ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOPHA001

ROBOTIZING SOLEIL BEAMLINES TO IMPROVE EXPERIMENTS AUTOMATION*

Y.-M. Abiven†, T. Bucaille, L. Chavas, E. Elkaim, P. Gourhant, Y. Liatimi, K. Medjoubi, S. Pierre-Joseph Zephir, V. Pinty, A. Somogyi, F. Thiam, Synchrotron SOLEIL, Paris, France
S. Bouvel‡, EFOR, Levallois Perret, France
B. Pilliaud, Mediane Systeme, Le Pecq, France

Abstract

Synchrotron beamlines can benefit from the implementation of industrial robots in several ways: minimization of dead-time, maximization of experimental throughput, and limiting human presence during experiments. Furthermore, the robots add flexibility in task management. The challenge for SOLEIL is to define a robotic standard on both hardware and software which would be versatile enough to cover beamlines requirements, while being: easy to implement, easy to use, and to maintain in operation.

This paper will present the process of finding the standard definition at SOLEIL, using 6-axis industrial robot arms. It will detail all aspects of this development, from market studies up to technical constraints. The specifications of the robots are aimed at addressing the most common technical constraints of beamlines, with a special care for mechanical properties. The robotic systems will be integrated into the TANGO [1] control system using a feature-based approach. This standard implementation is driven by two applications: picking and placing samples for powder diffraction on the CRISTAL beamline and positioning of a detector for x-rays coherent diffraction experiments on the NANOSCOPIUM beamline.

INTRODUCTION

Beamlines in synchrotron facilities can benefit from the automation of tasks that do not require a high level of expertise. This is especially true when scientists or users have to perform repetitive tasks over long periods of time, e.g. continuously switching between measurements and sample replacements. The industrial robot is commonly used for repetitive tasks such as these. In this paper, the term “robot” refers to six degrees-of-freedom serial-link robotic arms. Robots have been extensively used in the industry, as they can perform a variety of tasks while being very robust.

At SOLEIL, a survey among beamlines has been organized in order to poll for the potential use of industrial robots. Among the beamlines which responded to the survey: 40% expressed a need for robots, 30% answered they would need to study whether a robot would be useful or not, and 30% answered they would not benefit from a robot.

Robots in synchrotron facilities have several potential use-cases:

- Increased beam-availability: beam-exploitation could increase, as they can operate in harsher environments and inconvenient time schedules.
- Increased experimental efficiency: Less time lost at opening hutches, changing samples, etc.
- Limit human intervention to increase overall safety: Less tasks and time in hazardous environments directly diminishes risk – not only for personnel but also for delicate materials, such as samples or detectors.
- Improve the user experience by providing additional automation and therefore lowering the amount of dull tasks.

In order to deploy robots in an easy and efficient way, a standard has been defined: setting up robot criteria, and on the interfaces between the robot and the other equipment. This standardization process is essential for maintaining equipment operation in a complex facility such as a synchrotron.

For a successful implementation of the robots, they have to be fully integrated into the SOLEIL TANGO-based control architecture. This development is user-centered to make sure it is effectively beneficial to the users.

This paper presents the definition of the SOLEIL robotic standard as well as its implementation in two separate applications: a pick-and-place robot for powder diffraction on the CRISTAL [2] beamline, and a detector-positioning robot on the NANOSCOPIUM [3] beamline.

ROBOT INTEGRATION STANDARDIZATION

Several aspects of the robots have to be standardized to ensure a proper implementation. Any new robotic system must be compatible with maintenance in large facilities that holds a limited amount of personnel. This requires: a hard limitation on the assortment of deployed equipment, easy deployments for non-expert roboticists, as well as efficient interventions of technical personnel.

Standardization of the Robot Brand

There are several industrial robot brands that all produce robust and efficient products. Yet, synchrotron applications are quite different from common industrial applications. Each robot brand has its own perks over its competitors.

The criteria’s for choosing industrial robots are generally: price, mechanical characteristics, and velocity. For synchrotron applications, up until now, velocity is not the

* Work supported by Synchrotron SOLEIL, Paris, France
† yves-marie.abiven@synchrotron-soleil.fr
‡ simon.bouvel@synchrotron-soleil.fr

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOPHA001

most important characteristic, as the time is gained more from the absence of human intervention rather than gained from a hasty object manipulation. Regarding price, the difference between brands is hardly the significant factor – as the biggest price gains mostly comes from big-volume sales. However, beamlines are very demanding on mechanical properties of the robots. Most beamline applications consist in positioning an object (sample or detector) precisely, and hold it in place in a stable manner. Robots are originally designed to be able to repeat the same motion over and over, intensively. The use of robots in beamlines deviates from what they were originally designed for. The mechanical characteristics sought for in beamlines are absolute precision and stability.

Stability, in the sense “residual motion when the robot is controlled to be completely still”, is not a common characteristic for robot manufacturers to specify. In order to obtain quantitative information about this, some preliminary studies have been carried out by several manufacturers. The results of these studies indicate that robots should be stable enough for most beamline applications, meaning maintaining a 10µm stability over 48h. More detailed studies are currently being carried out to confirm these preliminary results on specific models.

The general movement in industrial robotics is towards collaborative robots, meaning robots that operate safely in close proximity with human beings. Even if the use of robots in beamlines is, for now, restricted to experimental areas where people aren’t present – opening up this standard to collaborative robotics is an open door for future requirements.

At SOLEIL, three different ranges of robots have been standardized to cover most of the applications:

- A “small” size robot, with about 900mm arm range. This robot is mounted on a frame designed to be easily movable from its environment, to be able to move it from one beamline to another.
- A “medium” size robot, with about 1200mm arm range
- A “large” size robot, with about 2000mm in arm range, in order to cover large areas and angles in the experimental environment.

With all of these robots, the same controller is associated, the only difference being the power output.

Interfaces Standardization

The robot itself is linked to many specific pieces of equipment in the beamlines. In order to make possible a standard integration of the robots, all the interfaces between the robot and the rest of the beamline have been specified. A diagram of the equipment and its interfaces is presented on Fig. 1. Some interfaces with the robot, like power supply, are pretty straightforward, others must be carefully specified:

- Interface between the robot and its tool, based on an automatic tool changer, it facilitates processes automation. The amount of electrical and pneumatic connections within the tool changer has been decided in order to anticipate future needs (with at least 10 electric contacts and 4 pneumatic links). The collision sensor associated with the tool changer give more security in order to limit collision damages.
- Interface between the robot and the hutch: The small sized robots are specified to be easily put in place and removed in a matter of minutes. In order to carried out this function, they are integrated on a mobile cart, with its controller.

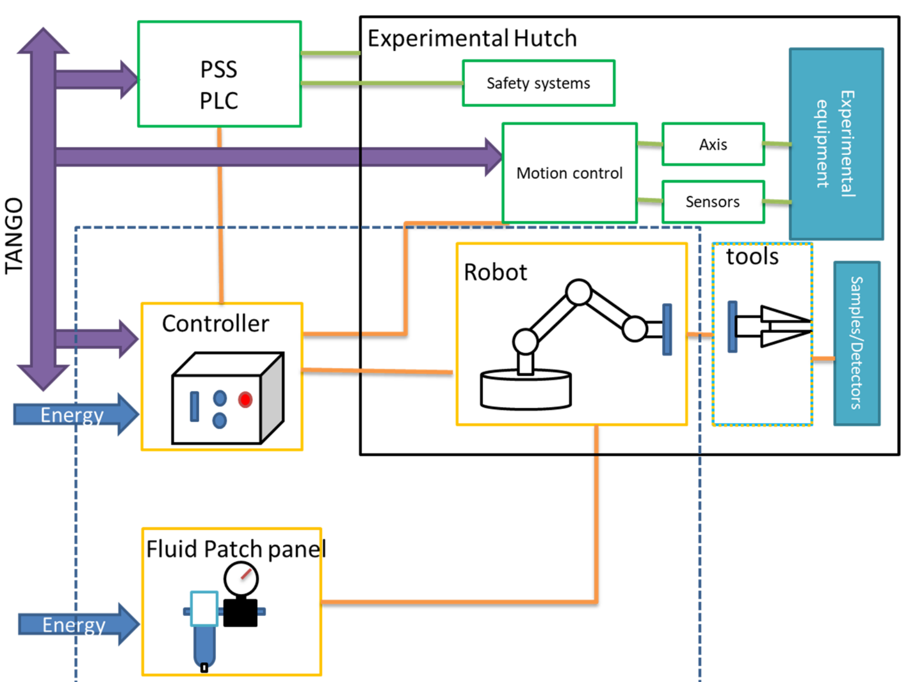

Figure 1: Architecture implementing an industrial robot at SOLEIL, and its interfaces.

17th Int. Conf. on Acc. and Large Exp. Physics Control Systems ICALEPCS2019, New York, NY, USA JACoW Publishing
ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOPHA001

SOFTWARE INTEGRATION OF THE ROBOTS

In conventional industrial implementation of robots, the controller only communicates with a PLC using a fieldbus. Thus the sequence of robot programs is executed in accordance to a predetermined order.

At SOLEIL the robot is not implemented with this PLC, because the TANGO control system already integrates a sequencer, scanning tools, etc... In this environment the robot is seen as a configurable objet contributing to beamline automation. In order to deal between operation and safety in this environment, several profiles of users are defined with higher to lower level of control over the robots. The users would have the weakest level of control, which is sufficient to run experiments autonomously. Then the beamline personnel, as well as technical personnel will have a higher degree of control on the robot, with access to some low-level commands. Finally, the expert roboticists will be the only ones to have full control on all the aspects of the robots, including security aspects.

From the control system point of view, the robot controller has methods and attributes. Methods are routines used to communicate and act on the physical environment, and attributes are parameters or variables of the controller. Some methods can be applied to any robot environment, such as ordering the robot to turn actuators on, having the robot go to a parking position, enabling robot brakes, etc. Some other methods can be task-specific, like picking up a sample in a certain experiment, or positioning a certain detector in space in another, etc. In order to keep the control system of the robot as generic as possible, all the task-specific methods are treated differently than generic methods. The task-specific methods were named “features”, and two generic methods have been implemented to interact with these features.

The two generic methods are the following:

- Interrogating the controller about the features that are available. The response takes form of a tree of features. That was, any number of features can be implemented, each with potentially different argument or responses.
- Executing a certain feature. Once the list of features has been extracted using the first method, this second method allows the user to launch these features.

The features themselves are coded inside the controlled by the roboticist. For each new application, the roboticist is able to program the corresponding features. The end-user will not be able to program these features directly, only to get a list of them, and call them. Thanks to an automatic identification of the environment the robot is placed in, available features can be limited for the user. This approach prevents allowing the end user to manipulate low-level functionalities of the robot, which is necessary for security reasons.

In practice, the users will be familiar with the generic methods and attributes of the robot from a control system point of view, and will also have access to some specific features, depending on their application. The following Fig. 2 present a schematic view of the software integration of the robots.

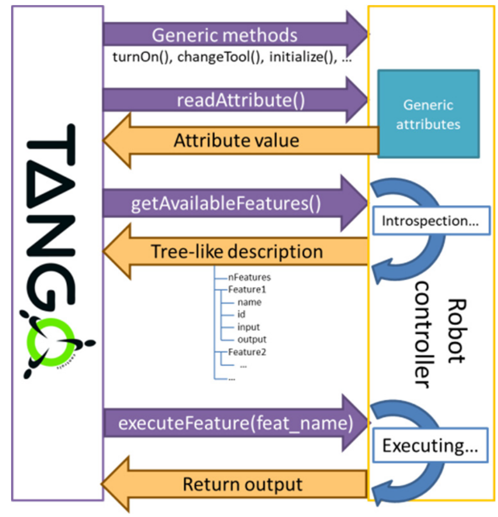

Figure 2: Software integration principle.

APPLICATIONS

The first beamlines to be robotized at SOLEIL will be the CRISTAL an NANOSCOPIUM beamlines.

CRISTAL Beamline

Robotization of the CRISTAL beamline will be used to automate the sample exchange for powder diffraction experiment. Because the beamline does not wish to have the robot in place at all times, and due to the overall dimensions of the beamline, a small size robot has been chosen.

As mentioned previously, this small robot in these standards is mounted on a cart that includes its controller and some electrical IOs, a fluid panel, and pneumatic control valves.

The robot is used to pick sample from a rack, and place it on the goniometer. The users can then proceed with their measurements. The sample replacement is automated thanks to the robot.

Figure 3 shows a CAD representation of the robot in the environment of CRISTAL beamline.

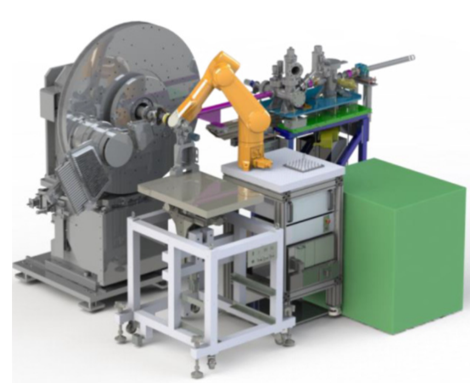

Figure 3: CAD representation of the robot to be integrated in the CRISTAL beamline.

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOPHA001

The sample magazine will be able to store 36 samples, all with identical sample holders. The users will then be able to prepare the samples beforehand, saving time on the beamline. We can nowadays estimate it will take the robot about 5s to replace a sample on the goniometer.

NANOSCOPIUM Beamline

The NANOSCOPIUM beamline wishes to use the robot as a tool to position a detector inside the beamline. The detector is to be mounted at the end of the robot to observe diffraction patterns.

The further the detector is from the sample, the better the resolution of the diffraction pattern will be. To be able to use all of the beamline space, the robot chosen is a large size robot, and it will be mounted on a large translation axis, as shown on Fig. 4.

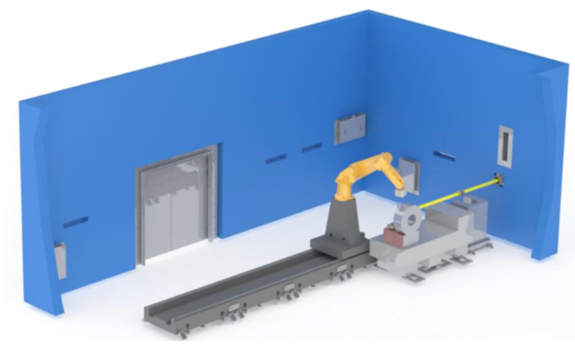

Figure 4: CAD representation of the robot to be integrated in the NANOSCOPIUM beamline, mounted on a translation axis.

A typical use of the robot in the experimental setup takes place in two phases:

- First an alignment phase: the robot moves the detector around a 500mm sphere centered on the sample, to identify a direction of interest for the diffraction.
- Then an acquisition phase: the detector is positioned by the robot in the identified direction, but much further away from the sample (up to 5m away). The detector must remain very still during this phase, so that changes in the data are caused by kinematic effects of the sample, not by motion of the detector.

In this application, the problem of using the robot is twofold: we must be able to perform precise positioning of the detector relative to the sample, and the detector must have great stability.

Positioning the end-effector of the robot is a common issue in industrial robotics, so manufacturers have built-in solutions that allow it. Working in close collaboration with the alignment group at SOLEIL, we are confident we can achieve a 200µm precision positioning.

The stability is, on the contrary, quite an unusual request for robot manufacturers. The preliminary studies performed make us confident that we can keep the undesired motion of the detector within a 10µm radius sphere, but more thorough studies are currently in progress.

CONCLUSION

In this paper, the project of robotizing SOLEIL beamline was presented. The process of standardization of the robotic solutions deployed was described. The most important criterion for the choice of a manufacturer in synchrotron facilities is the mechanical performance of the robot. At SOLEIL, the chosen robot brand is Staübli [4], a brand that has a history of mechanical excellence. As for software integration, a feature-based approach was chosen, as it provides flexibility and comfort to the users, but keeps the low-level security-sensitive programs to trained roboticists. There are currently two applications for robotic integration, a pick-and-place robot for the CRISTAL beamline, and a detector positioning robot in the NANOSCOPIUM beamline.

Other applications are currently taken into consideration, or using robots as tools for item classification for the upcoming upgrade. The robots of the first two applications will be deployed in early 2020 for the CRISTAL beamline, and mid-2020 for the NANOSCOPIUM beamline. A further review of the use of the robots in these applications will help us have an evaluation of the benefit and constraints of using robots in a synchrotron environment.

REFERENCES

[1] Tango controls, https://www.tango-controls.org

[2] CRISTAL beamline, https://www.synchrotron-soleil.fr/en/beamlines/cristal

[3] NANOSCOPIUM beamline, https://www.synchrotron-soleil.fr/en/beamlines/nanoscopium

[4] Staubli robotics, https://www.staubli.com/en-fr/robotics