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

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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 that are mainly performed manually today 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 to the 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 with teleoperation teaching?

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.

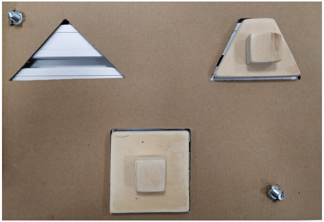
Every user perform the pre-experiment and experiment phase without seeing other users do the same.

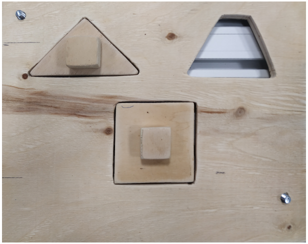
Experimental phase

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 that 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 into three phases that asks:

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

There were ten participants in the experiment: 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.

Results discussion

Results discussion

From the questionnaire many of the data collected were analyzed.

Especially, from the questions in the first part of the questionnaire, it's possible to spot the differences between the two modalities.

In fact the users had to answer questions related to physical and mental effort perceived during the experiment in both the modalities.

Results discussion

The efforts in the two modalities were analyzed separately to understand which data could be extracted.

From these data was possible to create different groups based on personal characteristics.

The two main classifications that have been determined based on:

- physical characteristics,
- confidence with the pad.

Results discussion

How was the group based on **personal characteristics** created?

In questionnaire was asked the weight and height keeping a range between $10kg$ and $10cm$. Two macro groups, both of them composed by five users, were composed:

- **LBU group**: composed by users which height is less or equal than $70kg$ and which height it's less or equal than $180cm$,
- **TBU group**: composed by users with weight greater that $70kg$ and height grater than $170cm$.

Results discussion

How users were classified based on their **confidence with the pad**?

In questionnaire was asked with how frequency the pad is used from the users. These users are called:

- **RP**: who replied more than once a week and at least once a month,
- **CP**: who replied that they use the pad once a year or they never used it. Also all users who have used the pad in the past are in this classification.

Results discussion

The work was mainly concentrated on the division into groups based on physical characteristics.

Therefore for each group the differences between the modalities were highlighted.

It's necessary to make an initial clarification. The **LBU** group is composed by four users which are defined as **RP**. This was noticed only after the analysis that was made on users by physical characteristics.

Results discussion

The first difference that was noticed was relative to time and distance for complete tasks in both the modalities. Instead, there is a correlation between time and distance.

Starting with these data, is possible to affirm that the phase relative to teleoperation teaching *is always slower* than the phase relative to kinesthetic teaching.

This aspect is *independent* from the division into groups.

Results discussion

Instead, from the next figures it's possible to see how the users of **LBU** group are faster in teleoperation teaching than **TBU** users. This is due to the fact that four users in **LBU** group are **RP**.

Instead, the users of **TBU** group are actually faster in kinesthetic teaching than the users of the other group. This is due to the physical characteristics of each user.

Results discussion

The time is calculated in seconds and the distance in meters. Only the times and distances about task $t1$ are shown, for task $t2$ the values are similar.

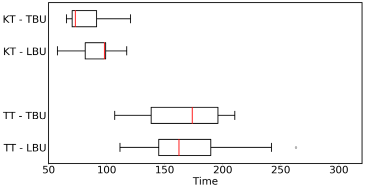


Figure 1: Time and distance for completing task $t1$

Results discussion

Related to the concept of time and distance to perform the task, there are the data relative to the `cartesian_wrench`. These collect data shows the force applied on the EE during the experiment.

It's possible to see how obviously the forces applied in the two modalities are completely different: in teleoperation the forces are practically nil, instead in kinesthetic there are more interaction forces.

Results discussion

Only the force calculated in N on z is shown. The same graphs are similar for x and y.

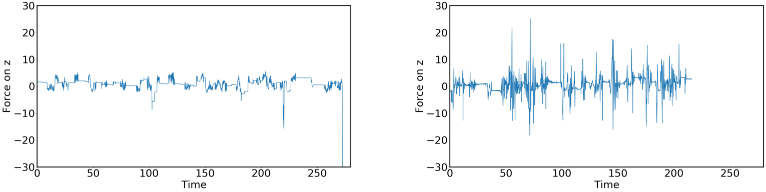


Figure 2: Difference between force on z in teleoperation e kinesthetic teaching

Results discussion

Given the difference in time and distance between the two groups, the force to perform the tasks was also analyzed.

An analysis was made on the force exerted on the EE by the users divided in groups during the experiment.

Has been noticed that the users of the **LBU** group use *more force* to perform the task. This also tells us why these users find the kinesthetic phase more tiring than the other group of users.

Results discussion

These figure shown the difference of force applied by the groups while they were performing the tasks in kinesthetic teaching. It's possible to notice how the force (in N) on x, z are higher for the **LBU** group. On y there aren't variations as no large movements are made.

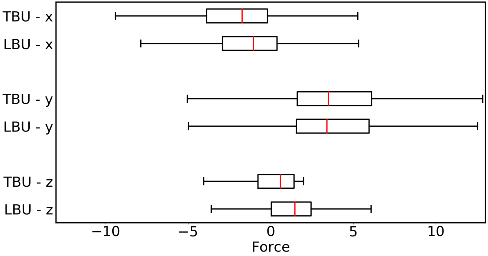


Figure 3: Force on x, y, z during kinesthetic teaching

Results discussion

Instead, related to the concept of **RP** these users perform the task faster. It's also introduced the concept of ratio of waypoints.

In fact, since the robot has to replay the sequence thought, some waypoints must be taken. The minimum number of waypoints is 16, the optimal number is 18.

It's also noted how in teleoperation the number of waypoints are minor respect to kinesthetic.

Results discussion

The users classified as **RP** during teleoperation take waypoints more precise and focused on the shapes. Also, these users take fewer waypoints.

This can be translated as a faster and more effective replay phase.

Instead, in kinesthetic there aren't differences between the two groups. Respect to teleoperation, in kinesthetic a lot of waypoints were taken out of the center of the figure.

Results discussion

Also the data relative to physical and mental effort were analyzed to focus on how much personal characteristics affect teleoperation and kinesthetic teaching.

From the data about **mental effort in teleoperation**, there isn't a lot of difference between the two groups. The **LBU** has a lower value, that is due to the fact that these users have confidence with the pad.

We can say that in general teleoperation isn't very mentally tiring or stressful, especially because there isn't interaction with the robot.

Results discussion

From the data about **mental effort in kinesthetic**, there is a little difference between the two groups. This is mainly due to the fact that more than half of the **LBU** group never use a root before this experiment.

So, kinesthetic teaching is rated as easy by the users who are familiar with the robots.

Instead, both the values of the mental effort given by the two groups are lower than the values of mental effort in teleoperation.

Results discussion

The two values obtained from the questionnaire are identical for **physical effort in teleoperation** because there isn't interaction with the robot.

Regarding **physical effort in kinesthetic**, there is a substantial difference between the two groups. This allows us to highlight how the characteristic differences affect kinesthetic in terms of strength.

Instead, the values of physical effort in kinesthetic are always slower than the values in teleoperation.

Conclusions

Conclusions

The modalities analyzed in this work have substantial differences. The first difference to highlight is the speed and naturalness with how the tasks can be taught in kinesthetic opposed to teleoperation.

We can say that kinesthetic teaching can be used when you want to teach simple tasks, such as pick and place.

But it's necessary to take into account the physical characteristics of the users.

Conclusions

To overcome this problem, teleoperation is therefore used because unifies the differences between the physical characteristics.

It offers the possibility of exploiting more functionalities of the collaborative robot.

But it introduces greater slowness but precision. We can therefore say that this can be used for difficult tasks that require precision.

Thank you for your interest and attention.