National University of Singapore

Department of Electrical and Computer Engineering
&
Department of Mechanical Engineering

ME4245 Robot Kinematics, Dynamics and Control

Experiment @ Mechatronics and Automation Laboratory, E4A, Level 3

1. Objectives:

   (I) Robot operations, moving the various degrees of freedom, teaching positions in space, returning to position taught, listing and deleting of positions in the position table in the memory
   (II) Transferring a block from Position A to position B
   (III) Fully synchronize two-robot pick-and-place program

2. Equipment:

   PERFORMER-MK2, ER14 and CONTROLLER-B Computer (PC)
   Level 5 software
   Connecting wires

3. Procedure:

   I (a) System Connection:

   Ensure that POWER ON/OFF and MOTOR ON/OFF switches are set to OFF and emergency buttons both on the Controller Box and teach pendant are pressed down.

   Strictly operate according to the following order:

   1. Connect the system to 220V AC supply;
   2. Set POWER ON/OFF switch to ON;
   3. Set MOTOR ON/OFF switch (on the Controller Box) to ON;
   4. Pull both emergency buttons out.

   When you want to turn off the system, please follow the order as:

   1. Set MOTOR ON/OFF switch (on the Controller Box) to OFF;
   2. Push both emergency buttons down;
   3. Set POWER ON/OFF switch to OFF;
   4. Disconnect the system from 220V AC supply.
(b) Run control software

After turning on the motor, open the control software. Click the shortcut on desktop “rob”, SCORE BASE Main Menu is displayed in Figure 1:

![Figure 1](image1)

(c) Homing the Robot

Select the HOME MENU from the MAIN MENU by typing the function key “F5”. Figure 2 will be shown. Then press “G” key to home the robot. Be sure that there is sufficient space for the robot to home. You can always use the key “Esc” to return to the preceding menu or to stop the current operation. Set speed to level 3 after homing is finished by pressing ‘s’ and then ‘3’.

(d) Moving the Robot Motors

Select the TEACH POSITIONS MENU from the MAIN MENU by typing the function key “F1”. The TEACH POSITIONS MENU will be displayed as shown in the Figure 3.

![Figure 2](image2)
This experiment uses the first five lines in the block on the left hand side of the TEACH POSITIONS MENU (not counting the heading). There are three columns in the block:

* Left: indicates key to be pressed in order to move a robot joint.
* Centre: indicates the joint to be moved.
* Right: indicates direction of movement.

The ‘left’ and ‘right’ are defined as the directions facing the robot.

For example, consider the 2nd line:

2/W MOVE SHOULDER UP/DOWN

Hold on the button to move the robot.
Press "2" to move the robot shoulder up.
Press "w" to move the robot shoulder down.
Complete the table:

<table>
<thead>
<tr>
<th>ACTION TAKEN</th>
<th>JOINT MOVED</th>
<th>DIRECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press &quot;1&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press &quot;Q&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press &quot;2&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press &quot;w&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press &quot;3&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press &quot;E&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press &quot;4&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press &quot;R&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press &quot;5&quot; (MK2 only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press &quot;T&quot; (MK2 only)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

II (a) Teaching positions in space ("Teach-In")

You can use arrow key or space key to alternate between the two blocks of the TEACH POSITIONS MENU. This experiment is related to the following lines in the block on the right side of TEACH POSITIONS MENU:

RP          Record Position #.
GP          Go To Position   #.
GH          Go Home

For example, by typing in “RP”, the following message appears at the bottom of the screen

RECORD POSITION ( 1-400 )...

The computer is now waiting to receive a number from 1 to 400 inclusive (from the keyboard). This number identifies a position in space equivalent to the position of the robot joints at the time the RECORD POSITION key is typed in.

The task of this experiment is to record six positions of the robot. When recording positions, you do not have to maintain strict numerical order.

1. Typing in “GH” brings the robot arm to the home position. The corresponding message is displayed on the screen to tell you the procedure of the homing. After homing is done, type in “RP”, and the following message appears on screen:

RECORD POSITION ( 1-400 )
Type in "1" and press <CR>. You have recorded position #1.

2. Turn the base to 45° (by estimation) left and record the position as position #2.

3. Move the shoulder 45° down (for MK2)/left (for ER14) and record the position as #3.

4. Move the elbow 45° down and record it as #4 (for MK2 only).

5. Turn the wrist-pitch 45° (for MK2)/10cm (for ER14) down and record it as position #5.

6. Turn the wrist-roll 45° left and record the position as #6.

You have just recorded six different positions in the computer memory.

(b) Return to Positions Taught

The robot is now in the position previously recorded as position #6.

Make sure that the block on the right hand side is highlighted and type in "GP".

The following message appears on screen:

GO POSITION ...

Type in "5" and press <CR>. The robot will go to the position recorded as position #5, rotating the wrist (roll) joint only.

Now type in "GP" again, type in "4" and press <CR>. Which joint moved? (for MK2 only)

Now type in "GP" again, type in "3" and press <CR>. Which joint moved?

Now type in "GP" again, type in "2" and press <CR>. Which joint moved?

Now type in "GP" again, type in "1" and press <CR>. Which joint moved?

The above commands resulted in the motion of only one axis at a time. Now type in "GH" again and press <CR>. Describe the response, including the number and names of axes (joints) moved.

(c) List/delete Positions

Type in "L". The List/delete Position will be displayed as shown in Figure 4:
Typing in “LP”, the following message will be displayed on the screen:

LIST POSITION …

To display the coordinates of position #1 as recorded in memory, type in "1" and press <CR>. Fill in the coordinates displayed for position #2:

<table>
<thead>
<tr>
<th>#</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>PITCH</th>
<th>ROLL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
</tbody>
</table>

(MK2 only)

To display the coordinates of all positions starting from position #1, as recorded in memory, type in “LF”. The following message will appear on screen:

LIST FROM POSITION …

Type in “1” and press <CR> for details.

To delete a position from the table, say position #2, type in “DP”. The following will appear on the screen.

DELETE POSITION …

Type in “2” and <CR>. After a moment, the computer will ask for your confirmation. After you type "Y", the "delete" command will be executed and the following message is displayed:

-DONE-
III Transfer a block from Position A to Position B

You will begin with a relatively short exercise, demonstrating the operation of the robot.

(a) Operational Procedure

The robot is required to transfer the block from position A to position B by two intermediate positions (dummy points) as shown in Figure 5.

1. The robot will go to position A from its home position, and pick up the block.
2. The robot will go to position B via two dummy points C, D, release it from the gripper, and leave it at position B.
3. The robot will return to position B, pick up the block, and transfer it to position A via two dummy points, and leave it at position A.

NOTE: DO NOT move the robot directly from position A to B or vice versa. It may cause clash!

The same applies to the following experiment.

(b) Writing the program:

1. Select the EDIT PROGRAM from the MAIN MENU by typing in “F2”, the EDIT PROGRAM will be displayed as shown in Figure 6
2. The sequence of operations described above is broken down into individual operations which may be defined to the robot, such as “open gripper” and “go to position”. Each operation is listed on a separate line. Now translate each operation written above into a command appearing on the EDIT Program Menu. Type in the following program:

1. OPEN GRIPPER
2. GO POSITION #1 SPEED #2
3. CLOSE GRIPPER
4. GO POSITION #3 SPEED #3
5. GO POSITION #4 SPEED #3
6. GO POSITION #2 SPEED #2
7. OPEN GRIPPER
8. GO POSITION #4 SPEED #3
9. GO POSITION #2 SPEED #2
10. CLOSE GRIPPER
11. GO POSITION #4 SPEED #3
12. GO POSITION #3 SPEED #3
13. GO POSITION #1 SPEED #2
14. OPEN GRIPPER

where “#1”, “#2”, “#3”, and “#4” respective denote position “A”, “B”, “C”, and “D” in Figure 5.

3. Teach the robot the required points. Motion should begin from the home position.
4. Store the program under the PROGRAM HANDLING, which can be entered by press “F3” from the MAIN MENU.
(c) Running the program

Press the functional key “F4” from the MAIN MENU to run the program under the RUN PROGRAM MENU, which is shown in Figure 7.

![Figure 7: Menu options for running the program](image)

1. Run the program in RUN Single Line mode by press “F1”;
2. Run the same program in RUN Cycle mode by press “F3”;
3. Run the same one in RUN Continuously mode by press “F5”;
4. Record the design procedure and experiment result, explain the observation.

**NOTE:** Following parts involve coordination of two robots; do NOT operate them simultaneously to avoid any possible clash.

IV. Fully Synchronized Transfer Robot Operation

a) System Connection

In this experiment, for the first time, you will synchronize the actions of two robots to perform a common task. To accomplish this, you will cross-connect the input of one robot to the output of the other and vice versa.

Connect input 10 of Robot MK2 to output 5 of Robot ER14, and connect input 10 of Robot ER14 to output 5 of Robot MK2. Connect COM(-) and COM(+) of
the input of MK2 to COM(-) and COM(+) of the output of ER14, respectively.

Once output 5 of Robot ER14 has been activated (set to ON), Robot MK2 will consistently find that its input 10 is ON at all input state checks. Only after Robot ER14 turns its output 5 OFF the Robot MK2 will identify its input 10 as OFF.

The above also applies, in reverse, to input 10 of Robot ER14 and output 5 of Robot MK2. The connections between the inputs of one robot and the outputs of the other are accomplished using wires.

**Article I. b) Procedure**

The operating procedure is shown in Figure 1 and described as follows:

1. Place the two robots MK2 and ER14 at their “home” positions.
2. Robot MK2 descends to the block, closes its gripper, opens its gripper, and returns to its “home”. On reaching its "home", it signals robot ER14.
3. Robot ER14 receives the signal from robot MK2, descends to the block, closes its gripper, opens its gripper, returns to its "home", and signals to robot ER14.
4. Robot MK2 receives the signal from robot ER14 and repeats the previously described sequence.

![Figure 8](image)

The flow chart for the synchronized operation is shown in Figure 9.
Now teach both robots the following three positions:

* Position #1: "home" of the robots.
* Position #2: slightly above the block.
* Position #3: gripping position for the block.

The programs for the two robots are shown in the following:

**MK2**

1. OPEN GRIPPER
2. GO POSITION 1 #SPEED #3
3. GO POSITION 2 #SPEED #3
4. GO POSITION 3 #SPEED #3
5. CLOSE GRIPPER
6. OPEN GRIPPER
7. GO POSITION 2 #SPEED #3
8. GO POSITION 1 #SPEED #3
9. TURN ON OUTPUT #5
10. WAIT #10 10ths OF SECOND
11. TURN OFF OUTPUT #5
12. IF INPUT #10 ON JUMP 2
13. JUMP TO 12

**ER14**

1. OPEN GRIPPER
2. IF INPUT #10 ON JUMP 4
3. JUMP TO 2
4. GO POSITION 1 #SPEED #3
5. GO POSITION 2 #SPEED #3
6. GO POSITION 3 #SPEED #3
7. CLOSE GRIPPER
8. OPEN GRIPPER
9. GO POSITION 2 #SPEED #3
10. GO POSITION 1 #SPEED #3
11. TURN ON OUTPUT #5
12. WAIT #10 10ths OF SECOND
13. TURN OFF OUTPUT #5

Figure 9

Figure 10
Enter the programs written above on the respective computers of robot MK2 and robot ER14.

Save the programs under the PROGRAM HANDLING menu using the names MK2A for robot MK2 and ER14A for robot ER14.

c) Run the programs:
Now run the program under the RUN CELL CONTROL menu:

![Programs Menu](image)

First, run the entire program for robot MK2, line by line, then run the entire program for robot ER14, line by line by pressing “F1”.

Then run the programs in RUN CYCLE mode by pressing “F3”

Now run both programs in RUN CON. At the same time, first press the "F5" key for robot MK2 and immediately press the "F5" key for robot ER14.

V. Fully Synchronized Transfer of a Block from Robot to Robot

You will now write programs for both robots, resulting in the transfer of a block back and forth from one robot to another. These programs will be named: MK2B for Robot MK2 and ER14B for Robot ER14.

Article II. a) Procedure

The robots' operation is shown in Figure 4 and described as the follows:
1. Place the robot MK2 and ER14 at their “home” positions.
2. Robot MK2 descends to the block at position B, closes its gripper, lifts the block, and transfers it to position A. Then returns to position B, opens its gripper, puts the block at position B. Robot MK2 returns to its “home” position and signals robot ER14.
3. Robot ER14 takes the block from position B, transfers the block to position C. Then returns to position B, puts the block at position B. Finally, ER14 goes to its “home” and sends a signal to MK2.
4. Robot MK2 repeats the procedure (2).

![Diagram of positions A, B, and C]

Figure 12

Write flow charts for programs MK2B and ER14B.

Now teach each of the robots the positions required by its respective program. Enter and save each program in turn, under the names: MK2B and ER14B.

**b) Run the programs:**

As in previous procedures, run both programs under the RUN CELL CONTROL mode. Firstly, run line by line under RUN LINE mode. If no errors are found, run them under RUN CYCLE mode. Finally, run the programs continuously.

**Requirements**

Record all the design procedures, programs, flow chart, experiment results and the problems encountered during the operation. Note down the observations made.