JOpenShowVar: an Open-Source Cross-Platform Communication Interface to *Kuka* Robots*

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***Abstract*— This paper introduces *JOpenShowVar*, a Java open-source cross-platform communication interface to *Kuka* robots that allows for reading and writing variables and data structures of the controlled manipulators. This interface, which is compatible with all *Kuka* robots that use *KR C4* and previous versions, runs as a client on a remote computer connected with the *Kuka* controller via *TCP/IP*. *JOpenShowVar* opens up to a variety of possible applications making it possible to use different input devices, sensors and to develop alternative control methods.**

To show the potential of the proposed interface, two case studies are presented. In the first one, *JOpenShowVar* is used to control a *Kuka KR 6 R900 SIXX (KR AGILUS)* robot with an *Android* mobile device. In the second case study, the same manipulator is controlled with a *Leap Motion Controller* that supports hand and finger motions as input without requiring contact or touching. Related simulations are carried out to validate efficiency and flexibility of the proposed communication interface.

***Index Terms*— Robot interface, Manipulator, Control system.**

I. INTRODUCTION

As far as robotics is concerned, very few industrial manipulators with an open control interface have been released. Restricting the focus to *Kuka* robots [1], the standard programming language is the *Kuka Robot Language* (KRL) [2]. This language is text based and offers the possibility of declaring data types, specifying simple motions, and interacting with tools and sensors via I/O operations. A KRL program can only run on the *KUKA Robot Controller* (KRC), where it is executed according to real-time constraints. While the KRL offers an easy to use interface for industrial applications, it is very limited when it comes to research purposes [3], [4]. In particular, the KRL is tailored to the underlying controller and, as a consequence, it only offers a fixed, controller-specific set of instructions [5]. The KRL does not support advanced mathematical tools such as matrix operations, optimisation or filtering methods, thus making it very difficult to implement novel control approaches. There is no mechanism for including third party libraries. Due to this design, it is very difficult to extend the KRL with new instructions and functionalities. Moreover, no external input devices can be directly used. The standard workaround for partially expanding the robot's capabilities consists of using supplementary software packages provided by *Kuka*. Some examples of such packages are the *KUKA.RobotSensorInterface* [1], which makes it possible to influence the manipulator motion or program execution via sensor data, or the *KUKA.Ethernet KRL XML* [1], a module that allows the robot controller to be connected with up to nine external systems (e.g. sensors). However, these supplementary software packages have several drawbacks such as limited I/O, a narrow set of functions and often require major capital investments.

To overcome these problems, this paper presents *JOpenShowVar*, a Java open-source cross-platform communication interface that makes it possible to read and write all of the controlled manipulator variables, allowing researchers to use different input devices, sensors and to develop alternative control methods. This interface is compatible with all *Kuka* robots that use *KR C4* or previous versions. *JOpenShowVar* works as a *middleware* between the user program and the KRL. *JOpenShowVar* is an open-source project and it is available on the Internet at `https://github.com/aauc-mechlab/jopenshowvar`, along with several detailed class diagrams, documentation and demo videos.

The paper is organised as follows. A review of the related research work is given in Section II. In Section III, we focus on the description of the *JOpenShowVar* architecture, analysing the communication protocol and possible control approaches. In Section IV two case studies are presented. In the first case study, *JOpenShowVar* is used to control a *Kuka KR 6 R900 SIXX (KR AGILUS)* robot with an *Android* [6] mobile application. In the second case study, the same manipulator is controlled with a *Leap Motion Controller* [7] that supports hand and finger motions as input without requiring contact or touching. Concerning the latter case study, related simulations and results are shown in Section V. In Section VI, conclusions and future works are outlined.

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II. Related Research Work

Several research groups have investigated the possibility of creating a software interface to the *Kuka* industrial robots. In [3], *OpenKC*, an open-source real-time control software for the *Kuka lightweight* robot was presented. This software allows the external triggering and control of all the robot features by using a simple set of routines that can easily be integrated in existing software. This enables developers of robot applications to find solutions for a variety of different software scenarios. However, this software interface is restricted to a specific model of *Kuka* robots, the *Kuka lightweight* manipulator, and requires the use of the *KUKA.RobotSensorInterface* package. In [8], the *Kuka Control Toolbox* (KCT), a collection of *MATLAB* functions for motion control of *Kuka* robots was introduced to offer an intuitive and high-level programming interface for the user. This toolbox is compatible with all six degrees of freedom (DOFs) small and low-payload *Kuka* robots. In detail, a multi-thread server runs on the KRC and communicates via *KUKA.Ethernet KRL XML* with a client that manages the information exchange with the manipulator. This communication scheme guarantees high transmission rates, thus enabling real-time control applications. Nonetheless, as in the previous work, this approach is still tailored to the underlying controller and requires the use of the *KUKA.Ethernet KRL XML* package.

Other researchers have tried a different approach aimed at the disclosure of internal control architecture of the *Kuka* industrial manipulators. In [5], for instance, the reverse engineering of KRL was investigated and a set of Java-based *Robotics APIs* were presented for programming industrial robots on top of a general-purpose language. The *Robotics APIs* implement robot commands like motions and access to I/O calls. However, the *Robotics APIs* set presents some safety limitations because it is the result of a reverse engineering approach and it does not include a way of specifying complex triggers like it is possible in KRL.

Recently, *Kuka* has shown more interest in the research and education market. In particular, the *KUKA youBot*, a mobile manipulator platform with open interfaces that include several open-source software modules has been released [9]. However, even though, the *KUKA youBot* robot is the only manipulator from *Kuka* with such an open interface, it has several constraints concerning the limited payload and dimensions that make it more suitable for educational use rather than for industrial applications.

To the best of our knowledge, a cross-platform communication interface that works with all *Kuka* robots has not been released yet.

III. *JOpenShowVar* Architecture

In this section, the authors refer to several specific functions, variables and configurations related to the KRL and the KRC. For a deeper understanding the reader can refer to [2]. The proposed control system architecture is shown in Fig. 1. It is a client-server architecture with *JOpenShowVar* running as a client on a remote computer and *KUKAVARPROXY* acting as a server on the KRC. *JOpenShowVar* locally interacts with the user program and remotely communicates with the *KUKAVARPROXY* server via *TCP/IP*.

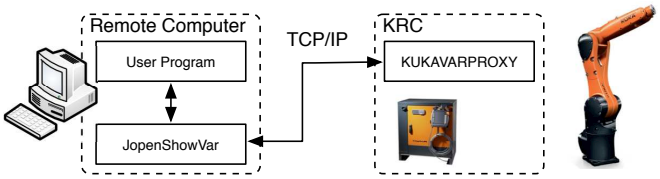


Fig. 1: The proposed architecture for *JOpenShowVar*: a client-server model is adopted.

In particular, *KUKAVARPROXY* is a multi-client server that is written in Visual Basic 6.0 and can serve up to 10 clients simultaneously. It implements the *Kuka CrossComm* class. The interface of this class allows for the interaction with the real-time control process of the robot and makes it possible to perform several operations such as selection or cancellation of a specific program, errors and faults detection, renaming program files, saving programs, resetting I/O drivers, reading variables and writing variables. *KUKAVARPROXY* implements the reading and writing methods. All the variables that need to be accessed by these methods have to be declared as global variables in the predefined global system data list $CONFIG.DAT. All kinds of variables can be declared in this file from basic types such as INT, BOOL and REAL to more complex structures like E6POS and E6AXIS that allow for storing the robot configuration. Moreover, several system variables can be accessed provided there are no restrictions due to the type of data such as for $PRO_IP, $POS_ACT, $AXIS_ACT or $AXIS_INC. For example, The current robot position cannot be written but only read. Restrictions of this nature are checked by the controller. However, it should be noted that the *Kuka CrossComm* class does not provide a real-time access to the robot's data. In fact, it takes a non-deterministic time to access a specific variable. Since *Kuka* does not offer any kind of documentation on this topic, several experimental tests were performed at our laboratory in order to asses this time interval. According to our experiments, reported in Section V, the average access time is about 5 ms. Moreover, this time interval is not affected by the kind of access to be performed (whether it is a reading or a writing operation) or by the length of the message. For these reasons, it is advantageous to aggregate several variables in logical structures when reading or writing data. By using structures of data it is possible to simultaneously access several variables thereby minimising the access time. The only limitation to this approach is on the length of the logical structures that cannot exceed 255 bytes.

JOpenShowVar is a client written in Java, thus making

TABLE I: Reading variables

Field	Description
00	message ID
09	length of the next segment
0	type of desired function
07	length of the next segment
$OV_PRO	Variable to be read

TABLE II: Writing variables

Field	Description
00	message ID
0b	length of the next segment
1	type of desired function
09	length of the next segment
$OV_PRO	Variable to be written
50	value to be written

cross-platform support possible. This client essentially provides one method, *sendRequest*, that allows for both reading and writing variables. The return type of the *sendRequest* method is a *Callback* instance containing the updated value.

A. Communication protocol

The communication protocol relies on the TCP/IP protocol. In particular, on top of the TCP/IP layer, specially formatted text strings are used for message exchanges. *KUKAVARPROXY* actively listens on TCP port 7000. Once the connection is established, the server is ready to receive any reading or writing request from the client.

In order to access a variable, the client must specify two parameters in the message: the desired type of function and the variable name. To read a specific variable, the type of function must be identified by the character "0". For instance, if the variable to be read is the system variable $OV_PRO, which is used to override the speed of the robot, the message that the client has to send to the server will have the format shown in Table I. In detail, the first two characters of this string specify the message identifier (ID) with a progressive integer number between 00 and 99. The answer from the server will contain the same ID so that it is always possible to associate the corresponding answer to each request even if the feedback from the server is delayed. The two successive reading message characters specify the length of the next segment in hexadecimal units. In this specific case, 09 accounts for one character specifying the function type, two characters indicating the length of the next segment and seven characters for the variable length. The fifth character 0 in the message represents the type of the desired function - reading, in this case. Subsequently, there are two more characters indicating the variable length (in hexadecimal units) and finally the variable itself is contained in the last section of the message.

To write a specific variable, three parameters must be specified: the type of function, the name of the desired variable and the value to be assigned. The writing function is specified by the character "1". For instance, if the variable to be written is the system variable $OV_PRO with a value of 50 (50% override speed), the message that the client has to send to the server will have the format shown in Table II.

B. Control approach

JOpenShowVar opens up to a variety of possible applications making it possible to use different input devices and to develop alternative control methods. In particular, the proposed interface provides the possibility of implementing either a position or a velocity control approach. The user experience is substantially different in each case. When using the position control mode, the operator simply controls the position of the robot's end-effector with constant velocity; when operating in velocity control mode, the operator also sets the velocity of the robot tool. In the first case, when the operator releases the input device, the end-effector moves back to its starting point, while in the second scenario, the arm just stops moving but it keeps the last given position.

To control the robot motion according to the desired operational scenario, *JOpenShowVar* allows researchers to use the standard kinematics provided with the KRC. However, it is also possible to implement alternative control algorithms according to current needs as shown in Fig. 2-a and in Fig. 2-b respectively. It should be noted that KRL does not provide a native way to obtain velocity control. When using the KRC kinematics, this limitation can be overcome by expressing the target position as:

$$\mathbf{x}_t = \mathbf{x}_d, \tag{1}$$

if operating in position control mode, or by:

$$\mathbf{x}_t = \mathbf{x}_a + \dot{\mathbf{x}}_d \Delta t, \tag{2}$$

if operating in velocity control mode, where Δt is the time interval between two successive iterations. Alternatively, when a custom control algorithm is needed, the target joint configuration is given by:

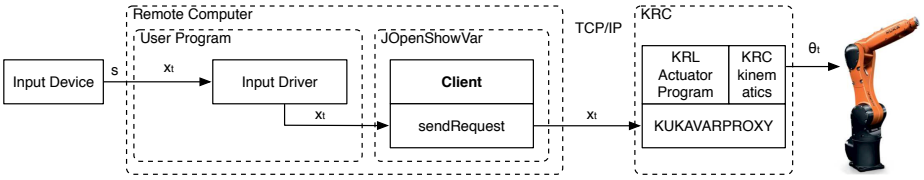
$$\theta_t = \theta_d, \tag{3}$$

if operating in position control mode, or by:

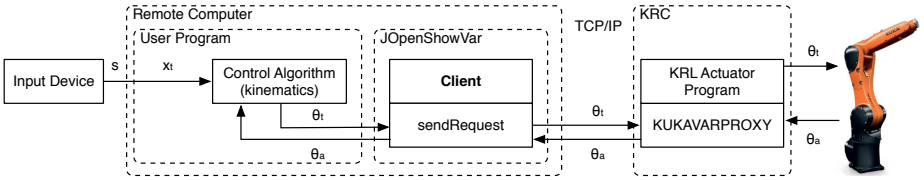
$$\theta_t = \theta_a + \dot{\theta}_d \Delta t, \tag{4}$$

if operating in velocity control mode.

When the operator manoeuvres the manipulator, a vector signal with no semantic, $\mathbf{s}$, is sent from the input device to the user program. Here, according to the operational scenario, the vector signal is interpreted as the target position $\mathbf{x}_t$. If the intent is to use the standard kinematics provided with the KRC, the user program simply works as a driver for the input device and uses the *sendRequest* method of *JOpenShowVar* to forward $\mathbf{x}_t$ to a KRL program where the standard KRC kinematics is used to calculate the joint angles θ_d. Alternatively, a custom control algorithm can be implemented within the user program to calculate the joint values for the robot according to $\mathbf{x}_t$. Essentially, the custom



(a)



(b)

Fig. 2: (a) the user program utilises *JOpenShowVar* to set the desired end-effector position and then the robot joints are calculated by the KRC using the standard kinematic model, (b) a custom control algorithm can be implemented by the user to calculate the joint values for the robot and then send these angles to the KRC to be actuated.

control method has to implement classic inverse kinematic functions that can be generalised as follows:

$$\theta_d = f_p^{-1}(\mathbf{x}_d), \tag{5}$$

concerning position control, and

$$\dot{\theta}_d = f_v^{-1}(\theta_a, \dot{\mathbf{x}}_d), \tag{6}$$

for velocity control, where θ_a is the the actual joint angles vector. These values are then forwarded to a KRL program where the standard KRC functions are used to actuate the robot.

Note that the possibility of implementing certain control features does not influence the design for the presented interface. Instead, *JOpenShowVar* extends the functionalities of the KRL language.

IV. Case Studies

A. Case study 1: controlling the Kuka KR 6 R900 SIXX manipulator with an Android mobile device

To show the potential of the presented interface in controlling a *Kuka* robot from an alternative input device, as a first case study, *JOpenShowVar* is used to control a *Kuka KR 6 R900 SIXX* manipulator with an *Android* mobile device. The *Kuka KR 6 R900 SIXX*, shown in Fig. 3-a, is a 6 DOFs robotic arm with a slim design and a small footprint.

According to the operational scenario, an *Android* mobile application whose Graphic User Interface (GUI) is shown in Fig. 3-b, is used to set the target position $\mathbf{x}_t$. By using the *sendRequest* method of *JOpenShowVar* this vector is forwarded to the *KUKAVARPROXY* and stored as a global value in a data structure. Finally, a KRL actuator program iteratively retrieves the new global data and uses the KRC kinematics to actuate the robot. The code of the KRL actuator program is shown in Algorithm 1. For *Kuka* robots, the idle time between motions can be shortened by executing the

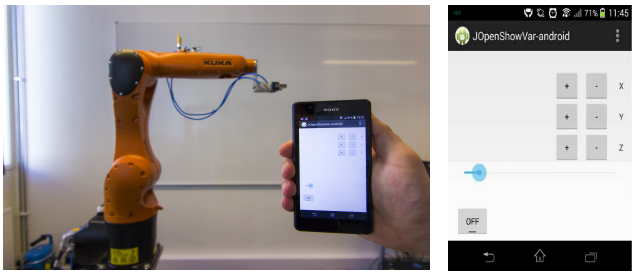


Fig. 3: (a) The *Kuka KR 6 R900 SIXX* manipulator, (b) the GUI of the Android mobile application used to control the arm.

```
DEF ACTUATOR()
  INI
  PTP HOME Vel = 100 % DEFAULT
  $ADVANCE=1
  LOOP
    PTP_REL MYPOS C_PTP
  ENDLOOP
  PTP HOME Vel = 100 % DEFAULT
END
```

Algorithm 1: KRL actuator program for the case study 1

time-consuming arithmetic and logic instructions between motion commands while the robot is moving, i.e. processing them during the advance run (the instructions “run” in advance of the motion). Using the system variable $ADVANCE, it is possible to define the maximum number of motion blocks the advance run may process ahead of the main run (the motion block currently being executed). Since the main loop of the Server program consists of only one instruction, the system variable $ADVANCE is initially set to 1 in order to avoid the unwanted execution of the same line of code. Inside the main loop, a relative movement is iteratively executed to the global variable MYPOS, which is the one that stores the target position. The key word C_PTP is used to approximate

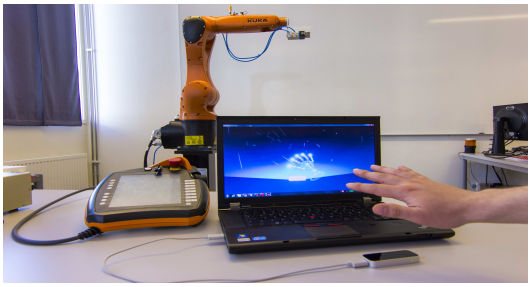


Fig. 4: The *Leap Motion Controller* used to operate the *Kuka KR 6 R900 SIXX* manipulator.

the movement. The approximate positioning instruction is executed in a time-optimised manner in the sense that there is always at least one axis moving with the programmed acceleration or velocity limits. The system simultaneously ensures that the permissible gear and motor torques for each axis are not exceeded. Furthermore, the higher motion profile, set by default, ensures motion that is optimised in terms of velocity and acceleration.

B. Case study 2: controlling the Kuka KR 6 R900 SIXX manipulator with a Leap Motion Controller

As a second case study, *JOpenShowVar* is used to control the same robot (from the first case study) with a custom control algorithm. This is done to highlight the potential of the presented interface in developing alternative control methods that do not use the standard kinematic model provided by *Kuka*. Moreover, a *Leap Motion Controller* [7], shown in Fig. 4, is used as alternative input device to control the robot. The *Leap Motion Controller* is a small USB input device that supports hand and finger motions as input without requiring contact or touching. This controller is designed to be placed on a physical desktop, facing upwards. Using two monochromatic infra-red (IR) cameras and three IR light-emitting diodes (LEDs), the device observes a roughly hemispherical area, to a distance of about 1 meter. The LEDs generate a 3D pattern of dots of IR light and the cameras generate almost 300 frames per second of reflected data, which is then sent through a USB cable to the host computer, where it is analysed by the *Leap Motion Controller* software and can be retrieved using the *Leap Motion APIs*. While the *Leap Motion Controller* makes it possible to control all the joints of human hands, in this specific case study, only the DOFs of the wrist are used as an input signal to control the robot's end-effector. Each DOF of the wrist corresponds to a translational axis in the workspace of the robot to be controlled. When operating in position control mode, the input device works as a position proportional replica so that the wrist motion maps exactly to the motion of the robot's end-effector with constant speed, while, when operating in velocity control mode, a movement of the wrist in a particular direction will produce a translational motion in the same direction at a velocity proportional to the wrist

```
DEF EXT_MOVE_AXIS()
  DECL AXIS LOCAL
  INI
  PTP HOME Vel = 100 % DEFAULT
  $ADVANCE=1
  LOCAL.A1 = $AXIS_ACT.A1
  ...
  LOCAL.A6 = $AXIS_ACT.A6
  LOOP
    LOCAL.A1 = LOCAL.A1 + MYAXIS.A1
    ...
    LOCAL.A6 = LOCAL.A6 + MYAXIS.A6
    PTP LOCAL C_PTP
  ENDLOOP
  PTP HOME Vel = 100 % DEFAULT
END
```

Algorithm 2: KRL actuator program for the case study 2

displacement. For better control interface usability, a small spherical imaginary volume with a diameter of about 8 cm is defined in the centre of the controller monitoring space. As long as the operator's wrist is located within this volume, the robot's end-effector does not move.

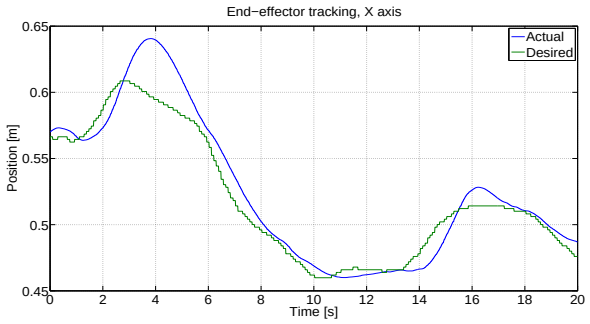
The user program runs on a remote computer and uses the *Leap Motion APIs* to retrieve the target position $\mathbf{x}_t$ according to the operational scenario. By using the *sendRequest* method of *JOpenShowVar*, the actual joint angles θ_a are received. This data is used as input for the custom control algorithm. In this specific case study, the classical kinematic functions and the Jacobian method [10] are used to implement (5) and (6). Then, by using the *sendRequest* method of *JOpenShowVar* the target joint configuration θ_t is forwarded to the *KUKAVARPROXY* and stored as global value in a structure. Finally, a KRL actuator program iteratively retrieves the new global data and actuates the robot.

The code of the KRL actuator program is shown in Algorithm 2. It should be noted that the variable MYAXIS is initialised to default values inside the INI fold. The system variable $ADVANCE is initially set to 1. Then the current joint values are assigned to a local structure variable named LOCAL. Inside the main loop, the desired joint angles are iteratively assigned to LOCAL, axis by axis. Finally a PTP movement with C_PTP approximation is executed.

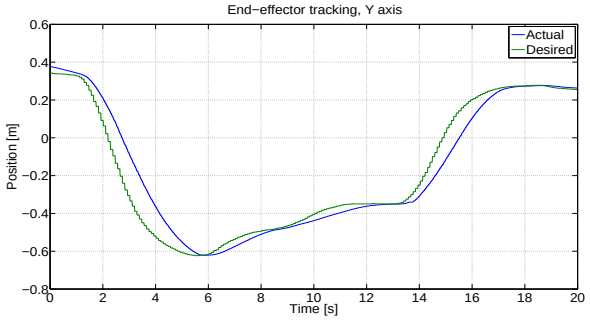
V. Simulations and Experimental Results

Related simulations are carried out in order to test the proposed communication interface within the particular case study of the *Leap Motion Controller*. A real-time trajectory tracking analysis of the Cartesian paths for X, Y and Z coordinates is performed, measuring the difference between the desired and actual position of the robot's end-effector. The results are shown in Fig. 5.

Moreover, to show the responsiveness of *JOpenShowVar*, a time-delay analysis is carried out for the same Cartesian paths as shown in Fig. 6. Even though there are few spikes with a larger time interval, an average access time of 4.27 ms is obtained in this case. The interface provided by



(a)



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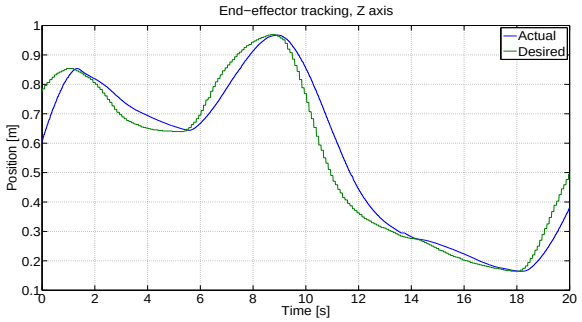

(c)

Fig. 5: Trajectory tracking for (a) the **X** coordinate, (b) the **Y** coordinate and (c) the **Z** coordinate.

JOpenShowVar demonstrates a fast reaction to the inputs and reasonable output error, considering the dimension of the controlled model.

VI. Conclusion and Future Work

This paper highlights the features of *JOpenShowVar* as a cross-platform communication interface to *Kuka* robots. Even though *JOpenShowVar* only provides a soft real-time access to the manipulator to be controlled, this *middleware* package opens up to a variety of possible applications making it feasible to use different input devices, sensors and to develop alternative control methods.

In the future, different control algorithms such as the ones implemented in [11], [12] and [13] may be tested as

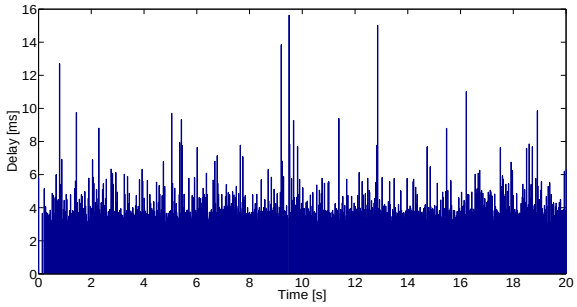

Fig. 6: Time-delay analysis for the corresponding Cartesian paths shown in Fig. 5.

alternatives to the standard KRC. Finally, some effort should be put in the standardisation process of *JOpenShowVar* to make it even more reliable for both the industrial and the academic practice. In the author's opinion, the key to maximising the long-term, macroeconomic benefits for the robotics industry and for academic robotics research relies on the closely integrated development of open content, open standards, and open source.

References

[1] KUKA Robotics Corporation. (2014, March) Kuka. [Online]. Available: http://www.kuka-robotics.com/

[2] KUKA, *Expert Programming*. KUKA Robotics Corporation, 2003.

[3] M. Schopfer, F. Schmidt, M. Pardowitz, and H. Ritter, "Open source real-time control software for the kuka light weight robot," in *8th World Congress on Intelligent Control and Automation (WCICA)*. IEEE, 2010, pp. 444–449.

[4] G. Schreiber, A. Stemmer, and R. Bischoff, "The fast research interface for the kuka lightweight robot," in *IEEE Workshop on Innovative Robot Control Architectures for Demanding (Research) Applications How to Modify and Enhance Commercial Controllers (ICRA 2010)*, 2010.

[5] H. Mühe, A. Angerer, A. Hoffmann, and W. Reif, "On reverse-engineering the kuka robot language," *arXiv preprint arXiv:1009.5004*, 2010.

[6] Google Inc. (2014, March) Android. [Online]. Available: http://www.android.com/

[7] Leap Motion Inc. (2014, March) The leap motion controller. [Online]. Available: http://www.leapmotion.com/

[8] F. Chinello, S. Scheggi, F. Morbidi, and D. Prattichizzo, "Kuka control toolbox," *Robotics & Automation Magazine, IEEE*, vol. 18, no. 4, pp. 69–79, 2011.

[9] R. Bischoff, U. Huggenberger, and E. Prassler, "Kuka youbot-a mobile manipulator for research and education," in *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2011, pp. 1–4.

[10] B. Siciliano and O. Khatib, *Springer handbook of robotics*. Springer, 2008.

[11] F. Sanfilippo, L. I. Hatledal, H. G. Schaathun, K. Y. Pettersen, and H. Zhang, "A universal control architecture for maritime cranes and robots using genetic algorithms as a possible mapping approach," in *Proceedings of the IEEE International Conference on Robotics and Biomimetics (ROBIO), Shenzhen, China*. IEEE, 2013, pp. 322–327.

[12] F. Sanfilippo, L. I. Hatledal, K. Y. Pettersen, and H. Zhang, "A mapping approach for controlling different maritime cranes and robots using ann," in *Proceeding of the 2014 IEEE International Conference on Mechatronics and Automation (ICMA 2014)*, in press.

[13] L. I. Hatledal, F. Sanfilippo, and H. Zhang, "Jiop: a java intelligent optimisation and machine learning framework," in *Proceedings of the 28th European Conference on Modelling and Simulation (ECMS), Brescia, Italy*. ECMS, 2014, pp. 101–107.