Towards an optimal method for teaching industrial assembly tasks using collaborative robots: teleoperation vs kinesthetic

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Table of contents

Introduction

Motivations

Within the industry 4.0, robots are increasingly exploited in production plants.

With the ambition to introduce robots into assembly lines the need to reconfigure the workspace requires faster modalities for robot reprogramming.

Motivations

Actually, in automotive industry, welding and painting tasks are already highly automated.

Instead assembly tasks are mainly performed manually today and they are absolutely repetitive and they can be constantly changed.

These tasks are mainly:

- pick and place
- peg into hole

Motivations

To facilitate reprogramming of robots, the new paradigm which is used more frequently is *PbD*: Programming by Demonstration.

Pbd is often used with collaborative robots that are installed in industrial environments.

It's a technique for teaching a robot new behaviors by demonstrating the task through a sequence of commands.

Goals

From *PbD* paradigm a comparison between two modalities was made to find the optimal method for teaching industrial assembly tasks.

The two modalities compared were:

- **kinesthetic teaching**: the robot is gravity compensated and the user physically guides the robot within his workspace
- **teleoperation teaching**: the user controls the robot with a **Ps4** pad

Goals

Before starting the work some research questions can be done:

- Which mode is preferred for ease of use?
- The two proposed approaches are said to be intuitive, but how much when they are used for assembly tasks in industry?
- There is a correlation between physical characteristics of the users and kinesthetic teaching?
- users who have familiarity with the pad are better teleoperation teaching?

The project

Setup overview

The KUKA LBR IIWA is a robot with collaborative features. It has a $14kg$ payload and an action range from $800mm$ to $820mm$.

Moreover is has a media flange with and internal wiring that is helpful to attach a lot of different tools.

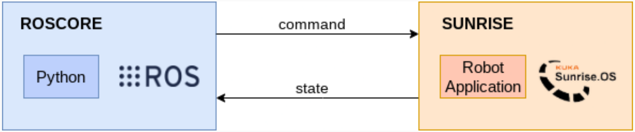
In our case the tool mounted on media flange is an electric parallel gripper with 2 self-centering two jaw with a total gripping force of $210N$.

Setup overview

Usually the KUKA LBR IIWA is programmed using the KUKA's Sunrise Workbench platform and its Java API's.

Instead in this work an open source stack compatible with ROS has been uses.

It provides a Java Robotic Application that establishes a point to point connection via ROS to the machine connected via Ethernet to the robot cabinet.



Setup overview

The machine with ROS installed, will be able to send and receive ROS messages to and from the Robotic Application.

The robot can be controlled using Python, C++ or via commands sent from console.

Using ROS there are some functionalities already implemented as `service`, `topic` and `action`.

Project Implementation

One goal of the thesis is to evaluate different modalities to teach quickly and simply assembly taks in industry.

For each of the two modalities a way to save waypoints and actions on the gripper has been implemented.

The actions were captured and saved in a `.csv` file. The sequence of waypoints and actions can be replicated by the robot.

Teach by demonstration

As described in introduction, teach by demonstration or also called kinesthetic is a way to move the robot in gravity compensation.

The gravity compensation mode has been implemented using *joint impedance*, then for every joint a stiffness and damping value has been set.

After changing the control mode in joint impedance, the robot seems falls and a small force contrary must be carried out to keep it up.

Teach by demonstration

On media flange there is a button that was dedicated for saving commands.

When the button is pressed according to the duration of the pressure, an action is recorded:

- one click for save a waypoint
- 2 seconds pressure for save the action on the gripper
- 5 seconds pressure to exit from teaching program

Teach with remote control

Remote control, or teleoperation indicates the movement of the robot at a distance. In our case, the KUKA LBR IIWA was controlled with a Ps4pad.

In *full task space* mode the robot will move respect to the base frame using linear and angular velocity on x, y and z:

- with **linear** velocity the robot will move the pose of the robot
- with **angular** velocity the robot will move the orientation of the EE

For these movements, the analogs of the pad were used. Instead, for security, the analogs must be used with the continued use of two deadman buttons.

Teach with remote control

The buttons used to do actions on robot were:

- $\times$: close or open gripper, therefore save action and the actual pose
- $\triangle$: save actual pose
- $\square$: change to control mode from position to cartesian impedance, and vice versa

The possibility to change the control mode to cartesian impedance allows the users to be more relaxed for precise movements.

Therefore, when an external force grater than a preset value is detected the **pad** start vibrating.

Experiment

Experimental design

The experimental design describes the entire flow which is done by every participants of the experiment.

During the experiment some data were collected from ROS `topic` with sample rate of $10Hz$. Those data are related to cartesian pose, cartesian wrench, joint position and joint velocity.

The experiment has been divided into three stages for convenience:

1. pre experiment
2. experiment
3. post experiment

Pre experiment phase

At this stage users were asked to take confidence with both the modalities.

If the user complete this phase an ascending unique id is assigned to him.

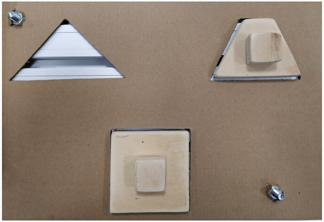
Every user perform the pre-experiment and experiment phase without seeing other users do the same.

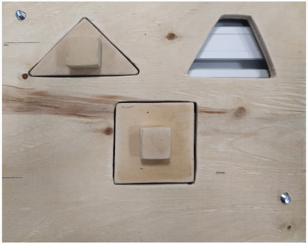
Experimental phase

The experiment was repeated both for kinesthetic and teleoperation.

It consists in two tasks in ascending order of difficulty repeated for three times. For simplicity the repetitions were called “trial”.

The figure on the left is a pick and place with a simple interlocking, while the figure on the right is a difficult interlocking.





Experimental phase

After every trial a *vote* to the work done is given to the user.

After the *first* trail of every task the replay phase based on the waypoints and actions on gripper is shown to the users. IN this way the user understands where he can improve

The starting position of the robot is always the same for all the users to unify the times.

Every trial of the users were considered valid, even if a mistake were made by the user.

Post experiment phase

At the end of the experiment an evaluation questionnaire was filled by the users.

It's divided in three parts:

1. personal informations as physical characteristics and confidence with pad
2. some questions about mental and physical effort
3. general questions about the experiment

Participants

The total number of participants is ten: seven male and three female. All of them are university graduates or students. Their ages are between 24 and 27 years old.

Half of them never use a robot as KUKA LBR IIWA.

To obtain better and diversified results among the participants, the modality in which each user starts with the experiment is diversified. Half of them started with teleoperation, the other with kinesthetic.