Finding possible solutions for hoist assembly and its development using collaborative robots.

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ABSTRACT

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ABSTRACT

The goal of this thesis project was to realise the use of a collaborative robot in the mechanical assembly stage of a QA-L type hoist and pilot testing of a collaborative robot assisted assembly process.

This thesis work can be considered as the first step in QA-L hoist assembly automation. Automation will increase the efficiency of the assembly process and decrease the adverse effect of vibrations from a pneumatic tool which is used in the QA-L hoist assembly process today.

This project was started by getting familiarized with the QA-L type hoist assembly process and setup creation for the pilot testing of a collaborative robot assembly. A list of improvements was made based on the results of the pilot test and these are also described in this thesis.

The thesis consist of a description and some pictures of the pilot test setup and its results, a description of possible ways to improve the robot assembly process and CAD models of 3D printed parts. All the solutions can be used to successfully implement a collaborative robot for a QA-L type hoist assembly process.

Keywords Assembly, Collaborative robots, Research and Development.

Pages 30 pages including appendices

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Appendices

1 INTRODUCTION

Nowadays, process automation has taken a big part in every industry. Manufacturers want to make production flow easier, faster, cheaper and therefore more efficiently. Usually industrial robots (3 or more axis high payload robot systems) are used for that purposes and a lot of companies use them to fully automate their manufacturing processes. These robots are located inside safety fences and replace human workers in repetitive tasks executing.

But not all operations can be fully automated. Sometimes you need human skills and abilities to complete a needed task more productive way, for example tasks there you need precision and fine motor skills.

But there is still a way to increase the efficiency of human work - collaborative robots. A cobot (stands for Collaborative robot) can assist employees with work that may be too dangerous, strenuous, or tedious for them to accomplish on their own, creating a safer, more efficient workplace without eliminating factory jobs involved in the actual fabrication of a product (Roehl C. 2017. Know your machine: industrial robots vs cobots). The main difference between industrial and collaborative robots is that collaborative robots were created to safely work alongside humans without using any safety fences due to other safety and collaborative features.

One more major advantage of collaborative robots over traditional industrial robots is their user-friendly, easy to use interface that makes programming, program modifying and I/O control easier.
Therefore, companies do not need to hire highly qualified robotics engineers if they want to automate their production line, they can easily teach their staff how to program collaborative robots.

2 DESCRIPTION OF PROBLEM

The task that was given to me was to develop a robot assembly application for a QA-L type hoist using a collaborative robot. The assembly process was to attach four fixing plates using screws and plates with threaded holes from behind. The main problem for the manufacturer is the amount of vibration acting on the human hand by the pneumatic tool during the final tightening of screws, so they would like to eliminate this adverse effect of tool vibrations on their employees.

According to the number of robots required (one robot to complete assembly) and familiarization with QA-L type hoist assembly process several key problems were discovered:

- *Impossibility for the robot to hold the plate with threaded holes during the process of pre-tightening of the fixing plate*. One robot cannot hold plates with threaded holes behind fixing plate and tighten the screws without using some extra device.
- *Presence of three screws that are tightened using a nut instead of a threaded hole in the plate* which is the same problem as problem one.
- *There is always some deviation of part orientation on the assembly table*. Parts are manually fixed on the assembly table which makes the location of parts not precise on the same place every time.
- *Finding the optimal robot position according to robot reach and existing assembly area layout.*

After the problem discussing with the manufacturer it was decided that all the pre-tightening operations were to be done by the human worker and the robot will be doing the tightening of all the screws. This eliminates problems with part holding and makes implementation of the collaborative robot to the assembly process much easier.

3 THESIS PROJECT PREPARATIONS

After familiarization with the task of this thesis project an initial plan of project execution was created. The initial plan consisted of main tasks that needed to be done during the project.

- Execute robot assembly tests with an actual part to identify the main problems that can hinder robot assembly implementation into production line.
- Process test results and proceed to problem solution research.
- Develop robot assembly process improvements.
- Propose improvements and solutions.

4 TEST SETUP

To check and prove the possibility of completing this project the first test was performed using an actual part and a custom made tool mounted on the Universal Robot UR5 collaborative robot.

Usage of a collaborative robot can be considered as the focus point in this thesis project due to its advantages over traditional industrial robots that were important for the hoist manufacturer:

No physical fence is needed for collaborative robot usage. In a situation of lack of space at the actual QA-L hoist assembly site this feature has critical importance for hoist manufacturer.

Collaborative robot mobility is another key feature that is helpful for manufacturer. Same robot can be used on different stages of hoist production process.

Easy to use interface of collaborative robot provides possibility for manufacturing company to train its own employees to operate and maintain robot which eliminates the need of hiring extra staff.

Safety features of collaborative robots allow assembler to work alongside with robot to make assembly process faster and more efficient. Main safety features are described below.

- Safety monitored stop – this feature is used when robot is mostly work apart from human but sometimes operator needs to enter working area to execute some task. In this situation when human being enters restricted area robot stop all its movements until worker is leaving and continue program executing. (Belanger-Barrette M. (2015). What does collaborative robot mean?)

- Hand guiding – this application is used if you want to hand guide the robot or quickly teach a path. This collaboration feature can be used also on regular industrial robots via special devices. (Belanger-Barrette M. (2015). What does collaborative robot mean?)

- Speed and separation monitoring – this safety feature is created by using different sensors and pre-set gradated safety zones. When worker is approaching robot, its reaction is produced according safety zone in which worker is located. Usually it is decreasing of robot moving speed with decreasing of distance between robot and human being. (Belanger-Barrette M. (2015). What does collaborative robot mean?)

- Power and force limiting – previous features can be used on regular industrial robots to make it collaborative, but this one is used only in robots that were initially created as collaborative. These robots can feel abnormal force impact on its path and programmed to immediately react with protective stop or position reversing if it feels overload in terms of force. The maximum force is limited by the amount of force that can be applied on human without any harm. (Belanger-Barrette M. (2015). What does collaborative robot mean?)

Actual part was delivered from QA-L type hoist manufacturer for robot assembly test and robot tool was created using regular electric screwdriver and 3D printed adaptor to robot flange.

4.1 Position of the parts and robot

Universal Robots UR5 as can be seen in Figure 1 was used to perform the first test. It was chosen as the best available option for the collaborative robot assembly application in the HAMK University Robotics lab.

The robot was located on a stiff platform to decrease the amount of extra movement.

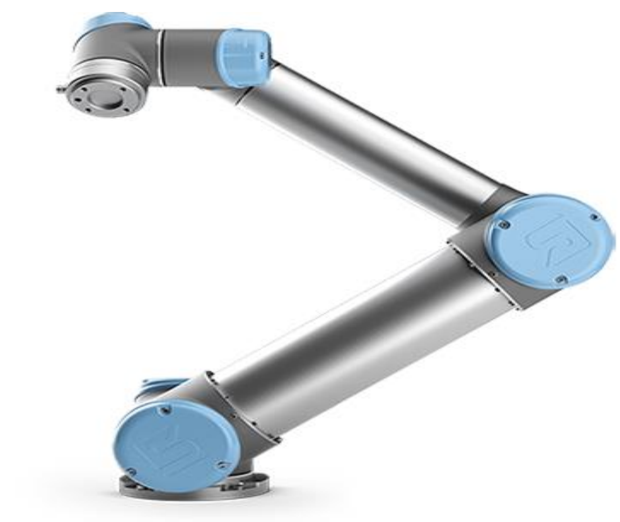


Figure 1. Universal Robots UR5 (Universal Robots, n.d.)

Parts were fixed on the table by four clamps. Ideal situation of totally fixed position of the part was taken for programming. Positioning of the robot and part can be seen in Figure 2 of test layout. Both sides of front fixing plates of test part were successfully reached by the robot using this position.

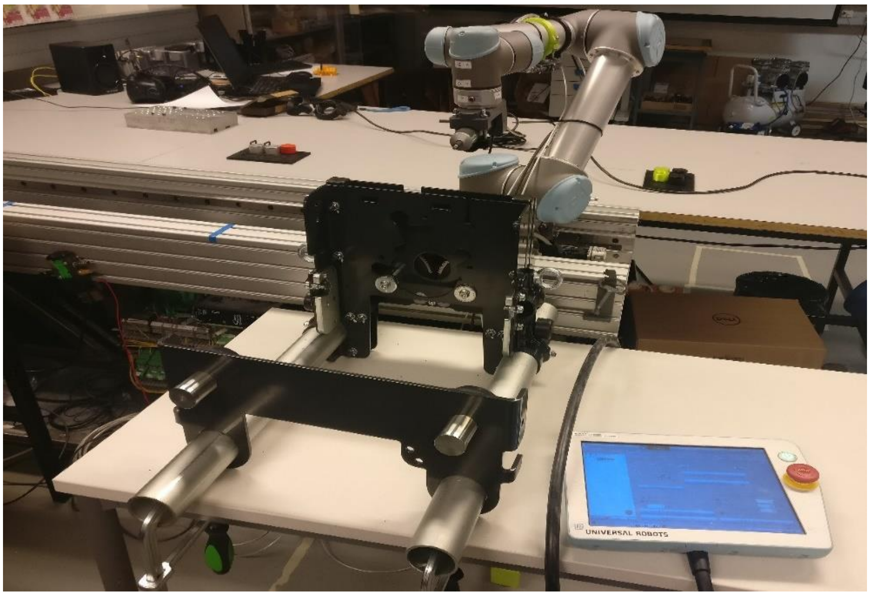


Figure 2. Test layout

4.2 Tool

For a proof of concept project a high variety of tools can be used. It can be commercial options of tools for robot arm or even manual tools connected to robot by using custom made adaptor. Adaptor can be made for any kind of tool and tool shape using its measured dimensions, technical drawings or 3D scanned model by manufacturing adaptor prototype using 3D printing, milling or other manufacturing process. 3D printed custom adaptor for manual tool was chosen as suitable option for this project. This way of manufacturing makes prototyping quick and provide ability to redesign your prototype at any moment of project.

18V Milwaukee screwdriver, 3.6V Bosch Go screwdriver and pneumatic screwdriver were considered as tool options for the first assembly test. All three options are manual tools without possibility for integration to the robot, so there could be no communication between robot and screwdriver. 18V screwdriver and pneumatic screwdriver were considered as more suitable options according to manufacturer requirements but taking into account that tool cannot be controlled by the robot and assembly is done using screws with hexagonal sockets these tools had big chance of socket damaging during test of assembly process.

For the first test BOSCH GO was chosen. The advantage of this screwdriver is PushDrive system: screwdriver is activated when force is applied on tip of the tool. This provide easier fitting of a tool tip into the head of the screw and not require any communication with the robot. To attach screwdriver to the UR5 3D-printed adaptor to the robot flange had been modelled using reverse engineering and 3D modelling: tool was 3D scanned using ATOS 3D Scanner, 3D mesh was exported to CREO Parametric, tool holder 3D model was done according to mesh dimensions and 3D printed on PRUSA 3D printer.

Figure 3. BOSCH GO (BOSCH n.d.)

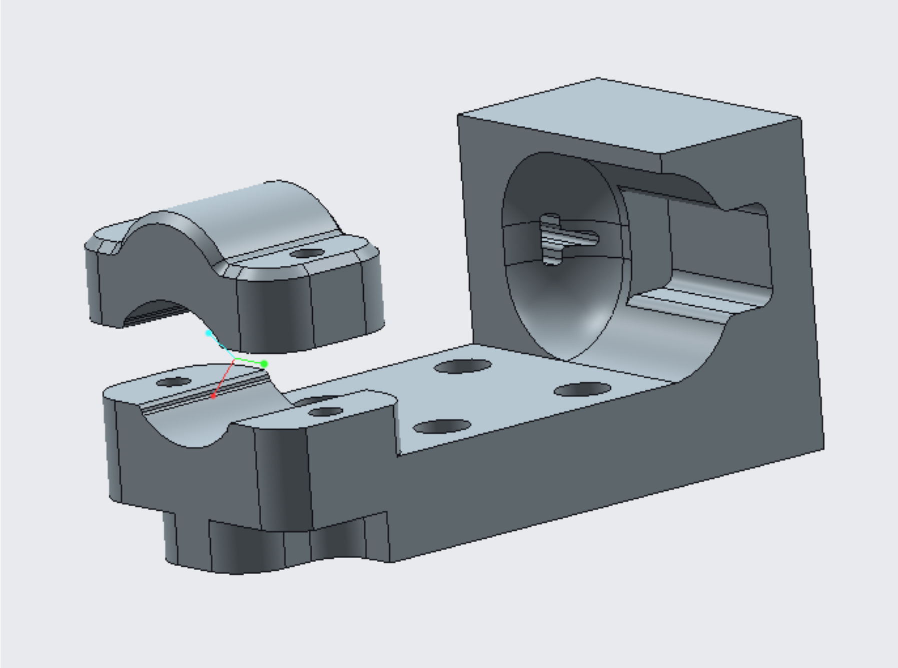


Figure 4. Adaptor BOSCH GO to the robot

To check how the robot will work with the actual pneumatic screwdriver that is used in a QA-L type hoist assembly (where torque is several times bigger), a tool was taken from customer, the adaptor was made same way as for Bosch GO and tested.

Figure 5. Pneumatic tool from customer

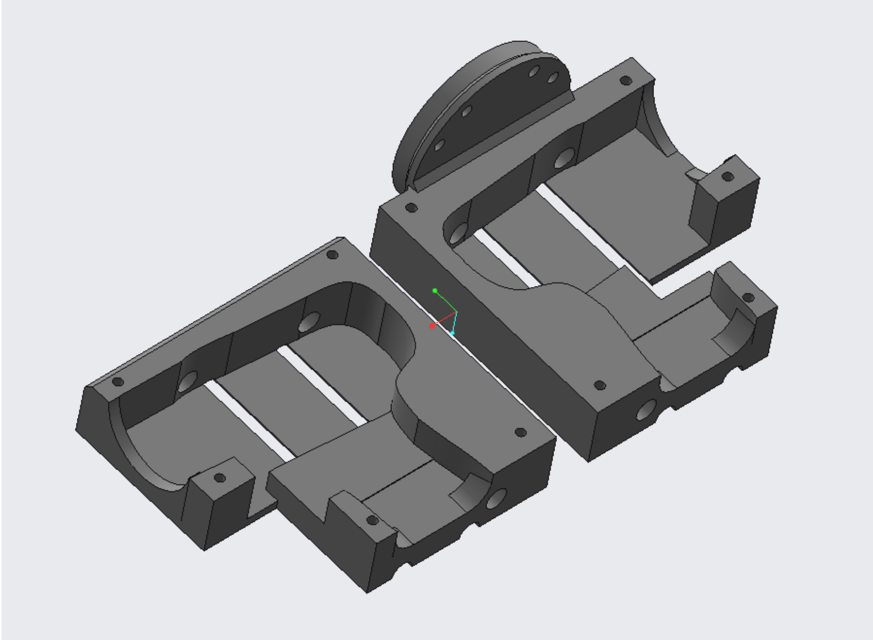


Figure 6. Adaptor for pneumatic tool

The tool was tested with a pressure of 7bar (maximum pressure) to get maximum possible torque. Robot stood the momentum generated by the tool and screw was tightened successfully. Possibility of using actual assembling tool in the robot assembly was confirmed on UR5 robot what makes the assumption of torque of 23Nm withstanding by the robots with the larger range robots almost proven.

4.3 Robot Programming

An easy to program interface is considered as one of the main features of collaborative robots and simple program creation does not take much effort from a person who is just starting to use collaborative robots.
All the robot movements are performed between waypoints which are set by the person who makes the program using hand guiding or “move” tab on the teach pendant. There are three types of movements that can be performed by the robot:

- MoveL (Linear Movement) – robot is moving from one waypoint to another in a linear path. Origin of TCP moves in a straight line between points.

- MoveJ (Joint movement) – robot is moving from one waypoint to another in fastest path. Robot moves the joints in the most efficient way and disregards the path of the robot`s TCP.

- MoveP (Process Movement) – robot is moving in Circular move (along an arc). Two points are used to program this type of movement: destination point and radius of desired arc.

A lot of features can be used to create needed program, main of them will be described further.

- *Loop* function can be used to repeat process several times or infinite amount of times.

- *If Then Else* function is used to perform some action which depend on exact conditions (inputs, number of loops done, variables etc.)

- The tool can be controlled by the robot inputs and outputs directly from the teach pendant using *set* function. Way of robot and tool connection should be taken into account during tool selection and robot programming process.

A program with the fixed waypoints for each screw was created to complete the main test. A fixed position of the parts and the robot is required in this way of programming.

In this program each screw has two fixed programmed points: approach point and point of full tightening. Two types of movement were used to create this program: MoveJ was used to move from one approach point to another and MoveL was used to move robot towards head of the screw to the point of full tightening. This increase size of program and make it not comfortable for editing, but easy to create, which is useful in testing.

Test program can be seen in appendices.

5 TEST RESULTS

Several issues appeared during the test execution. All four plates were not successfully reached by the robot arm. Screwdriver tip did not always fit into the hex socket which caused part moving and therefore a protective stop. A solution to tighten the screw and hold the nut on other side of the fixing plate by one robot was not found. Screws were not tightened enough. All these issues must be fixed for a successful implementation of the robot in an assembly process.

A list of problems was made for further research to find a solution.

Lack of robot reach. UR5 which was used for the tests had not enough reach for tightening all the four fixing plates in the final assembly.
Protective stops caused by the robot and the part movements relative to each other. This was caused by a lack of fixing between the part and the robot.
Imprecise tool aiming caused by an absence of any features for finding the screw and lack of fixing (see point 1)
Lack of tightening force. The tool, which was used for testing, did not meet the requirements from the customer.
Lack of tool control. The tool and tool torque were not controlled by the robot which could make complications in further application development.
Impossibility to tighten the screw with the nut without extra device using one robot.

The complete list was examined to find the best possible solutions and improvements of process.

6 SOLUTIONS AND IMPROVEMENTS

6.1 Robots

The deficiency of the UR5 robot reach (850 mm / 33.5 in) was revealed during the tests. To compensate this, a robot with a larger robot reach must be used. After searching through the market of collaborative robots two possible solutions were found: Universal Robots UR10 (1300 mm / 51.2 in) and FANUC CR-15iA (1441mm).

Figure 7. Universal Robots UR10 (Universal Robots ,n.d.)

Figure 8. FANUC CR-15iA (FANUK, n.d.)

6.2 **Tools**

Strict requirement was applied to tool selection: maximum torque for M8 screws that is used in this assembly should exceed 23 Nm (Table1). The usage of Bosch Go became impossible due to this requirement. Finding suitable tool for collaborative robots or create adaptor to the robot flange for manual industrial screwdriver were considered as tool options. For the second option actual pneumatic screwdriver that was used for this assembly by manufacturer of hoists was taken, adaptor was modelled and tested on the robot.

This tool requirement also led to a robot maximum torque verification. UR5, UR10 (Table 2) and FANUC CR-15iA (Table 3) documentation were checked for requirement compliance. After all verifications of technical documentation FANUC CR-15iA got limitations for tool orientation: tool should be located parallel to flange face to transfer momentum to fifth axis instead of flange.

Ready-made integrated screwdriver solution for collaborative robots that correspond to torque amount requirement have not been found on the collaborative robot market, so 3D modelled solution for industrial screwdriver left as the best option cause of its ease of creation and low cost.

Any pneumatic or electric screwdriver with high torque can be attached on the robot using 3D modelled adaptor and controlled by some system that will press trigger (for electric screwdrivers) or open air (for pneumatic screwdrivers). Adaptor can be made by using reverse engineering of a tool: 3D scanning of tool, mesh importing to 3D modelling software and adaptor creation according to the shape of the tool.

It is recommended to use electric screwdriver with torque control or pneumatic screwdriver with Force Torque Sensor to prevent overloading of robot motors by high torque.

6.3 Positions of the robot

There are several options for robot positioning in this assembly application. First position is the position which was used to perform process of assembly test: robot base is parallel to assembly table (Position 1). Second option is to put the robot above the assembly table – all four fixing plates are located on the same distance from the robot base, which makes approaching to the fixing plates easier for the robot (Position 2). Third option is to locate robot base at 45 degrees to the surface of assembly table: it is default position of UR10 on its mobile stand (Position 3).

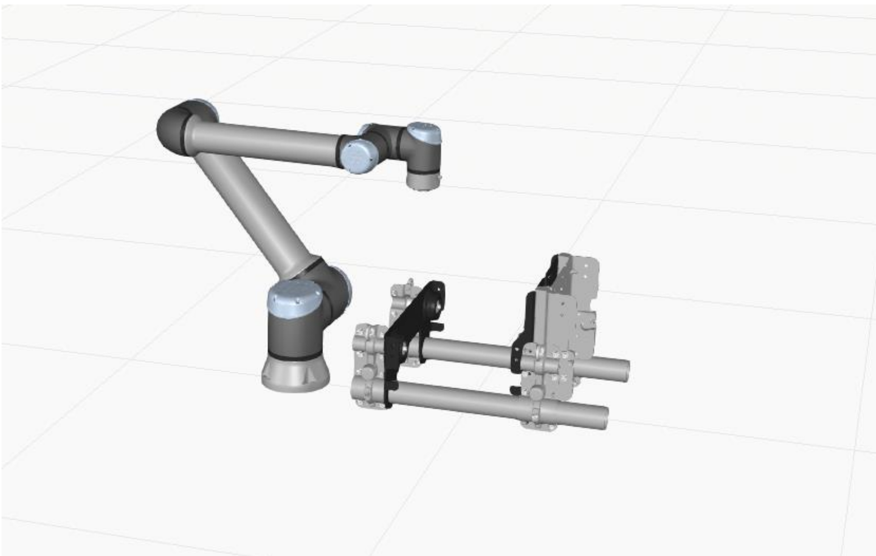


Figure 9. Position 1

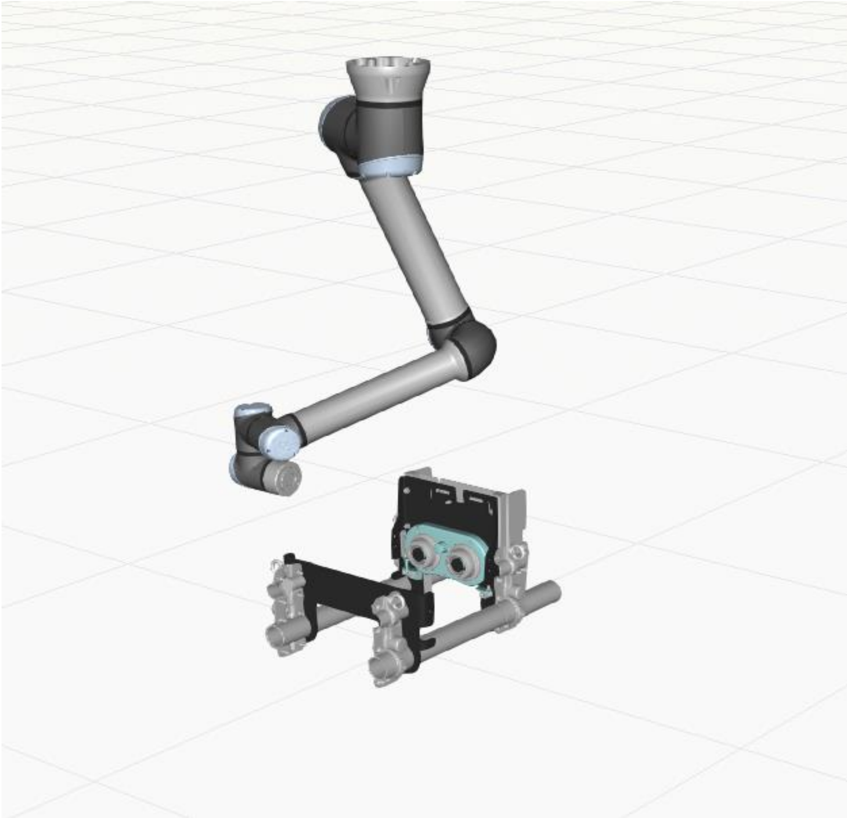


Figure 10. Position 2

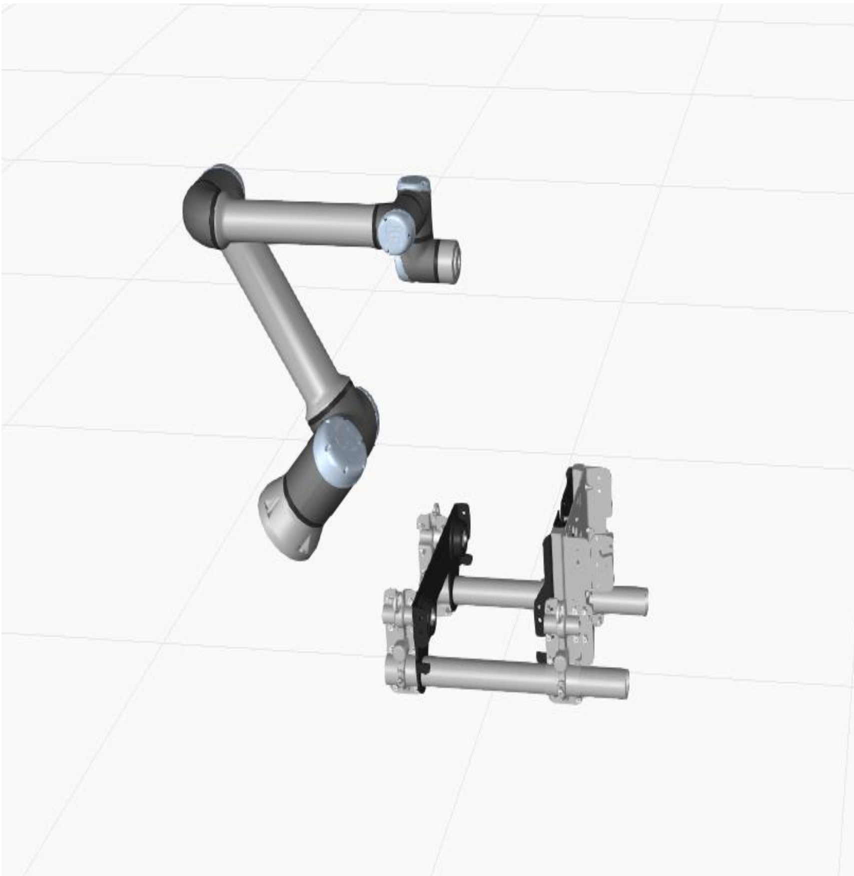


Figure 11. Position 3

Taking into account actual QA-L hoist assembly side layout was discovered that implementation of second option of robot location will require a lot of effort mostly because of room height and absence of rigid structures which can be used as a supports for robot platform. That makes this solution inefficient, so it is preferred to use first or third option.

Note that both robot and part should be placed on stiff fixed places to avoid protective stops caused by robot base or part movement during assembly process.

7 IMPROVEMENTS OF TIGHTENING PROCESS

7.1 Tool aiming

Vision Guided Robotics Systems can be considered as the reliable solution for tool aiming in condition of not exact same position of parts as in QA-L type hoist assembly.

Vision Guided System (VGR) is a collective term for vision systems and image processing systems used for position detection and inspection with robots. VGR consists of camera and microprocessor or computer. Two main types of VGR are 2D and 3D cameras. 3D camera can locate object in XYZ coordinates and 2D camera only in one plane (XY coordinates). Each type is divided by the way of mounting: robot arm-mounted camera and stationary mounted camera. Stationary camera is mounted on some stand and always observe entire working area, robot arm-mounted camera can see working area only if robot in “detection position”.

2D camera was considered as suitable solution for QA-L type hoist assembly because XY detection of screw socket would be enough for successful tool aiming. Stationary mounting could be done only with two cameras from both sides of QA-L type hoist, so robot arm-mounted camera was chosen as more appropriate and cheap solution.

As an example of best option of robot arm-mounted 2D camera for collaborative robots can be considered ROOBOTIQ Wrist camera.

Wrist camera is the robot mounted 2D visual system for collaborative robots which can recognize object location and orientation on the predefined working plane by making snapshot. It gets the objects coordinates (x;y) and orientation along z-axis which allow to precisely operate the robot to the object location.

Calibration of workplane and shape of object is performed by using teach pendant of robot what is facilitates usage of camera and programming process.

Wrist camera can recognize only one object per snapshot, so it will need eight snapshots per fixing plate which make whole process slower than manual programming, but more precise and independent

Figure 12. ROBOTIQ Wrist Camera (Robotiq, n.d.)

Screw detection was tested using black and silver colour screws. Silver screws were detected without model teaching just by setting its diameter. This was possible because of contrast between silver screw and black fixing plate.
Object teaching was required for black screws detection, but positive result was achieved. Pictures of detected objects can be seen in appendices.

7.1.1 Nut holder

To perform tightening of screws that have a nut, some jig or nut holder should be made to prevent nut from rotating. It can be made as a plate with slot for a nut in it, so the plate will act as a wrench, but worker do not have to hold it during tightening process.

Here is example of nut holding plate:

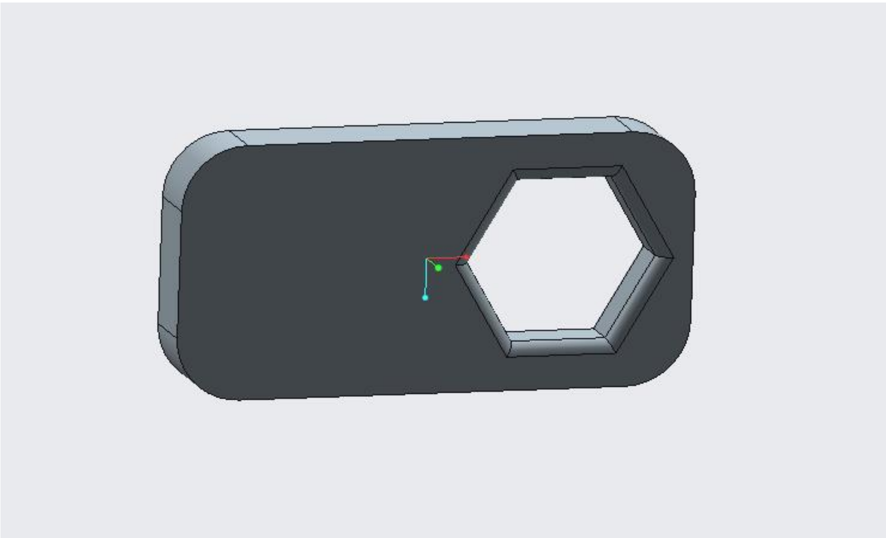


Figure 13. Nut Holder example

7.1.2 Torque control

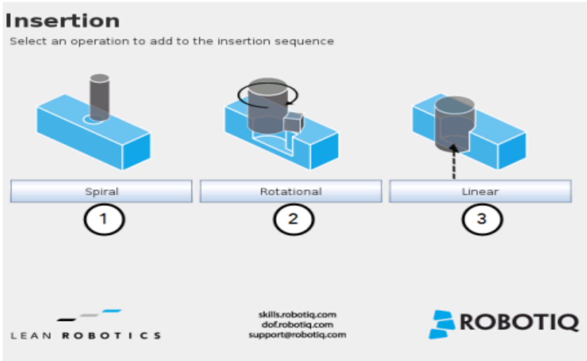
Three ways to control tool torque were considered as possible options for this project. First and easiest way is to get tool with integrated torque control, second is to get robot with integrated Force Torque Sensor and third is to get external Force Torque Sensor and connect it to robot flange.

External Force Torque Sensor was chosen as solution for improving of first test setup using UR5 robot. Work principal of Force Torque Sensor is described further.

Force Torque Sensor detects forces (Fx-Fy-Fz) and torque (Tx-Ty-Tz) that are applied on the robot in 3 different axes (X-Y-Z) by combining information from measuring elements (strain gauges) integrated into Force Torque Sensor. Attaching between robot flange and robot tool allow sensor to sense any possible external impact on the robot tool and control robot behaviour according to received information.

In screwing operation Force Torque Sensor can help to fit Allen wrench tip in head of the screw by using insertion function which will prevent damaging of tool and screw.
Applying exact tightening torque (Table 1) up to 30Nm (Table 4) can be done by using Force Torque Sensor.

Figure 14. ROBOTIQ Force Torque Sensor (Robotiq, n.d.)



1 **Spiral** button to insert a **Spiral** child node
2 **Rotational** button to insert a **Rotational** child node
3 **Linear** button to insert a **Linear** child node

Spiral	**Rotational**	**Linear**
Following a contact established between the object grasped by the end effector (or the end effector itself) and the corresponding mating part or surface, a spiral motion is engaged on a specific plane to find the path of least resistance according to the direction, speed, force, radius increment per turn and maximum radius parameters set by the user.	Following a contact established between the object grasped by the end effector (or the effector itself) and the corresponding mating part or surface, a rotational motion is engaged on a specific plane to find the path of least resistance, according to the direction, speed, force, maximum torque and maximum rotation angle parameters set by the user.	Following the successful spiral, rotational or fortuitous location of a mating hole or bore, a linear motion is engaged at a certain speed until the force threshold or maximum travel distance is reached.

Insertion operation for ROBOTIQ Force Torque Sensor (Robotiq, n.d.)

7.2 Ways of screwing process programming

Before programming TCP and Center of gravity of the tool should be checked and set.

7.2.1 By using fixed points

This way is programming was performed in assembly process tests. Program is based on fixed waypoints (one for approaching and one for tightening) for every screw. This program is good for testing because it is fast to create but not suitable for real application because it has large size, difficulties in editing and require the same position of product on the assembly table.

7.2.2 By using “0-point”

This program is created using one starting “0-point” and offsets from it to other points. All the coordinates for offsets can be taken from technical drawings of product, which make it easier for editing and adaptation to another similar products.

7.2.3 By using Wrist camera

This is more precise way to program such operation as screwing. This program is consisting of one snapshot position for each fixing plate to find locations of screws, approach waypoint and tightening waypoint. Significant advantage of this program is that camera finds screws coordinates itself, so it makes tool aiming very precise and keep size of program small.

8 CONCLUSION

Based on the completed tests it was discovered that a QA-L type hoist assembly can be successfully done with a suitable robot arm by using proper tools and devices for the main aspects of assembly: precise aiming, torque control, nut holding and positioning of the robot and part.

A suitable robot arm should be chosen according to its reach. The best candidates are Universal Robots UR10 and FANUC CR-15iA.

Aiming can be provided by a robot wrist camera, which can precisely recognize the head of the screw and aim the robot screwdriver to required position.

Torque control can be performed by a screwdriver with a function of torque limit or by using Force Torque Sensor which can feel all the forces and torque acting on the robot tool and stop it when it has reached the needed torque and the robot screwdriver with the maximum torque more than 23 Nm.

Nut holding could be execute by using some predesigned device which can prevent nut rotation during the tightening process and can be easily attached and detached to and from the nut.

Based on the information above it can be argued that the concept of a QA-L type hoist robot assembly is proven and can be successfully applied into the production line taking into account all the improvements in the assembly process that were mentioned in this thesis.

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APPENDIX 1. FIRST TEST VIDEO

Test video
https://drive.google.com/file/d/17uzOabzRZuTh1vlzLvl5ND6pNQaDC25c/view

APPENDIX 2. TABLES

Table 1. Tightening torques.

SERVICE MANUAL FOR HOIST KONECRANES®

11 APPENDIX: TIGHTENING TORQUES

The recommended tightening torques for fastenings.

Size	Tightening torque			
	Strength 8.8		Strength 10.9	
	[Nm]	[Ft lb]	[Nm]	[Ft lb]
M4	2.7	2.0	4.0	2.9
M5	5.4	4.0	7.9	5.8
M6	9.3	6.8	14	10.3
M8	23	17.0	33	24
M10	45	33.0	66	48.5
M12	77	56.6	115	84.6
M14	125	92	180	132
M16	190	140	280	206
M18	275	202	390	287
M20	385	283	550	404
M22	530	390	750	552
M24	660	485	950	699
M27	980	721	1400	1030
M30	1350	993	1900	1398

Note: It is recommended that self-locking nuts (Nyloc nut) are always replaced when removed. Self locking nuts can be reused no more than 5 times.

Table 2. Universal Robots maximum joint torques.

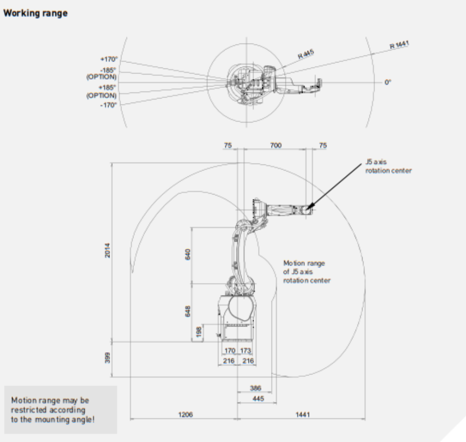
JOINT SIZE	TORQUE
Size 0	12 Nm
Size 1	28 Nm
Size 2	56 Nm
Size 3	150 Nm
Size 4	330 Nm

Joint	UR3/UR3e	UR5/UR5e	UR10/UR10e
Wrist 3	Size 0	Size 1	Size 2
Wrist 2	Size 0	Size 1	Size 2
Wrist 1	Size 0	Size 1	Size 2
Elbow	Size 1	Size 3	Size 3
Shoulder	Size 2	Size 3	Size 4
Base	Size 2	Size 3	Size 4

Table 3. FANUC CR-15iA specifications.

CR-15*i*A (Hollow wrist) — Max. load capacity at wrist: **15 kg** — Max. reach: **1441 mm**

Controlled axes	Repeatability (mm)	Mechanical weight (kg)	Motion range (°)						Maximum speed (mm/s)*1						J4 Moment/Inertia (Nm/kgm²)	J5 Moment/Inertia (Nm/kgm²)	J6 Moment/Inertia (Nm/kgm²)
			J1	J2	J3	J4	J5	J6	J1	J2	J3	J4	J5	J6			
6	± 0.02*	255	340	180	305	380	280	900	800 / 1500*2						26.0/0.90	26.0/0.90	11.0/0.30



MDS-00109-EN

Robot	**CR-15*i*A**
Robot footprint [mm]	346 x 346
Mounting position Floor	•
Mounting position Upside down	•
Mounting position Wall *3	•
Controller	**R-30*i*B Plus**
Open air cabinet	-
Mate cabinet	-
A-cabinet	•
B-cabinet	o
*i*Pendant Touch	•
Electrical connections	
Voltage 50/60Hz 3phase [V]	200-230
Voltage 50/60Hz 1phase [V]	-
Average power consumption [kW]	1
Integrated services	
Integrated signals on upper arm In/Out	7/5
Integrated air supply	1
Environment	
Acoustic noise level [dB]	< 70
Ambient temperature [° C]	0-45
Protection	
Body standard/optional	IP54
Wrist & J3 arm standard/optional	IP67

*1) In case of short distance motion, the speed may not reach the maximum value stated.
*2) if the area is monitored by a safety sensor (located separately)
*3) In case of the wall mount, the operation space will be restricted according with the payload.

• standard   o on request   - not available   [ ] with hardware and/or software option   *Based on ISO9283

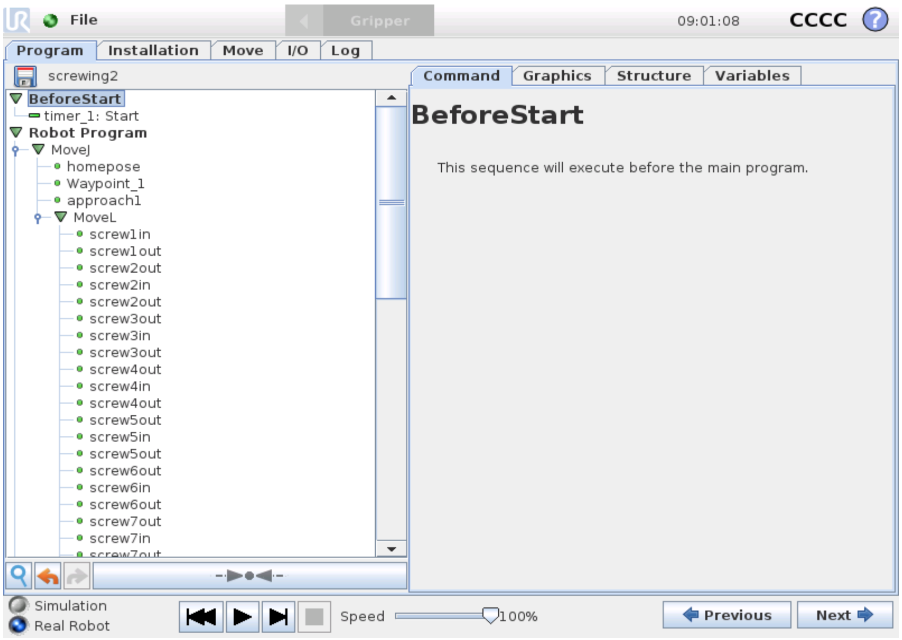
Table 4. ROBOTIQ Force Torque sensor specifications.

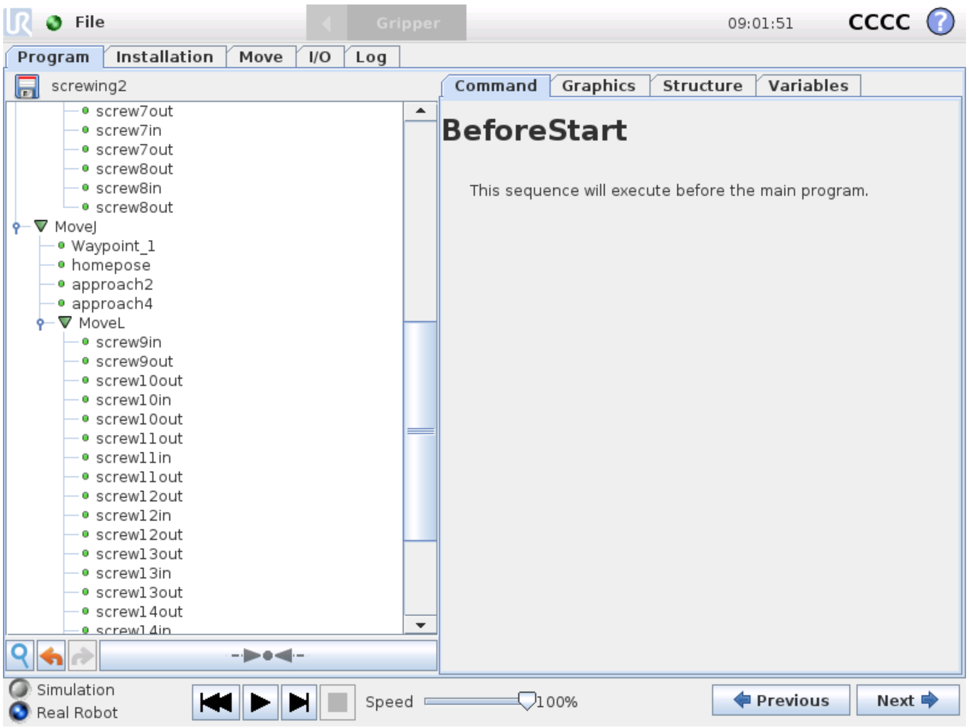
Specifications

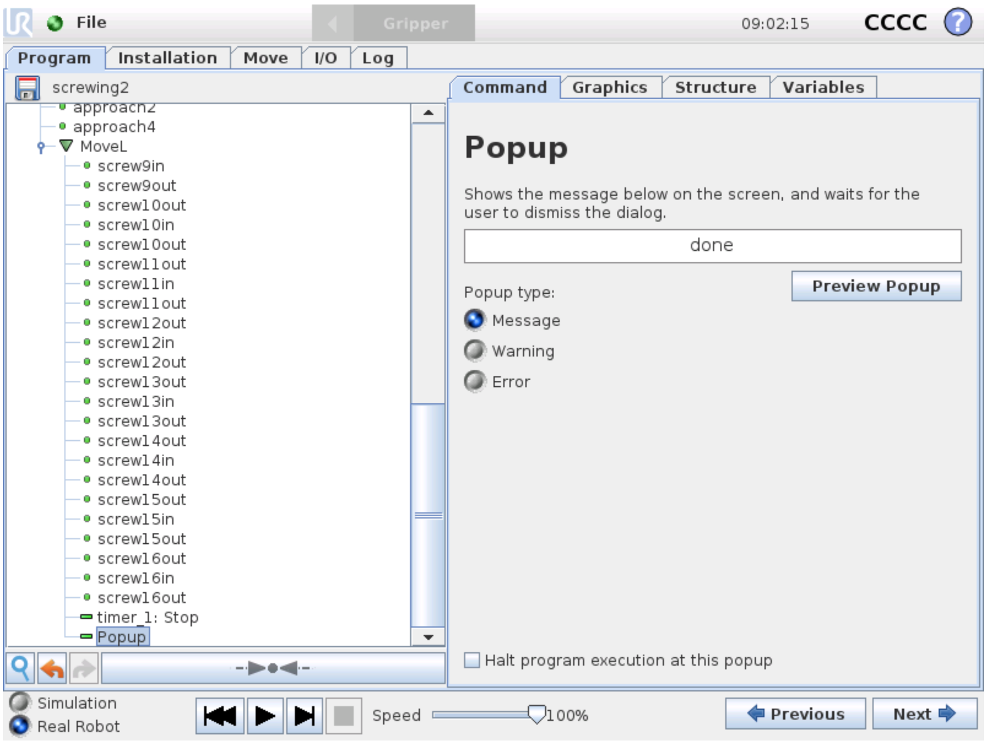
		Force Torque Sensor	
Main Specifications			
Measuring range	Force range Fx, Fy, Fz	± 300 N	
	Moment range Mx, My, Mz	± 30 N-m	
Signal noise*		Sensor signal noise	Recommended minimum threshold for contact in robot static state
	Force in X, Y, Z	0.1 N	1 N
	Moment in X, Y	0.005 N·m	0.02 N·m
	Moment in Z	0.003 N·m	0.01 N·m
External noise sensitivity	All axes	Immune	
Data output rate	100 Hz		
Temperature compensation	15°C to 35°C		
Weight	300 g		
Recommended minimum threshold for contact during robot quasi-static motion	For threshold during quasi-static motion, ask your integration coach at support@robotiq.com		

* Signal noise is the standard deviation of the signal measured over a period of one (1) second.

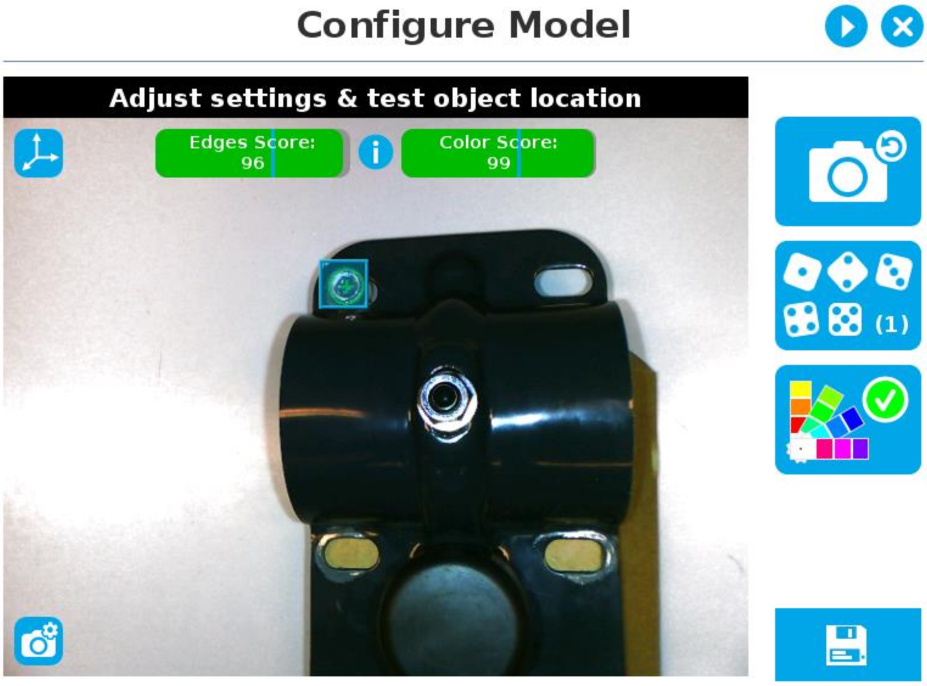
APPENDIX 3. TEST PROGRAM




File
Gripper
09:01:51
CCCC
Program
Installation
Move
I/O
Log
screwing2
Command
Graphics
Structure
Variables
screw7out
screw7in
screw7out
screw8out
screw8in
screw8out
MoveJ
Waypoint_1
homepose
approach2
approach4
MoveL
screw9in
screw9out
screw10out
screw10in
screw10out
screw11out
screw11in
screw11out
screw12out
screw12in
screw12out
screw13out
screw13in
screw13out
screw14out
BeforeStart
This sequence will execute before the main program.
Simulation
Real Robot
Speed
100%
Previous
Next


File
Gripper
09:02:15
CCCC
Program
Installation
Move
I/O
Log
screwing2
Command
Graphics
Structure
Variables
approach4
MoveL
screw9in
screw9out
screw10out
screw10in
screw10out
screw11out
screw11in
screw11out
screw12out
screw12in
screw12out
screw13out
screw13in
screw13out
screw14out
screw14in
screw14out
screw15out
screw15in
screw15out
screw16out
screw16in
screw16out
timer_1: Stop
Popup
Popup
Shows the message below on the screen, and waits for the user to dismiss the dialog.
done
Preview Popup
Popup type:
Message
Warning
Error
Halt program execution at this popup
Simulation
Real Robot
Speed
100%
Previous
Next

APPENDIX 4. SCREW DETECTION



Silver screw detection

Black screw detection