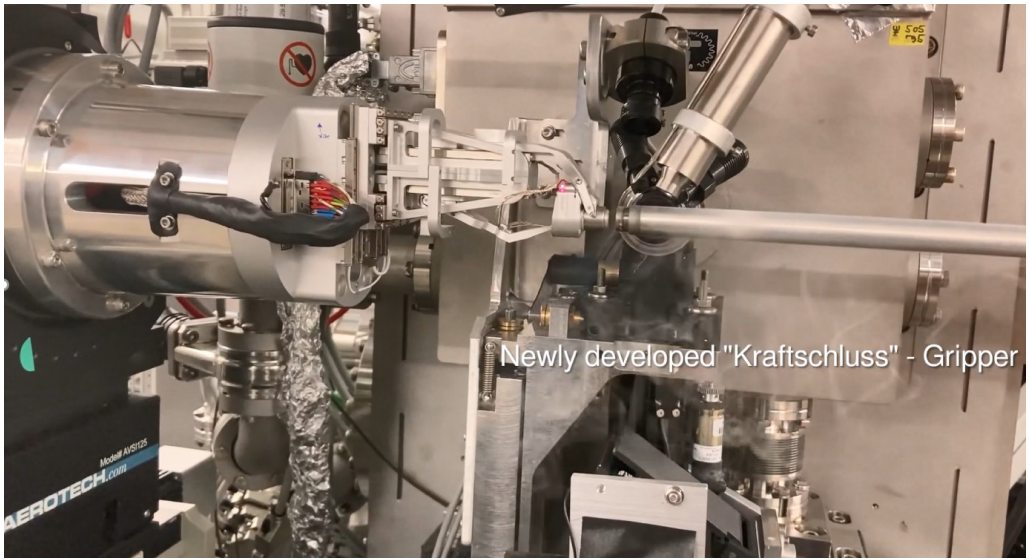
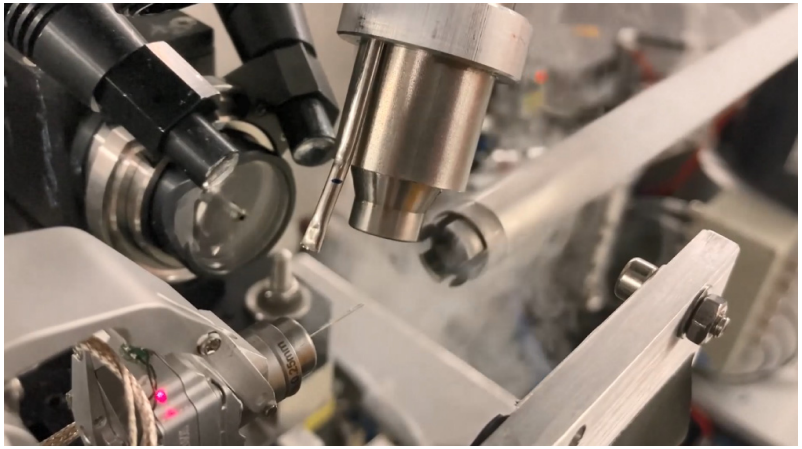

SmarAct
PERFECT MOTION

Issues in real-world use

MX beamlines :

- High throughput, hundreds of samples a day.
- Remotely controlled, now increasingly in unattended automatic operation. -> no human intervention should be necessary.
- -> Minimization of downtime
- -> Recovery must be fast





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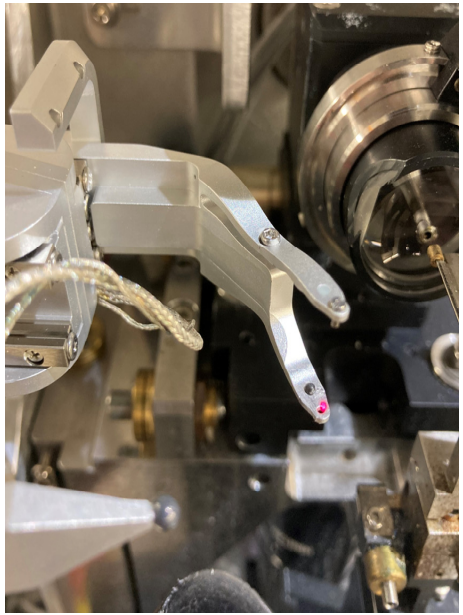
Accidents happen…



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We don’t want to break hardware

- As you must know, fixing broken machines is time consuming.
- If only SmarGon had a **control system** that could help us avoid this.

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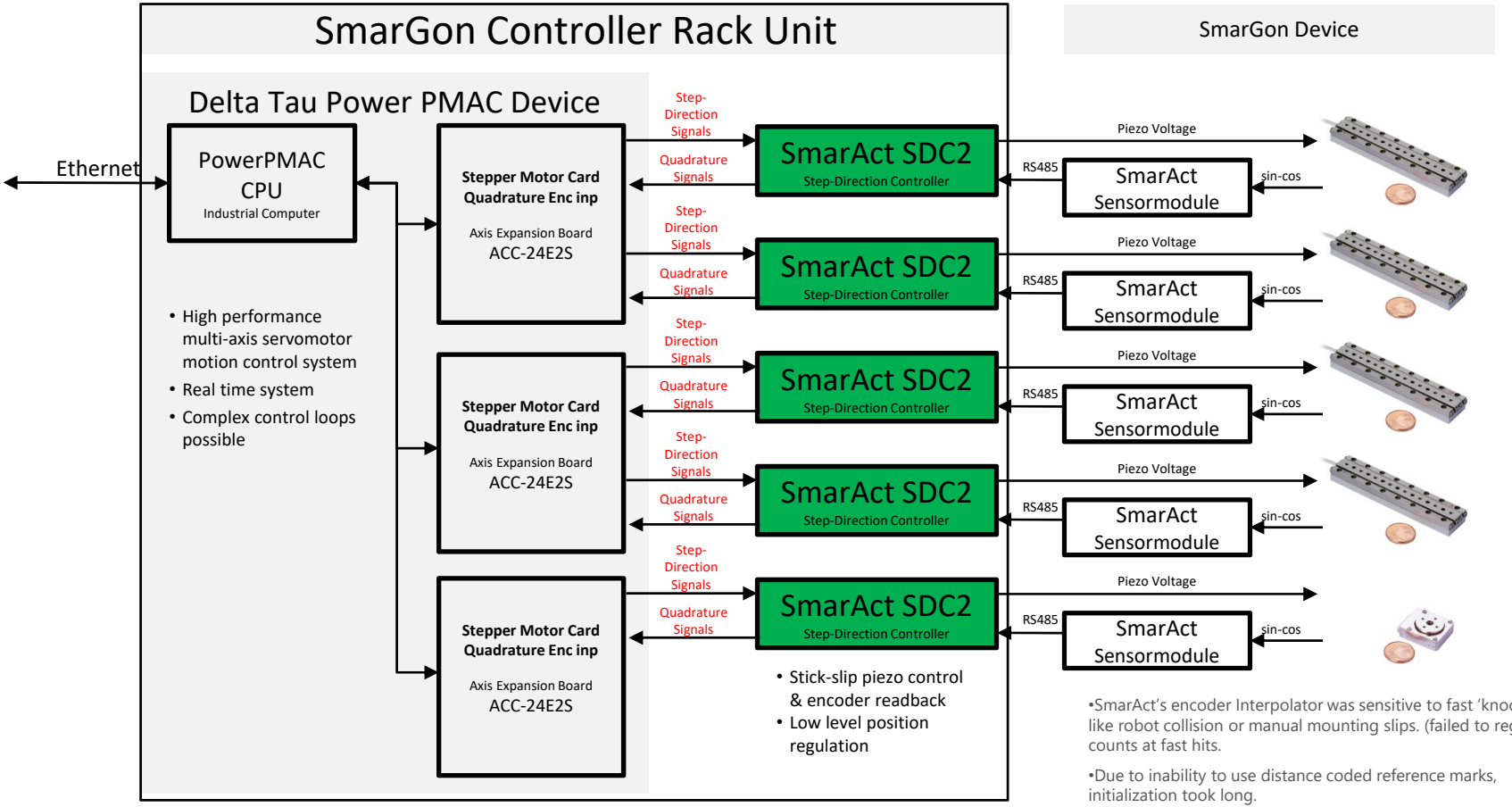
Old SmarGon Controller



•SmarAct's encoder Interpolator was sensitive to fast 'knocks' like robot collision or manual mounting slips. (failed to register counts at fast hits.

•Due to inability to use distance coded reference marks, initialization took long.

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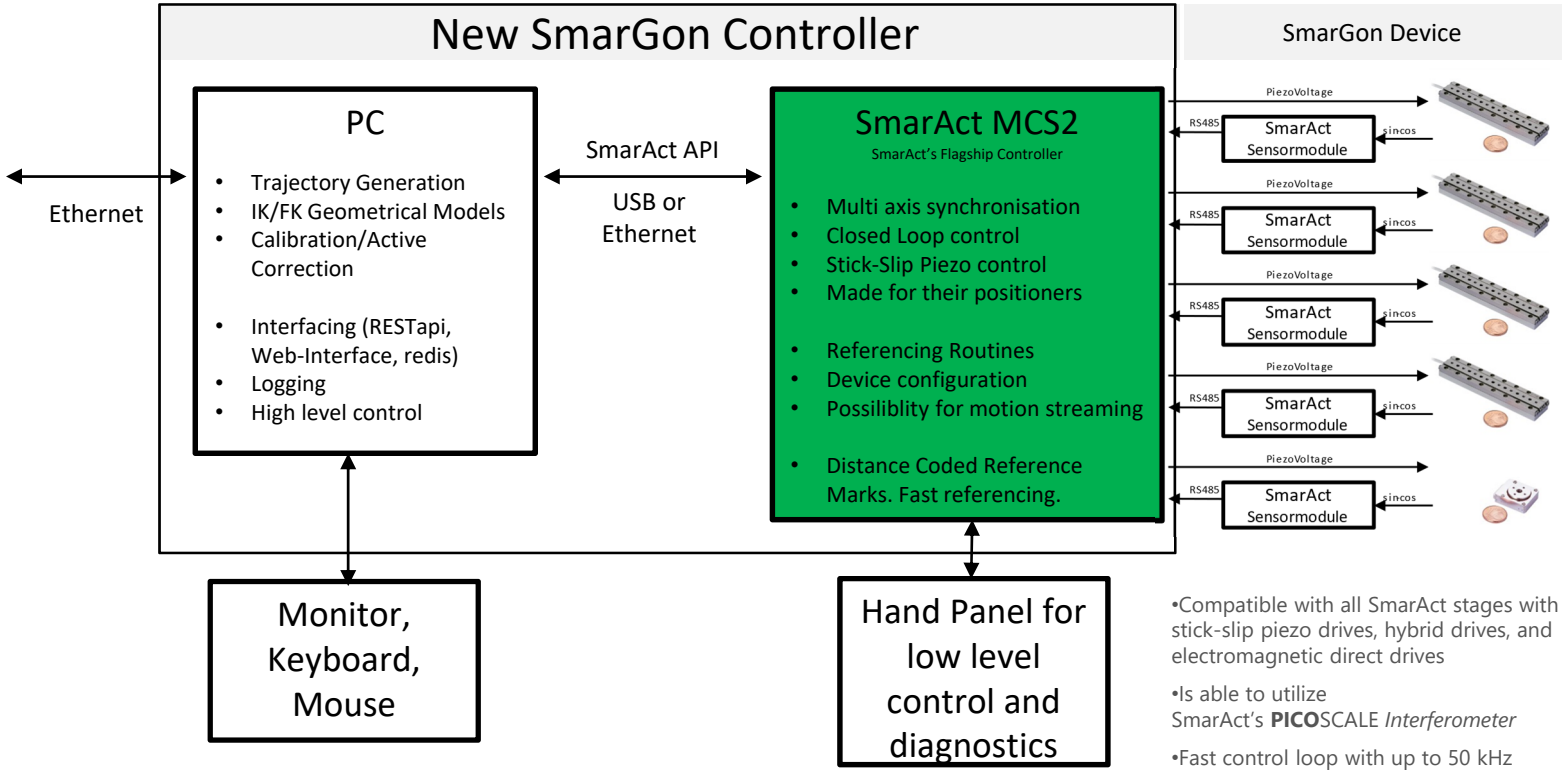
New MCS2 Controller



- Compatible with all SmarAct stages with stick-slip piezo drives, hybrid drives, and electromagnetic direct drives
- Is able to utilize SmarAct's **PICO**SCALE *Interferometer*
- Fast control loop with up to 50 kHz

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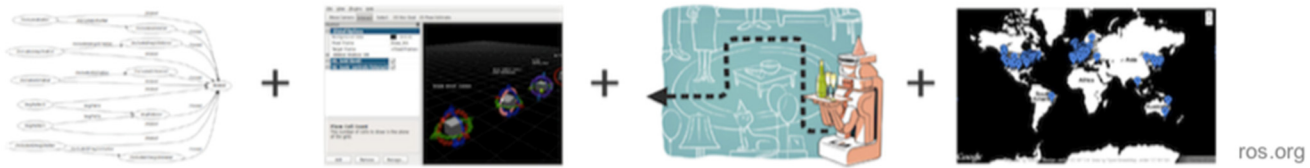
Controller PC System Architecture

What is ROS

- ROS (Robot Operating System) is an open-source framework and set of tools to build robotic applications. It has widespread use in robotics research and has strong community support.

ROS = Robot Operating System



Plumbing	Tools	Capabilities	Ecosystem
▪ Process management ▪ Inter-process communication ▪ Device drivers	▪ Simulation ▪ Visualization ▪ Graphical user interface ▪ Data logging	▪ Control ▪ Planning ▪ Perception ▪ Mapping ▪ Manipulation	▪ Package organization ▪ Software distribution ▪ Documentation ▪ Tutorials

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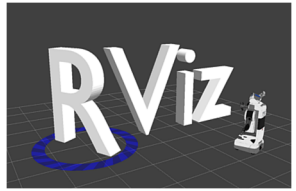
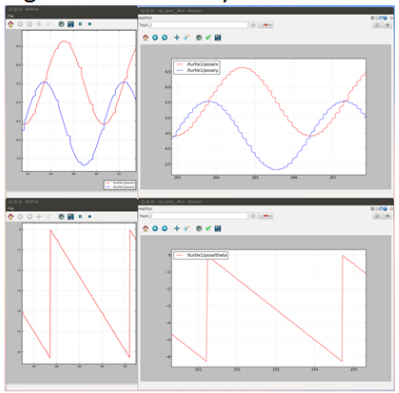
ROS

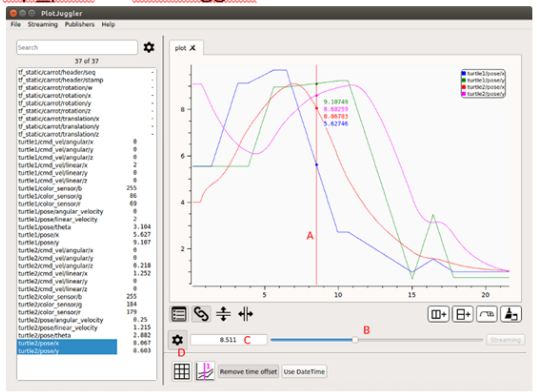
3D models and motion planning can be visualized with RViz

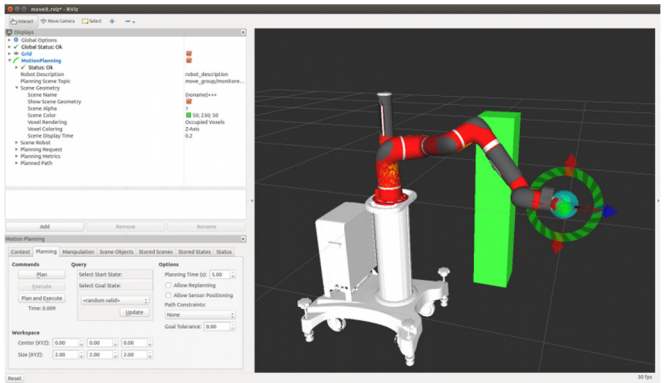


10.1.2. Visualization tools

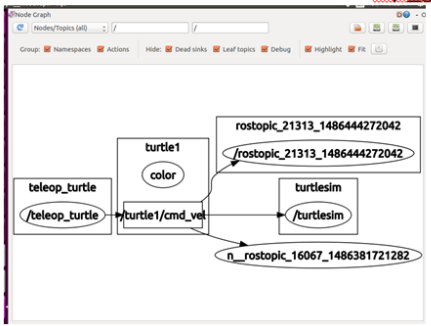
Signals can be easily visualized with rqt_plot or PlotJuggler.

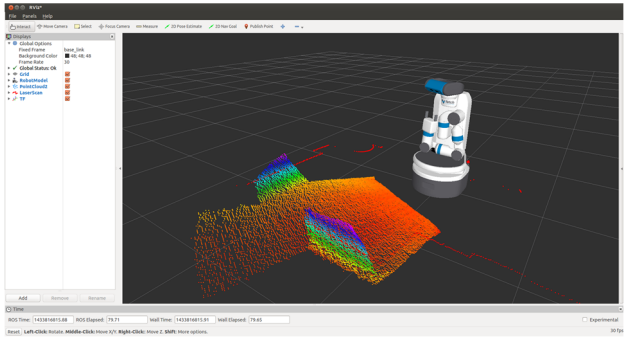


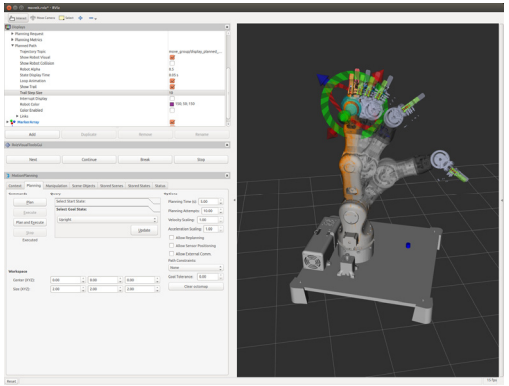




Modules can be visualized with rqt_graph.







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ROS Microservices architecture & event streams

RESTful API

Can talk to anything that can interface a RESTful API ☺
HTML/CSS/JS, Python, Java, EPICS, Pshell, etc.

Web-Interface

- Using the RESTful API, with HTML/CSS/JS, hosted on the smargopolo server.

redis

- real time position feedback to the existing beamlines software suite.

ROS smargopolo package

/Moderator
smargonMCS2.cpp
Subscribed to: /mode_request
Publishes on: /mode
Loop Rate: 50Hz

/mode_request
/mode_request
/mode

Flask + flask_restful
/RESTful_API
restful.py
Subscribed to:
/mode
/corr_type
/readbackBCS
/readbackSCS
/readbackMCS
/readbackCAL
/rosout_agg
/targetSCS_request
Publishes on:
/mode_request
/corr_type
/target_BCS_request
/target_SCS_request
/target_MCS
/nudgeBCS
/nudgeOBCS

/Nudge
nudge.cpp
Subscribed to:
/mode
/LJUE9_JointState
/readbackMCS
/nudgeBCS
/nudgeOBCS
Publishes on:
/target_SCS_request
ros::spin()

/Traj
smargonTraj.cpp
Subscribed to:
/mode
/target_SCS_request
Publishes on:
/target_SCS
Loop rate: 50Hz

/activeCorrection
activeCorrection.cpp
Subscribed to:
/mode
/target_SCS
/LJUE9_JointState
/corr_type
/readbackMCS
Publishes on:
/target_SCS_corr
/corr_val
ros::spin()

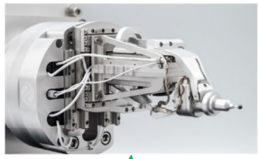
/SmarGonGM
smargonGM.cpp
Subscribed to:
/mode
/target_SCS_corr
/readbackMCS
Publishes on:
/target_MCS
/readback_SCS
ros::spin()

/SmarGon_MCS2
smargonMCS2.cpp
Subscribed to:
/mode
/target_MCS
Publishes on:
/mode_request
/readbackMCS
Loop Rate: 50Hz

/LJUE9_OMEGA
LabJackUE9.cpp
Subscribed to:
/mode
Publishes on:
/LJUE9_JointState
Loop rate: 200Hz

ros::spin() signifies the the main loop remains idle and only reacts to callback functions.

SmarGonMCS2



SmarAct

SmarAct MCS2 Controller

LabJack

LabJack UE9

Analog Signal

Aerotech Omega

Air-Bearing Rotary Stage

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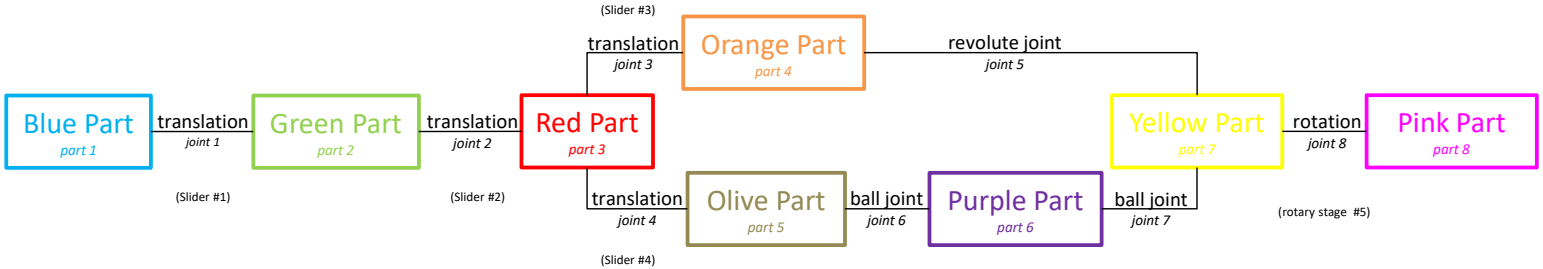
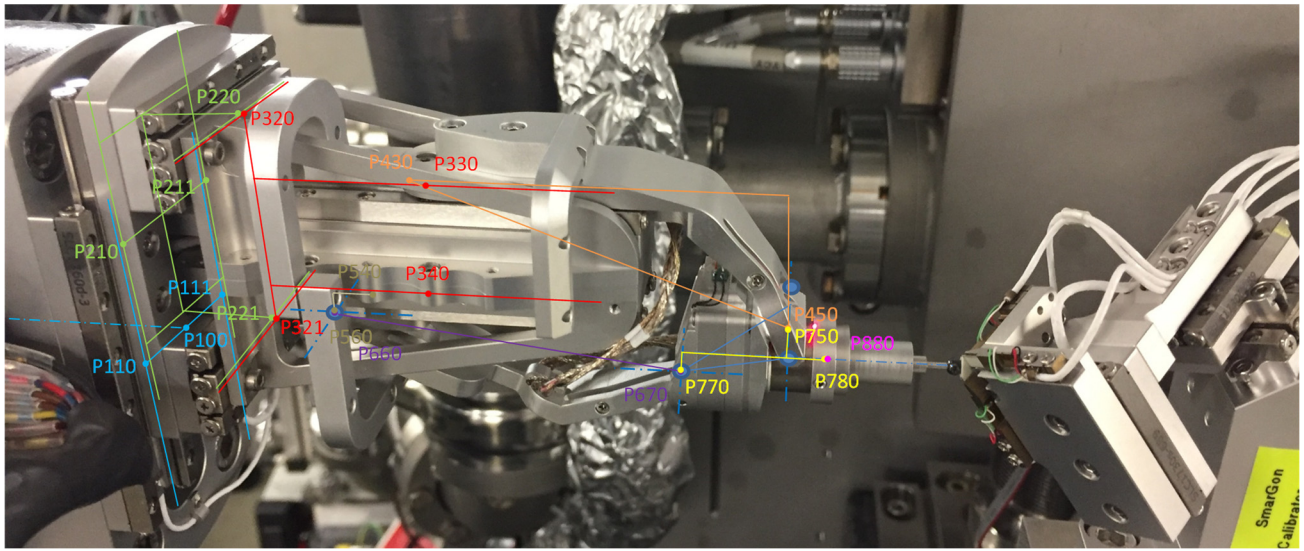
Rigid Body Geometrical Model





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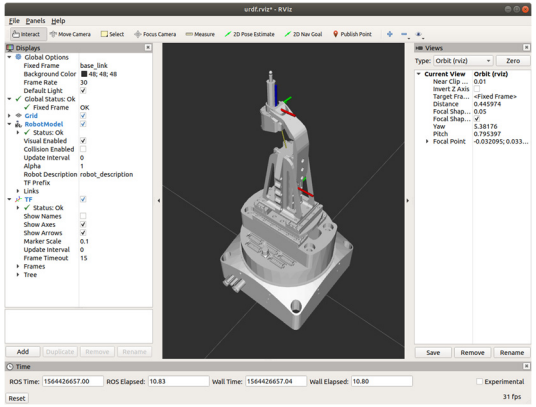
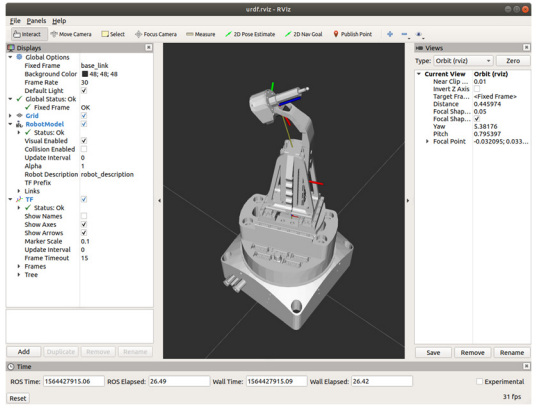
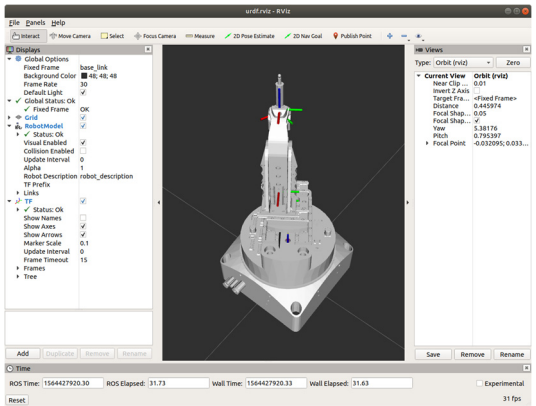
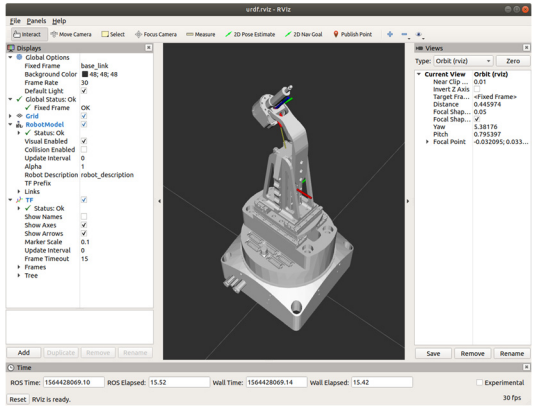
ROS Visualisation Tools









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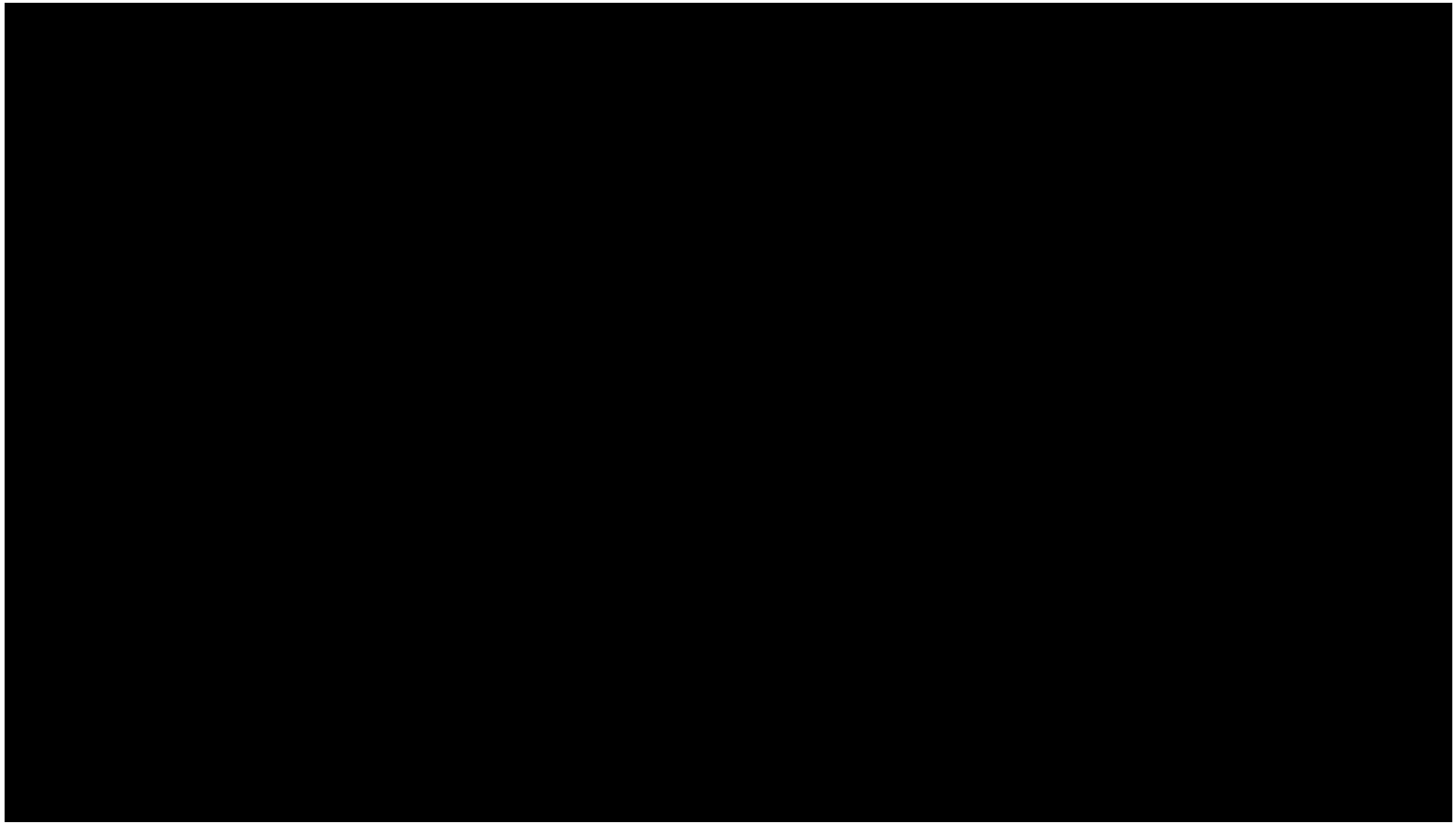
Digital Twin



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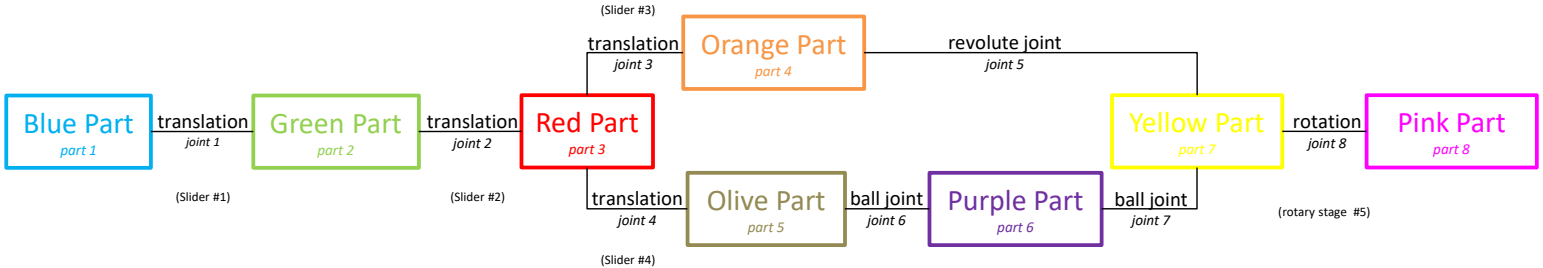
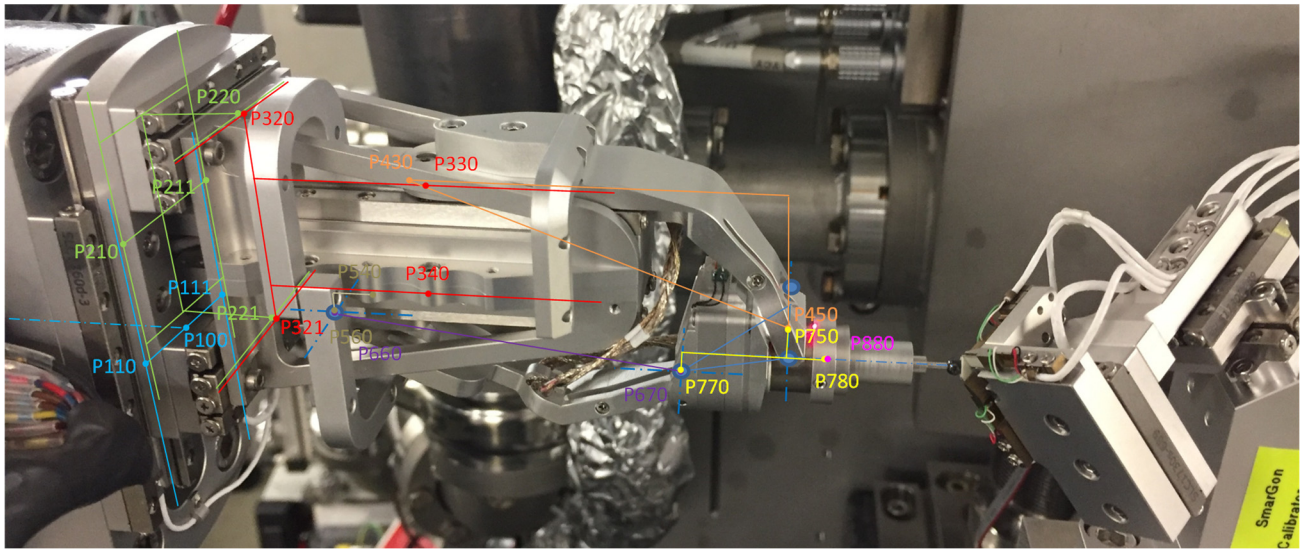
Rigid Body Geometrical Model





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Calibration

Measure the residual systematic error, actively correct for it in operation.
(-> using the system's repeatability to achieve accuracy)

In theory: for every point in the entire workspace, a correction vector must be known. For SmarGon this means, in 6 dimensional space (3 linear + 3 rotational coordinates) corrections in 6 dimensions need to be known.

In practice we can concentrate on a sub-portion of the workspace:
The workspace coordinates of main concern for the MX application are the ω and the χ axes. Radial and axial runout of these rotations must be kept to minimum.
In MX, this performance metric is referred to as the sphere of confusion (SoC).

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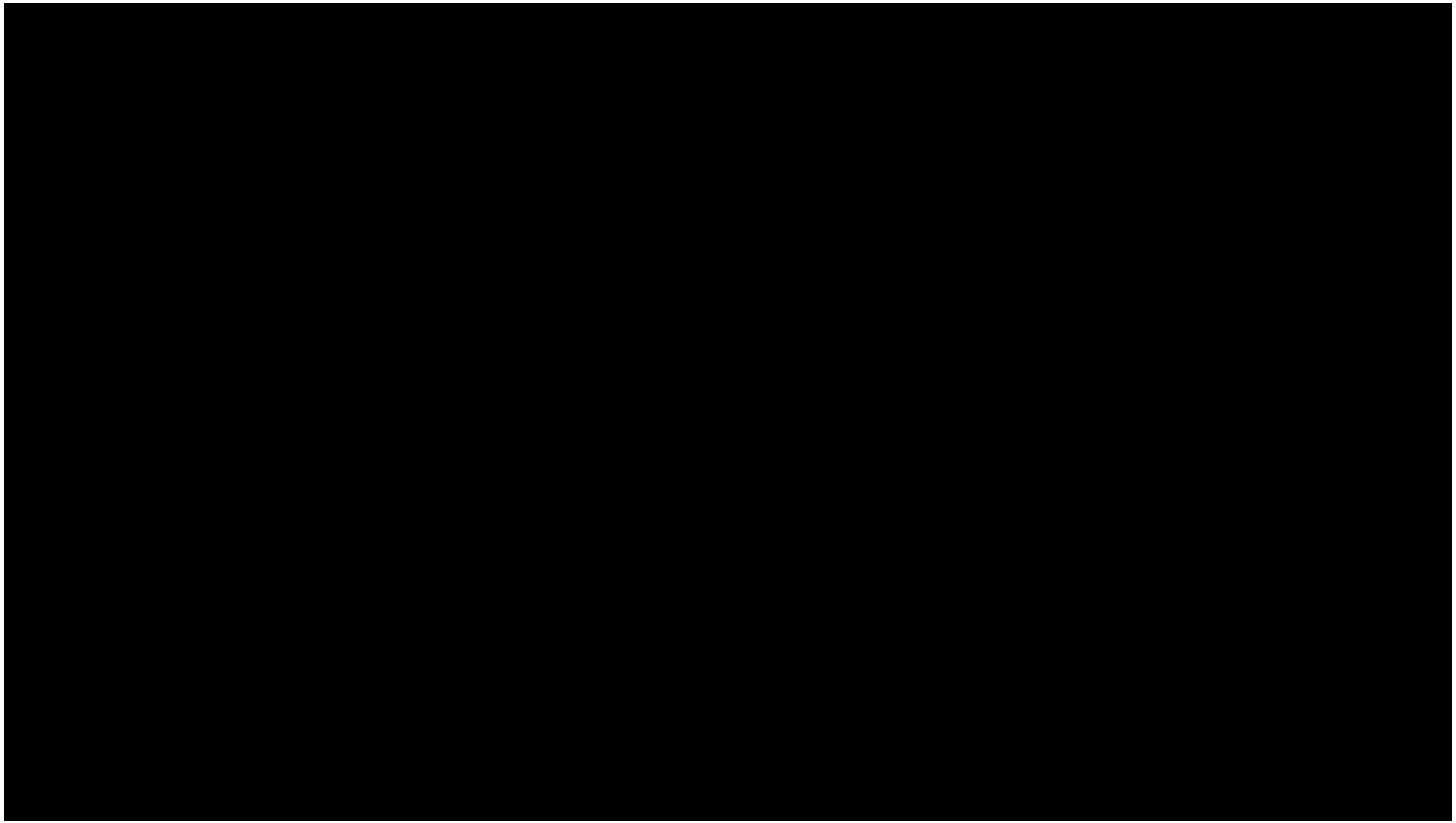
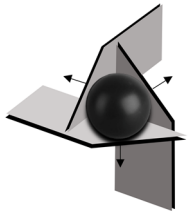
Calibration Tool





3 paddles with strain gauges

By moving 3 SmarAct Positioners

Regulate to a given strain (e.g. F=1g)

Encoders of SmarAct give the position with nm resolution over 25mm range.

A bit like a 3D CMM touch probe.

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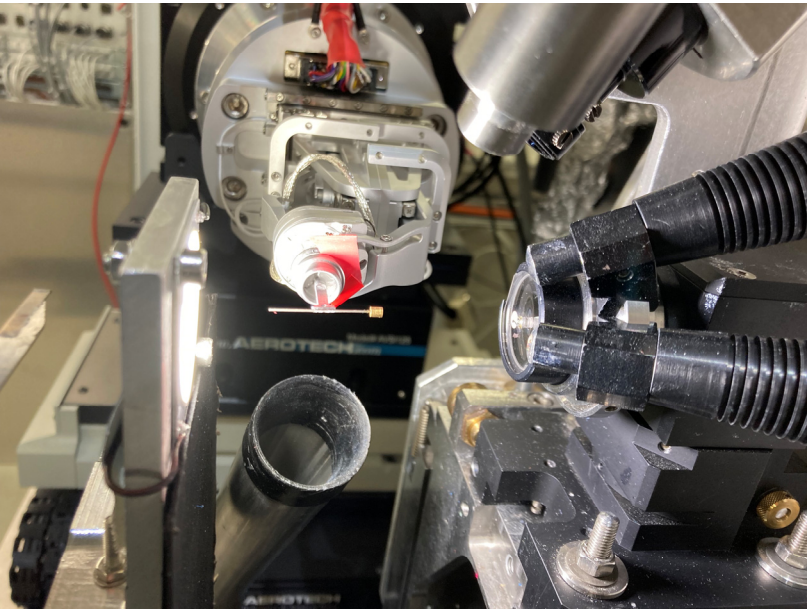
Calibration Results

- It is possible to do a calibration run within one hour.
- It's a step-by-step procedure, we can redo measurements, if the results look suspicious.
- So, on a machine day, Tuesday, a broken SmarGon get get back working.

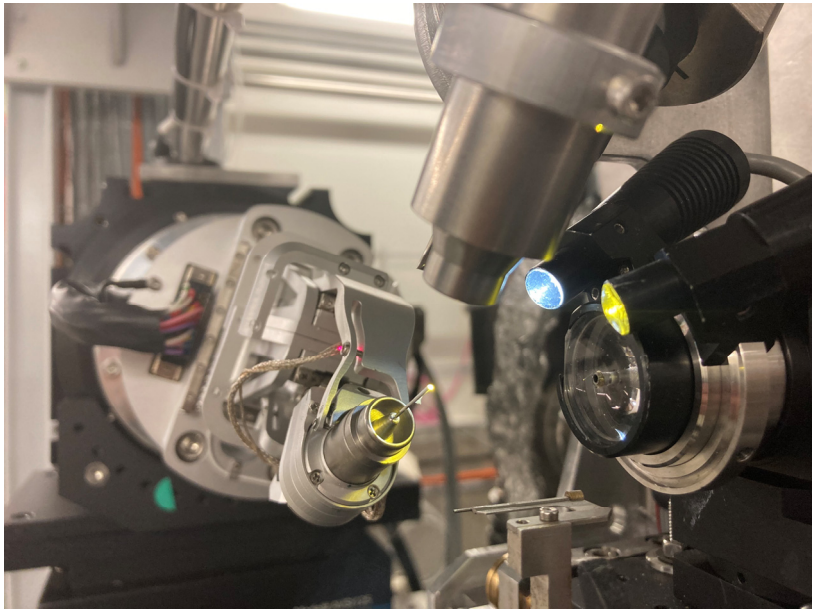
- within an hour we typically get calibration results of:
  - SoC of ω: 2 μm
  - SoC of χ : <7 μm

- With more time for data analysis and experimentation we have reached:
  - SoC of ω: 1 μm
  - SoC of χ : <5 μm

Other Applications



Align collimator tube (24mm, Din=100µm)
so
50µm X-ray beam
passes through it



SAS-Tensor Tomography setup evaluated at PXI, SmarGon could be re-purposed to allow orientation of the sample along axes commonly used in tomography experiments.

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Conclusion

- SmarGon MCS2 with smargopolo is now reliable enough to be constantly operated at all MX beamlines at SLS. Two devices have been in continuous 24/7 use for two years at beamlines PXI & PXII at SLS, with very satisfactory results.
- The replacement of PRIGo at PXIII, after 13 years of operation, is planned during the SLS 2.0 upgrade.
- Thanks to the open platform, we are confident to be able to further optimise and adapt the design to accommodate emerging applications in the future.

Thank you for your attention! - Questions?

My thanks go to

- PSI:
  - Dominik Buntschu
  - Zac Panepucci
  - Meitian Wang
- SmarAct GmbH:
  - Alexander Omelcenko
  - Stefan Bauroth
  - Jörg Sauter & Team