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Hybrid Force/Position Control of UR10 Robot Manipulator for Electrode Pasting Operation

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Abstract: The pasting operation is to assemble tubes (either 2 poles or 3 poles) which are mounted into sealing graphite for electrode ceramic tubes. This is one of the operations that is conducted in TDK Electronics for electrode ceramic tube production. The manual pasting operation is initiated by mixing the material of paste with ethanol and followed by the stirring process using a spoon until it turns out to be slightly wet and sticky. Next, the mixture is applied to the electrode wafer using pasting rubber which required consistency, precise and repetitive movement. Therefore, the purpose of this project is to automate the pasting process by introducing the UR10 robot arm robotic system to maintain the desired contact between the rubber pasting and the pasting plate. For that reason, a hybrid force/position-controlled robot system has been developed in a simulation environment. The UR10 robotic system involves a 6-degree of freedom (DOF) articulated robot arm to control the pasting rubber movement, and a force/torque (F/T) sensor system to measure the contact force of the pasting rubber and pasting plate. The UR10 robot arm is simulated using ROS MoveIt and RViz in Ubuntu 18.04 and ROS Melodic before real implementation on a real robot.

Keywords: UR10, Pasting Operation, F/T Sensor, ROS

1. Introduction

The pasting operation is to assemble tubes (either 2 poles or 3 poles) which are mounted into sealing graphite for electrode ceramic tubes. The arrester design for the finished product after the pasting operation. This is one of the operations that is conducted in TDK Electronics for electrode ceramic tube production. The manual pasting operation is initiated by mixing the material of paste with ethanol and followed by the stirring process using a spoon until it turns out to be slightly wet and sticky. Next, the mixture is applied to the electrode wafer using pasting rubber which required consistency, precise and repetitive movement. The operator must make sure that the full with paste. Two criteria output of the pasting process which is 'accepted' and 'rejected'. The pasting electrode ceramic tubes must be covered 100% to be accepted. Examples of rejected criteria are of the pasting electrodes ceramic tubes are 1)

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insufficient paste on a wafer or 2) excess paste on pin shoulder. If all the requirements are fulfilled, the pasted electrode can immediately mount onto the graphite. The paste electrode can be kept in the oven at the temperature of 40℃ to 50℃ for a maximum of 2 days. If the storage time is more than 2 days after the pasting process, those electrodes need to be scrapped. This study proposes to automate the existing electrode pasting operation to increase productivity by having a consistent and accurate robotized procedure.

The main objectives of this project are to conduct a feasibility study on pasting operation and robotic system integration. Next, this project will develop a hybrid force/position control algorithm for pasting operations. Finally, the objective of this project is to evaluate the proposed system via a series of the experimental program.

2. Methodology

This chapter will discuss the technique that has been used for the proposed control system including the device, equipment, procedure, and, processes related to the software and hardware development of the task. The development of robotized electrode pasting operation can be divided into 5 stages as shown in the following Figure 1.

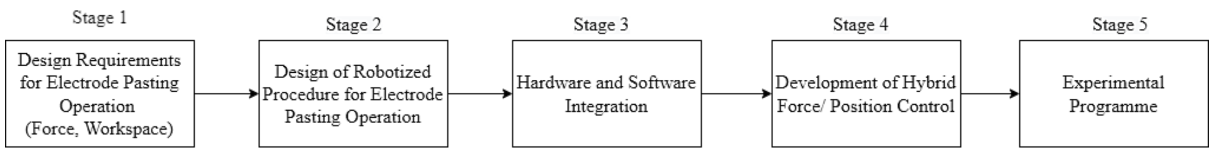

Figure 1: The development of robotized electrode pasting operation

2.1 Overall Schematic Diagram

The overall configuration of the proposed hybrid force/position control of the UR10 robot system is given in Figure 2. All of the main components of the system are connected to the host computer which serves as a master to handle input and output signals coming from the ATI F/T controller and UR10 robot controller. The UR10 arms are a kind of 6-DOF joint collaborative robot, safe and easy to operate, so it is widely used in industry between the F/T transducer and the robot end-effector is used for precise handling of the transducer and to continuously maintain low contact force on the pasting rubber and electrode plate. The F/T sensor is used to measure the force acting upon the pasting rubber and electrode plate while the computer will then acquire the force data from the F/T controller.

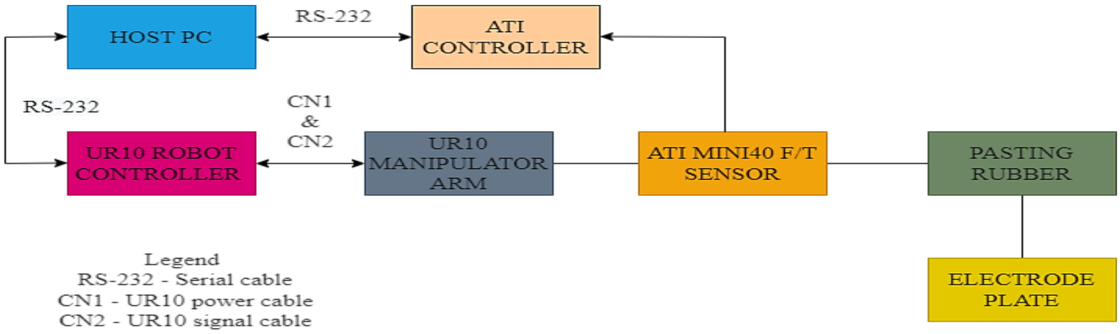

Figure 2: Overall configuration of the UR10 robot system

The UR10 arms are a kind of 6-DOF joint collaborative robot, safe and easy to operate, so it is widely used in industry [1]. Each joint is driven by pneumatic actuators and rotates with the pressure change inside, thus changing the position of the end-effector. The rotation range of each joint is -360º~ +360º. The robot is designed to mimic the range of motion of a human arm and its effective working radius is up to 1300mm [1]. Thus far, TDK Electronics try to apply the UR10 robot for automated operation for pasting procedures. However, several technical challenges have been addressed such as the UR10 robot cannot apply the consistent force 25 until 30N and the UR10 robot cannot maintain the control position at the electrode plate.

2.2 F/T Controller Communication

The flowchart of the F/T user application is shown in Figure 3. The program started by performing a warm start, which is equivalent to pressing the reset button, to reset the system. The end-effector is then subjected to a sensor bias to negate the effects of gravity on the tool weight or other forces acting on it. The F/T controller will read the current forces and torques and use these measurements as a basic reference for future readings when a sensor bias is applied. Future readings will have this reference subtracted from them before they are transmitted.

Since the focus of contact force on the electrode plate in the proposed UR10 robot in this research is on the z-axis, hence only the force component of this axis is selected to simplify the force output. In addition, query output of a stream of data in pre-selected type and mode. In the Universal robots UR10 system, the force output is then used to provide force feedback to the robot movement.

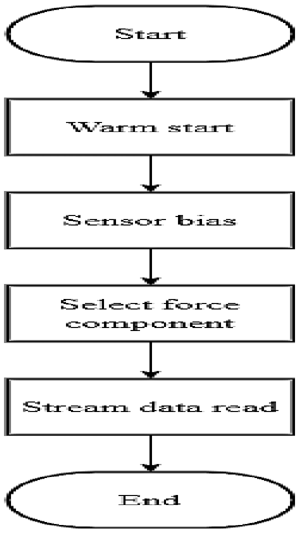

Figure 3: F/T function software

2.3 ROS MoveIt and UR10 Communication Setup

Figure 4 shows the flowchart of the ROS MoveIt and UR10 communication setup. Firstly, install the ROS Melodic package and create a catkin workspace to set up the computer. The Unified Robot Description Format (URDF) file used for robot modeling in ROS describes the fundamental physical attributes of the UR10 manipulator, including the appearance, collision, position, and other properties of each joint and connecting rod. One loads the model by importing the resulting URDF file into the Setup Assistant program offered by MoveIt. Setup Assistant can generate the required configuration file function package for MoveIt control.

Furthermore, to actually control the UR10 need to establish a connection, enable the motors, launch the driver, launch the planner and finally launch RViz. Moreover, power on the arm robot and enable the static address. Then, installing a URCap external control has to copy it to the robot's programs folder which can be done using a UBS stick and set up the IP address of the external PC. In the next step, key in the IP address at the terminal and check ping the arm. The roslaunch of RViz will be open and send the position data to the UR10 robot. So, the robot receives the data and the robot arm will move at the position that will be set.

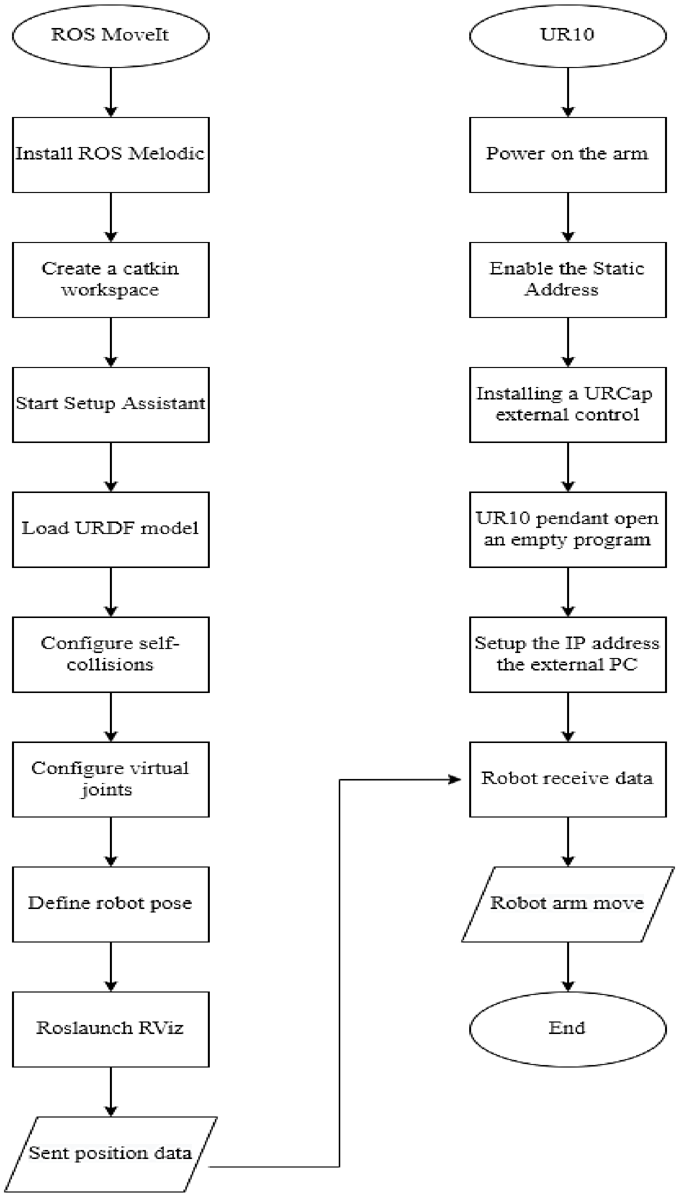

Figure 4: Flowchart ROS MoveIt and UR10 communication setup

3. Results and Discussion

This chapter briefly explained the outcome of the project this semester. It covered the demonstration using the load cell, UR10 movement setup, and F/T sensor using HyperTerminal software. The load cell is used to determine how much force the UR10 robot can generate and to record the x, y, z, Rx, Ry, and Rz values on the teach pendant. Furthermore, record the limitation of movement of the robot arm. Next, the demonstration to test the F/T sensor to get reliable data. The result of the demonstration for this project is to measure the force of the F/T sensor using 1kg, 2kg, and 3kg of sugar. Furthermore, the ROS MoveIt trajectory planning makes collects data on the robot arm's movement. The robot position for shoulder pan, shoulder lift, elbow, wrist 1, wrist 2, and wrist 3 during the random position to make sure the joint position will be the same position when recording the data five-time. Then, the purpose of this research is to obtain a random position movement of the robot and record the data for the teach pendant. It has three random positions that will be taken three times to make a record at the position for x,y,z, Rx, Ry, and Rz. This data compares the desired actual position for three random positions.

Additionally, the purpose of this research is to obtain three positions of the UR10 robot arm when doing the pasting process, and lastly, the purpose of this research is to record data on the robot arm movement of pasting operation at the teach pendant. It is just controlling the movement of the robot using a teach pendant.

3.1 Desired Contact Force Measurement using Load Cell

A load cell is used to identify the suitably applied contact force. The sensor measure force, such as tension, compression, pressure, or torque, into a measurable and standardized electrical signal. The electrical signal changes proportionally to the force applied to the load cell. Strain gauges, pneumatic, and hydraulic load cells are the most often utilized types of load cells.

The purpose of this research is to obtain a relative robot position if the constant force is applied to the UR10 robot. The load cell will be attached to the UR10 robot and will be used to configure the robot under a contact situation is applied. Then, record the reading force and torque at the teach pendant as shown in Table 1.

Table 1: Before applying the force (N)

UR10 robot Axis	UR10 End Effector Position
x	255.24 mm
y	1027.97 mm
z	-344.30 mm
Rx	0.1385 rad
Ry	3.1407 rad
Rz	-0.0003 rad

The condition robot’s x-axis at the teach pendant is 255.24 mm, while the condition robot’s y-axis is 1027.97 mm. The robot position for the z-axis is -344.30mm. The z-axis of the UR10 robot will condition the pasting rubber near at electrode plate without any force. The UR10 robot's z-axis will condition the pasting rubber on the electrode plate without any force or setting zero Newton. Then, on the axis Rx, 0.1385 rad is obtained, while Ry equals 3.1407 rad. Finally, the axis Rz is given a value of -0.0003 rad.

Table 2: After applying the 40N force

UR10 robot Axis	UR10 End Effector Position
x	255.22 mm
y	1028.10 mm
z	-350.25 mm
Rx	0.1383 rad
Ry	3.1407 rad
Rz	-0.0019 rad

However, Table 2 illustrates the condition axis of the UR10 robot when the 40N force is applied. The x-axis and y-axis robot positions are 255.22mm and 1028.10mm, respectively. The x-axis and y-axis readings will be nearly identical after applying the 40N between 0N. While the robot’s position on the z-axis is -350.25mm. When comparing the readings at the z-axis after applying the 40N between 0N, the readings will differ by -5.95 mm. This is because the z-axis is used to apply force while pasting rubber at the electrode pasting. Furthermore, the Rx and Ry are 0.1383 rad and 3.1407 rad, respectively, which are nearly identical to the zero-newton result. Finally, the Rz is -0.0019 rad.

When the UR10 robot applies a force of more than 40N, the teach pendant displays an error on the screen. So, for this project, the UR10 robot will use 25 N, which can be applied to the robot arm without causing errors.

3.2 Identification of UR10 Robot Workspace for Pasting Operation

The purpose of this research is to collect data on the robot arm's movement limitations for the pasting operation. Table 3 depicts the robot position for the x, y, and z axes for the minimum, maximum, and center during the pasting operation using the UR10 robot while the pasting rubber sweep on the electrode plate.

Table 3: Axis x, y, and z limitation of movement

Axis	Minimum (mm)	Maximum (mm)	Center (mm)
x	135.02	400.70	252.49
y	1104.04	632.11	1029.66
z	0	326.29	-206.90

The minimum reading on the x-axis is 135.02 mm, the maximum is 400.70 mm, and the center is -206.90 mm. Furthermore, the robot movement on the y-axis is at the minimum position is 1104.04 mm, while the robot arm moves to the maximum position of 632.11 mm. The y-axis length at the center of the electrode plate is 1029.66 mm. Finally, the z-axis minimum is 0mm and the z-axis maximum is 326.29 mm. The center must be fixed at -206.90 mm. The recorded values will be used as limit position inputs for further development of the hybrid position and force control algorithm.

3.3 F/T Sensor Reading and Calibration

A simple test has been conducted to verify the ATI F/T sensor reading to provide reliable data for further development of the control algorithm. The test is designed to measure 1kg, 2kg, and 3kg of sugar. Figure 5 shows the ATI graphical user interface to obtain the F/T sensor reading that can be measured in different data types such as gages, counts, and Force/Torque units.

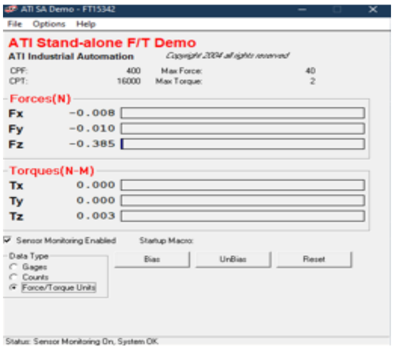

Figure 5: ATI software

The weight of sugar with actual and software is provided in Table 4. This experiment takes three reading times to compare the actual and software. The weight of sugar 1 kg data for T, T2, and T3 the actual and software is remarkably similar. Furthermore, the weight of sugar 2 kg values for the actual and software at T1, T2, and T3 are nearly the same. Finally, the weight of sugar 3 kg values for the actual and software at T1, T2, and T3 are virtually the same. At the end of this experiment, the results are nearly identical, and the F/T sensor is in good working order.

Table 4: the weight of sugar with actual and software

Weight sugar	Actual T1 (N)	Software T1 (N)	Actual T2 (N)	Software T2 (N)	Actual T3 (N)	Software T3 (N)
1 kg	9.80665	-9.745	9.80665	-9.855	9.80665	-9.768
2 kg	19.6133	-19.975	19.6133	-20.285	19.6133	-19.973
3 kg	29.41995	-29.055	29.41995	-20.093	29.41995	-29.305

3.4 ROS MoveIt Trajectory Planning

The purpose of this research is to collect data on the robot arm's movement using ROS MoveIt. Table 5 depicts the robot position for shoulder pan, shoulder lift, elbow, wrist 1, wrist 2, and wrist 3 during the random position to make sure the joint position will be the same position when recording the data five-time.

Table 5: ROS MoveIt Trajectory Planning

Trial	Joint	Position (Degree, °)		
		A	B	C
1	Shoulder pan	0	0	0
	Shoulder lift	0	-90	-110
	Elbow	0	0	-79
	Wrist 1	0	-90	-75
	Wrist 2	0	0	87
	Wrist 3	0	0	0
2	Shoulder pan	0	0	0
	Shoulder lift	0	-90	-100
	Elbow	0	0	-79
	Wrist 1	0	-90	-75
	Wrist 2	0	0	87
	Wrist 3	0	0	0
3	Shoulder pan	0	0	0
	Shoulder lift	0	-90	-110
	Elbow	0	0	-79
	Wrist 1	0	-90	-75
	Wrist 2	0	0	87
	Wrist 3	0	0	0
4	Shoulder pan	0	0	0
	Shoulder lift	0	-90	-110
	Elbow	0	0	-79
	Wrist 1	0	-90	-75
	Wrist 2	0	0	87
	Wrist 3	0	0	0
5	Shoulder pan	0	0	0
	Shoulder lift	0	-90	-110
	Elbow	0	0	-79
	Wrist 1	0	-90	-75
	Wrist 2	0	0	87
	Wrist 3	0	0	0

For position A the shoulder pan joint is 0º, shoulder lift is 0º, the elbow is 0º, and at wrist 1,2,3 is 0º. It will take five times and all the results will be in the same position. Moreover, for position B the shoulder pan joint is 0º, shoulder lift is -90º, the elbow is 0º, wrist 1 is -90º, wrist 2 is 0º, and wrist 3 is 0º. It will take five times and all the results will be in the same position. The position C the shoulder pan joint is 0º, shoulder lift is -110º, the elbow is -79º, wrist 1 is -75º, wrist 2 is 87º and wrist 3 is 0º. It will take five times and all the results will be in the same position.

3.5 Desired at Real Robot Control using Teach Pendant

The purpose of this research is to obtain a random position movement of the robot and record the data for the teach pendant as shown in Table 6. It has three random positions that will be taken three times to make a record at the position for x,y,z, Rx, Ry, and Rz. This data compares the desired actual position for three random positions. The data record for the first time and second time will be a little different data while for the third time will be the same as for the first time.

Table 6: Desired real robot control

Position	Desired	Actual Position		
		1	2	3
A	x	255.93 mm	255.98 mm	255.93 mm
	y	-13.19 mm	-13.23 mm	-13.19 mm
	z	1026.54 mm	1026.58 mm	1026.54 mm
	Rx	2.3194 rad	2.3199 rad	2.3194 rad
	Ry	-2.4421 rad	-2.4428 rad	-2.4421 rad
	Rz	2.4388 rad	2.4390 rad	2.4388 rad
B	x	203.17 mm	203.24 mm	203.17 mm
	y	674.43 mm	674.49 mm	674.43 mm
	z	525.48 mm	525.56 mm	525.48 mm
	Rx	3.7469 rad	3.7469 rad	3.7469 rad
	Ry	-0.1209 rad	-0.1215 rad	-0.1209 rad
	Rz	0.0906 rad	0.0915 rad	0.0906 rad
C	x	217.54 mm	217.55 mm	217.54 mm
	y	885.61 mm	885.66 mm	885.61 mm
	z	123.98 mm	123.95 mm	123.98 mm
	Rx	3.2303 rad	3.2306 rad	3.2303 rad
	Ry	-0.0922 rad	-0.0925 rad	-0.0922 rad
	Rz	0.0461 rad	0.0466 rad	0.461

3.6 Joint Position for the Pasting Process

The purpose of this research is to obtain three positions of the UR10 robot arm when doing the pasting process. The UR10 robot arm has six joints, it is shoulder pan, shoulder lift, elbow, wrist 1, wrist 2, and wrist 3. Then, record the reading degrees of freedom when using MoveIt and Gazebo simulation shown in Table 7.

Table 7: Joint Position for the pasting process

Position	Joint	MoveIt (°)	Simulation Positon (°)
A	**Shoulder pan**	0	0
	Shoulder lift	-110	-110
	Elbow	-79	-79
	Wrist 1	-75	-75
	Wrist 2	87	87
	Wrist 3	0	0
B	**Shoulder pan**	-6	-6
	Shoulder lift	-122	-122
	Elbow	-98	-98
	Wrist 1	-45	-45
	Wrist 2	87	87
	Wrist 3	-171	-171
C	**Shoulder pan**	-6	-6
	Shoulder lift	-147	-147
	Elbow	-55	-55
	Wrist 1	-65	-65
	Wrist 2	87	87
	Wrist 3	-171	-171

Position A at the shoulder pan joint is 0°, the shoulder lift is -110°, elbow position is -79°, wrist 1 is -75°, wrist 2 is 87°, and wrist 3 is 0° using MoveIt while using the simulation the position of UR10 will be the same position as shown in Figure 4.7. Furthermore, the position B at the shoulder pan joint is -6°, the shoulder lift is -122°, the elbow position is -98°, wrist 1 is -45 °, wrist 2 is 87°, and wrist 3 is -171° using MoveIt while using the simulation the position of UR10 will be the same position as shown in Figure 4.8. Lastly, the position C at the shoulder pan joint is -6°, the shoulder lift is -147°, the elbow position is -55º, wrist 1 is -65 º, wrist 2 is 87º, and wrist 3 is -171º using MoveIt while using the simulation the position of UR10 will be the same position.

3.7 Joint and Cartesian Trajectory for Real Robot

The purpose of this research is to record data on the robot arm movement of pasting operation at the teach pendant. It is just controlling the movement of the robot using a teach pendant. Table 8 shows the reading of joint and Cartesian of the real robot at the teach pendant.

Table 8: Joint and Cartesian for Real robot

Position	Joint	Real Robot (º)	Cartesian	Real Robot
A	Shoulder pan	6.74	x	112.67 mm
	Shoulder lift	-109.84	y	886.89 mm
	Elbow	-85.46	z	64.89 mm
	Wrist 1	-72.10	Rx	0.1339 rad
	Wrist 2	88.18	Ry	3.1193rad
	Wrist 3	-171.55	Rz	0.0729 rad
B	Shoulder pan	6.76	x	112.66 mm
	Shoulder lift	-122.97	y	886.87 mm
	Elbow	-98.83	z	-227.77 mm
	Wrist 1	-45.59	Rx	0.1338 rad
	Wrist 2	88.05	Ry	3.1193 rad
	Wrist 3	-171.70	Rz	0.0730 rad
C	Shoulder pan	6.22	x	112.63 mm
	Shoulder lift	-146.16	y	1167.13 mm
	Elbow	-55.20	z	-227.73 mm
	Wrist 1	-65.62	Rx	0.1338 rad
	Wrist 2	87.79	Ry	3.1195 rad
	Wrist 3	-172.50	Rz	0.0838 rad

Position A at the shoulder pan joint is 6.74º, the shoulder lift is -109.84º, elbow position is -85.46º, wrist 1 is -72.10º, wrist 2 is 88.18º, and wrist 3 is 171.55º. Then, the Cartesian for the robot arm is x, y, z, Rx, Ry, and Rz. The condition robot's x-axis at the teaching pendant is 112.67 mm, while the condition y-axis is 886.89 mm. The robot position for the z-axis is 64.89mm. After that, Then, on the axis Rx, 0.1339 rad is obtained, while Ry equals 3.1193 rad. Finally, the axis Rz is given a value of 0.0729 rad. The position B at the shoulder pan joint is 6.76º, the shoulder lift is -122.97º, the elbow position is -98.83º, wrist 1 is -45.59º, wrist 2 is 88.05º, and wrist 3 is 171.70º. The condition robot's x-axis at the teach pendant is 112.67 mm, while the condition y-axis is 886.87 mm. The robot position for the z-axis is -227.77mm. After that, Then, on the axis Rx, 0.1338 rad is obtained, while Ry equals 3.1193 rad. Finally, the axis Rz is given a value of 0.0730 rad. Lastly, position C at the shoulder pan joint is 6.22º, the shoulder lift is -146.16º, elbow position is -55.20º, wrist 1 is -65.62º, wrist 2 is 87.79º, and wrist 3 is 17º. The condition robot's x-axis at the teaching pendant is 112.63 mm, while the condition y-axis is 1167.13 mm. The robot position for the z-axis is -227.773 mm. After that, Then, on the axis Rx, 0.1338 rad is obtained, while Ry equals 3.1195 rad. Finally, the axis Rz is given a value of 0.0838 rad.

4. Conclusion

According to the previous chapter, the demonstration of the F/T sensor modulation analysis produced correct findings as a preliminary outcome. However, it needs to identify the mounting plate for the F/T sensor to connect with the UR10 robot and how to connect with UR10 systems. To control and set up the robot arm, it using at the teach pendant with the UR10 software. The robotics electrode pasting operation the three points of the robot arm operation such as Point A, Point B, and Point C. To control and set up the robot arm, it using at the teach pendant with the UR10 software. The robotics electrode pasting operation the three points of the robot arm operation such as Point A, Point B, and Point C. The sensor is mounted between the robot and pasting rubber to measure all six components of force and torque from all three Cartesian coordinates x, y, and z. The pasting rubber is used to sweep the electrode paste on the surface of the electrode plate. Furthermore, this research is to conduct a feasibility study on the pasting operation and the integration of a robotic system and develop a hybrid force/position control algorithm for the pasting operation. Next, evaluate the proposed system via a series of the experimental program. Next, the goal of this study is to use ROS MoveIt to collect data on the robot arm's movement. Moreover, obtain a random position movement of the robot and record the data for the teach pendant for three random positions. Additionally, the goal of this study is to collect data on the robot arm movement during the paste operation at the teach pendant. Lastly, for the UR10 robot control using the ROS MoveIt.

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References

[1] Wenzheng Liu, Jiaxin Zhao, Lipin Shi, Nan Xu, Feng Liu, Fei Lin Heming Zhang. (2019). A Mapping Approach of Virtual- Real UR10 Twins Based on Long Short- Term Memory Neural Net. 2019 IEEE 23rd International Conference on Computer Supported Cooperative Work in Design (CSCWD).