PX01-Switch: A Hardware Extension for KUKA Robot Controller Enabling Realtime Safe Operation

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Abstract. PX01-Switch is a research investigation based on an internationally filed patent by the author, focused on human-robot interaction and robotic control/motion in the field of design (Poustinchi, E. 2020). Using hardware solutions, PX01-Switch enables users—with limited or no programming background, to convert any simple or complicated "offline" developed robotic operations for KUKA robots, to realtime online operational strategies without needing any additional software package or coding knowledge. Operating as a hardware plug-in, PX01-Switch—as a device, can be added to any KUKA robot with the 4th generation controller—KRC4, regardless of the robot's type and payload. PX01-Switch aims to make realtime robotic interaction more accessible to general users, by simplifying some of the advanced programming aspects of the process, at the cost of reducing the operation/interaction resolution.

Keywords: Interface design, Human Robot Interaction, Robotics, Design, Digital fabrication

1 Introduction

Not very late after the introduction of computers in creative fields in the late 60s, artists and designers started to investigate the use of this new tool as possible creative agents and as a design medium. In their early stages, these investigations led to computer-generated graphics, art, and imagery; Engineers and creative minds, programmed machines to generate visual patterns as art (Noll, 1994).

Later—before and after the digital art movement, there has been a growing interest in using the agency of machines in a more active way as a design medium. The work of Harold Cohen and drawing robots/machines in the late 70s and early 80s, and the work of Ken Goldberg in the early 90s—among many others, are just a few examples of this interest (Harold, 2014; Goldberg, Vera, 1992).

Although the mentioned projects are precious when it comes to the creative use of technological machines, it is crucial to mention most of these creators have had engineering backgrounds. In another word, although numbers of projects from the early 60s to early 90s that use machines and technology in extremely novel and creative ways, there are many others that have not been done, since the creator did not have the technological expertise.

However, after the establishment of digital tools in design fields in the early 90s, and through domestication of some of the digital tools for creative usage, for the past three decades, we have seen a variety of innovative usage of machines and digital tools with art and design-oriented agendas. The manifestation of surface architecture, presence of parametric design, augmentation of the ML/AI conversation within the field of design, the advancement of robotic fabrication, and creation of responsive performative artifacts—among many others, are just a few examples to testify this transition.

Although digital tools and platforms are becoming more and more accessible for designers and artists to experiment with them as possible creative mediums, there has always been a gap between the creative user of these technologies and the platform/interface's technicality. This issue has been addressed in many artists/technologists' work through new digital interfaces and platforms. Ranging from custom-made programming languages such as Processing in the work of Reas and Fry, to game-like platforms such as Block'hood in the work of Sanchez, and physical interfaces and controllers in the work of Poustinchi, many designers/technologists attempted to close the gap between the creative non-technical user and the technological tools and mediums (Reas, Fry, 2007; Sanchez, 2016; Poustinchi, Wang, Luhan, 2018).

Among the digital tools and platforms that are slowly becoming more and more available to users with limited technical backgrounds, are robots. One of the most common brands of robots within the creative disciplines—and industry at large, is KUKA (International Map of Robots in the Creative Industry, n.d.).

The communication between robots—KUKA robots in this example, and design software platforms such as MAYA and Rhino/Grasshopper 3D are already established through a variety of plug-ins and interfaces such as KUKA|Prc, and Esprant.O (Schwartz, 2013; Braumann and Brell-Cokcan, 2015; Kruysman, and Proto, 2014; Poustinchi, 2019). However, to unlock the realtime communication—even for executing the code, there is a need for either expensive software/hardware packages—such as PLC, and mxAutomation, from KUKA—the manufacturer of the KUKA robots, or advanced programming knowledge. (Sanfilippo et al., 2014).

To address this issue, PX01-Switch, as part of a broader research investigation, proposes a new workflow to interact with KUKA robots in realtime and through hardware manipulation instead of software. This method enables users to trigger a pre-designed motion of the robot interactively—based on sensors or any desired inputs from the familiar design software, without needing any additional software packages from KUKA or new advanced programming knowledge beyond design software platforms.

2 Method

In current set-ups using KUKA robotics, there are two primary ways to execute or stop a programmed robotic motion:

- Using software/digital controlling platforms or custom KUKA packages to either enable to control or facilitate the real-time communication with the robot.
- Physically and directly using the "teaching pendant"—as part of the KRC controller, and pushing stop/play bottoms.

PX01-Switch is bridging these two platforms/methods to create a seamless, customizable/open-source way of activating/stopping the KUKA robot program operation through the majority of programming platforms and interactive sensors. PX01-Switch is a new solution for human-machine interaction in both industrial and creative robotic settings using KUKA robots. As a physical add-on to the KUKA teaching pendant, PX01-Switch acts a remote "operator" pushing the stop/play bottoms. However, the significant difference is that this stop/play process can be controlled off-site and through almost infinite numbers of ways with any microcontroller-friendly inputs. With PX01-Switch, It is also possible to control a predefined/preprogrammed motion of the robot in forward or backward mode through either USB or wireless connection (Figure 1).

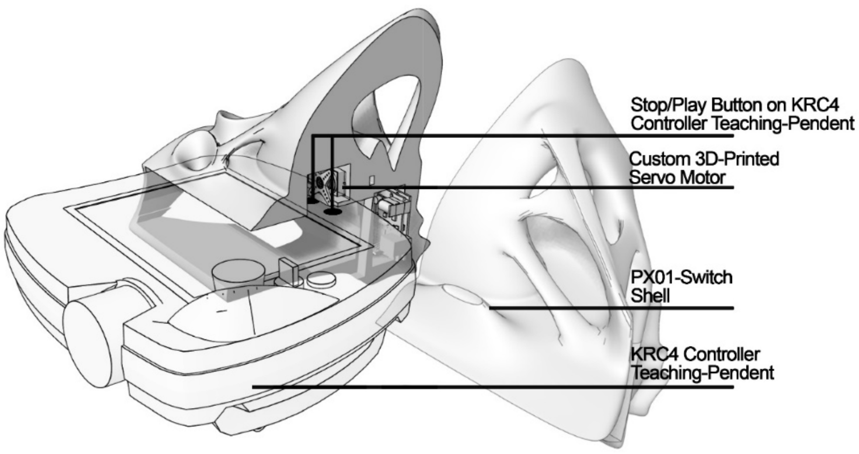

Figure 1. PX01-Switch, controls the KRC4 Teaching-pendent through pushing the Start/Stop buttons.

Invented at the Robotically Augmented Design (RAD) Lab, and internationally secured under the patent cooperation treaty (PCT), PX01-Switch as project-based research is focused on three central themes:

1- Examining the potentials of hardware platforms, as possibly more intuitive interfaces for designers/users with limited technical/programming background, to enable users to use advanced machines—such as KUKA industrial robot arms, with less programming.

2- Proposing a cost-effective in-house solution for human-robot interaction in the field of design and with a focus on accessibility and usability.

3- Developing a hardware-bridge between the KUKA robotic operation system (ROS) and easy-to-use creative/interactive programming platforms.

In light of the mentioned themes, PX01-Switch was developed and tested at the Robotically Augmented Design (RAD) Lab and Kent State College of Architecture and Environmental Design (CAED) users—with limited or no programming background, have been asked to develop and control a robotic motion/task using PX01-Switch and their software interface of choice.

Throughout the testing process and as a method to evaluate the success of PX01-Switch, participants with no programming and coding background have been selected to use PX01-Switch in conjunction with a simple Grasshopper 3D code, as a way to design and execute their first robotic motion design.

3 PX01-Switch

PX01-Switch—discussed in detail below, serves as a hardware package that enables realtime sensing and pre-designed task triggering—mainly focused on creative applications. As a hardware interface, PX01-Switch activates and deactivates a robotic task in forward and backward mode, using almost any sensing/programming platform—Kinect, leap-motion, web-based communication, Grasshopper, Arduino, and analog sensors, to name a few, without needing advanced programming knowledge or investing in expensive robotic software packages. KUKA software packages use KUKA's programming language, known as KUKA Robotic Language (KRL); however, PX01-Switch can use any open-source software platforms and languages, including but not limited to Arduino, Python, Java, C#, C++, Mel, and other visual programming platforms such as Grasshopper 3D and MatLab (Figure 2 and 3).

Figure 2. PX01-Switch installed and work as a hybrid hardware bridge between the KUKA robot and the digital environment.

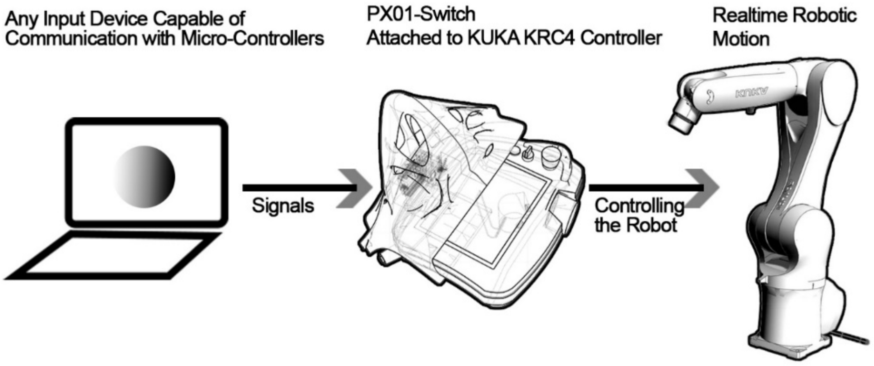

Figure 3. PX01-Switch serves as a bridge between the interactive signals from the "input device" and the robot.

4 PX01-Switch Components

As a hardware add-on and a physical plug-in, PX01-Switch is made of four main components:1-Microcontroller, 2-Customized 3D printed Servo Motor, 3-Communication method, and 4-3D Printed Housing Shell. In addition to the mentioned components and to complete the operational workflow of PX01-Switch, there is a need for an input source—to send the triggering command, and a KUKA robotic arm with a KRC4 controller (Figure 4 and 5).

4.1 PX01- Microcontroller

As one of the main components of PX01-Switch, and to be able to receive, process, and send data in the form of signal—a motion triggering commands, through the switch, there is a need for a microcontroller. To enhance the capabilities of PX01-Switch to communicate with multiple software and sensor platforms, Arduino as an open-source microcontroller has been used.

Using Arduino as the most-used microcontroller in creative fields, PX01-Switch, can receive signals from the majority of communicable digital platforms and can convert those signals into rotational commands for servo motor motion as a way to control the KRC4 controller via pushing the stop/play buttons on the teach-pendent. This method enables users to execute pre-programmed motions of the robot, in realtime and in response to sensory data without any advanced programming or communication knowledge; for instance, based on the audience's motion in a robotic performance or the level of noise, or any other input.

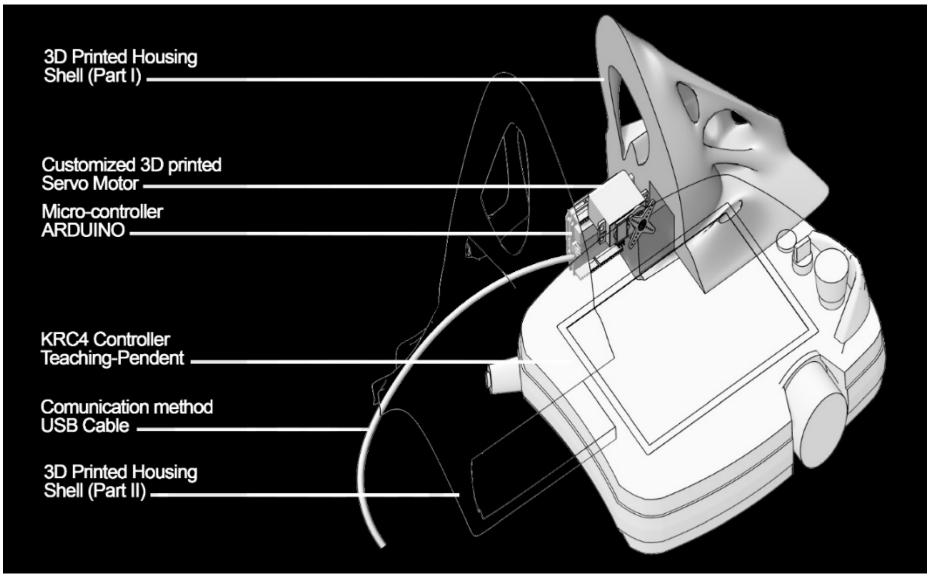

Figure 4. PX01-Switch Components.

4.2 PX01- Customized 3D printed Servo Motor

To be able to remotely control the teaching-pendent by pushing the play/stop buttons, there is a need for precise custom-made servo to control those buttons. To be able to achieve the precision and the exact dimensions of the KRC4 teaching-pendent controller, the 3D model of the pendent—from the manufacturer, and a 3d scan of the physical pendent were used to design the customized servo motor legs (Figure 6).

Adapting existing medium payload servo motors and substituting their legs with customized 3D-printed legs, we were able to directly align the servos active range with the KRC4 Teaching-pendent controller's buttons.

4.3 PX01-Communication method

To be able to communicate with the microcontroller to trigger the motion of the servo—and as a result, the robot, there are two main methods: 1-Wireless communication and 2-USB communication. Although there is enough room allocated in the PX01-Switch's 3D-printed shell for possible Arduino shields—WIFI shield, for instance, to make the reproduction of PX01-Switch easier and less dependent on programming knowledge, the primary selected communication method is a USB connection.

Communication through USB ports—as native Arduino ports, PX01-Switch can connect to a variety of computers, input devices, and sensors and receive the triggering signal from them.

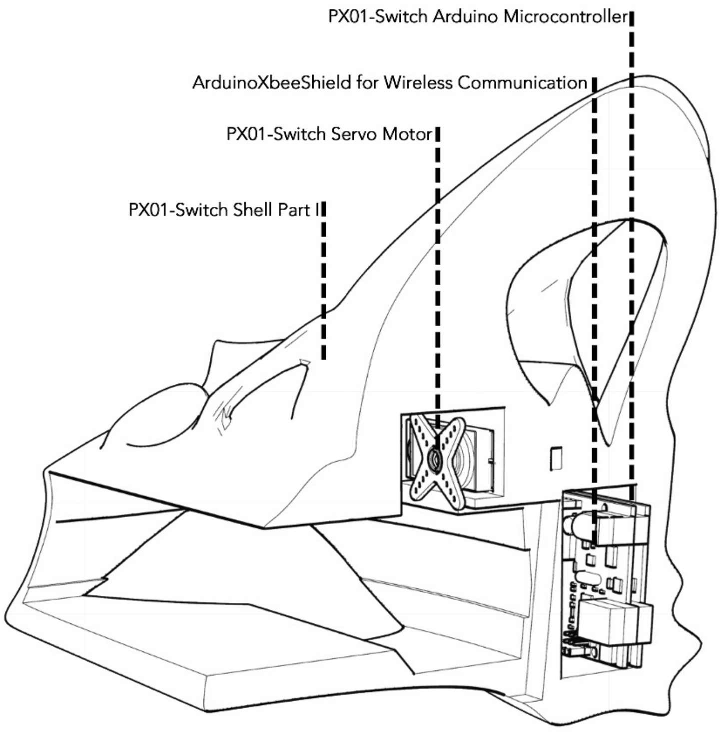

Figure 5. PX01-Switch Components Details.

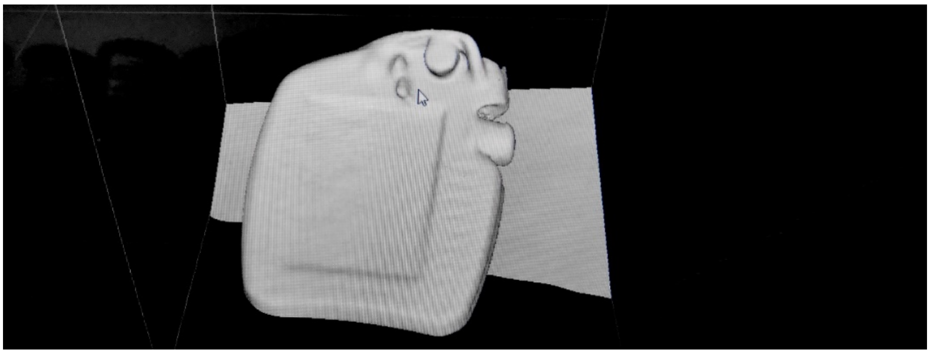

Figure 6. 3D-Scanned model of the KRC4 Teaching-pendent controller was used to design a customized servo motor to control the stop/play buttons.

4.4 PX01-3D Printed Housing Shell

To precisely position PX01-Switch components in relation to each other and the KRC4 Teaching-pendent, we used a 3D-printed shell to receive all of these components and fit into the pendent as a physical add-on (Figure 7 and 8).

Using the precision of the pendent's 3D-scanned model, the 3D-printed housing shell accurately fits the pendent and positions the customized 3D-printed servo motor, exactly on top of the stop/play buttons of the pendent.

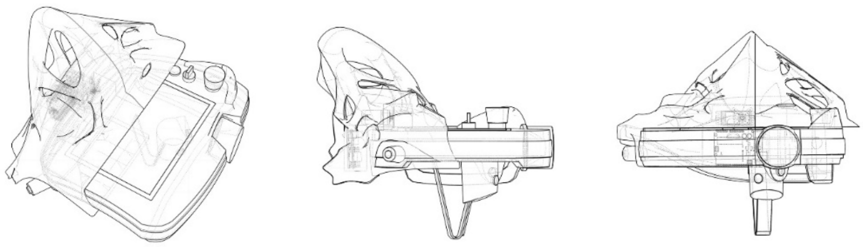

Figure 7. PX01-Switch fits the KRC4 Teaching-pendent and interacts with the stop/play button.

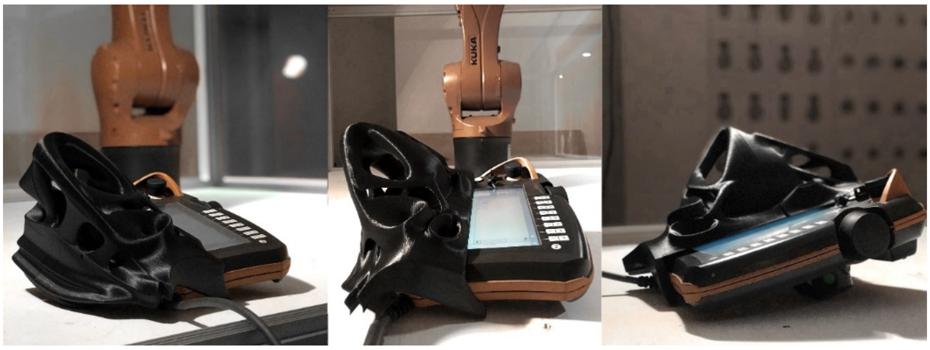

Figure 8. PX01-Switch serving as a physical plug-in for KRC4 Teaching-pendent controller.

5 Testing and Results | PX01-Switch Operation

Tested as part of an ongoing installation series, PX01-Switch demonstrated the capability of adopting different input systems, to trigger a robotic motion and control it in forward and backward in realtime.
Used in multiple scenarios, ranging from custom-made multi-material fabrication processes, to interactive gesture-based installation, to safety-oriented stop/play operations, until now PX01-Switch successfully employed various inputs, including but not limited to Kinect—depth-sensing camera, Arduino analog sensors, image-based inputs, and voice recognition triggers.
One of the recent test projects with PX01-Switch is based on using a very popular music/MIDI controlling platforms to trigger a pre-designed motion of the robot, in realtime and in response to MIDI music compositions (TouchOSC, n.d.). Using touchOSC—an original touchscreen MIDI and OSC control app, PX01-Switch was tested to create an interactive realtime robotic performance based on users' MIDI slider input (Figure 9).

Since TouchOSC is already an established controlling platform, in less than 5 minutes, musicians/DJs with no programming or robotic background were able to connect the OSC app from their phone to the robot, to trigger the designed motion.

As a result of this short experience/performance at the Robotically Augmented Design (RAD) Lab and Kent State CAED, within seconds, every user was able to create a unique robotic performance based on the music—MIDI controller, and triggering the robotic motion in forward and backward and through a custom timeline.

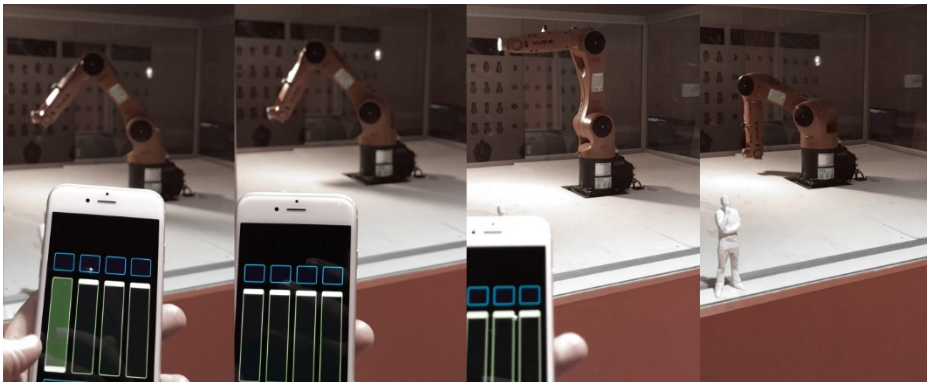

Figure 9. Using TouchOCS--a touch-screen MIDI controller, to trigger robotic motion via PX01-Switch.

6 Discussion

PX01-Switch is part of a more significant research investigation looking at the accessibility of robotics for designers and users with a limited technical background. It is intended for this research to be tested for a bigger audience to evaluate its full capacities, and limitations. As mentioned, PX01-Switch is developed as a secured patent, yet open-source invention with a lot of flexibilities to receive inputs from various sources. It is crucial for such invention to be tested by large groups of creative users not only to examine the success of some of the claimed ease of usability, but to expand the iterative process of PX-Switch development to address possible issues and augment the strengths. One of the main futures developments for PX01-Switch is focused on developing stronger web-based controlling platforms to use PX01-Swtich as platform for realtime telerobotic across physical/digital platforms. This development would enable users from different backgrounds to collaborate on creating a robotic performance/interaction though their medium of creation—music, architecture, digital painting, etc.

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