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PC-Based 5DOF industrial robotic arm with object color sorting by image processing

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Abstract

Robotics arm getting popular in a wide range of application ranging from manufacturing in order to handle various tasks that might be difficult, hazardous, or boring from human being. The robotic arm in this research is a 5DOF vertical articulated education robot and its all joints are revolute. It is designed with a gripper to perform pick and place task. By merging image processing to this robotic arm, it is more efficient. The robot arm can not only pick and place the object to the desired position of the users, but also it can sort the color of the objects. As the same time, robot and machine vision systems can also perform objective measurements, such as determining a spark plug gap or providing location information that guides a robot to align parts in a manufacturing process. This research presents the modelling and analysis of forward kinematics of the robotic arm used in this research and the software development of 5DOF industrial robotic arm by using a new PC-based control and Image processing by NI Vision Builder is merged to this control method to sort the object colors and place them to the desired positions. PC-and EtherCAT based control technology from BECKHOFF is mainly used as control system for robotics arm to express this task. According to the automated applications in which a combination of hardware and software provide operational guidance to devices in the execution of their functions based on the capture and processing of images.

Keywords: Robotics arm; Image Processing; PC-Based control; PC-and EtherCAT based control

1. Introduction

Nowadays, robotic arm is extensively used in industries. The reason behind this is the requirements of accuracy, efficiency in repetitive tasks, high productivity and budget for industrial processes. The field of robotic is blooming with a fast speed in recent years and many progressive technologies are coming with their own advancement [1]. The robotic arm can perform many main applications according to its kind of design such as welding, painting, assembly, packing, labelling, product inspection, testing and so on. The pick and place task is one of the applications of the robotic arm described above. In order to make this kind of tasks more efficient and popular for using in manufacturing processes, PC-based control is mostly used as the controller and other functions is merged with the controller such as various object inspection sensor, image processing and human machine interface control method. PC-based control is effectively used with the robotics arm [2].

Image processing is a method of some operation on an image, in order to get an enhanced image or to extract some useful information from it. Image processing with the robotic arm is among rapidly growing technologies [3]. There are two types of method used image processing namely, digital and analogue image processing. Analogue image processing can be used for the hard copies like printouts and photographs. Forward kinematics is determining the cartesian position and orientation of a mechanism, given the joint coordinates. Inverse kinematics is computing the joint variables given the manipulator end effector position and orientation. For serial robotic manipulators, inverse kinematics problem is more complex than forward kinematics problem [4].

A lot of research technologies are developed improvement in robotics arm sector including its kinematics problem modelling and analysis. In [4], have developed robotic arm using image processing to sort object used PLC with position based and image based algorithm in robotic manipulator. [5] have developed vision controlled pick and place of moving object by 3R robot. [6] have demonstrated 6-DOF pc-based robotic arm (PC-Roboarm) with efficient trajectory planning and speed control. [7] have developed Color Sensor Based Object Sorting Robot. Jamshed et al. [8] have modeled a 6 DOF robotic arm manipulator, ED7220C with modelling and analysis its workspace. [9] have modeled and analyzed forward kinematics of 6-DOF underwear manipulator. Prasad et al. [10] analyzes performance of SCORBOT ER 4u robot arm. This research focuses on software development of the 5DOF robotic arm by using pc-base control technology from Beckhoff, PC-and EtherCAT based control and this is merged with the image processing by using NI Vision Builder software to recognize object colors then pick and place them to the desired positions, and also model and analysis forward kinematics of this robotic arm.

2. Materials and methods

The robotics arm used in this research is developed by Intelitek company. This robotics arm has been extensively used in research, development and teaching. It is basically a serial manipulator having all joints as revolute and one gripper for pick and place task. The arm geometrical configuration is made up of waist, shoulder, elbow and wrist in correspondence with the human arm joints. Fig.1 shows joints configuration of this robotics arm. Each of these joint except the wrist has single DOF. Wrist can move in two planes (roll and pitch). The build in mechanical safety limits restrict the joint motion in case something in the control algorithm goes wrong. Table 1 lists movement descriptions of the all joints.

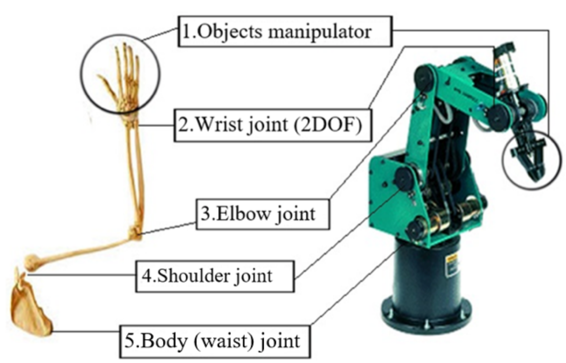


Fig. 1 A comparison of robotics arm and the actual arm

Table 1 Types of body Movements

Axis No.	Joint Name	Motion
1	Objects manipulator	Rotates the end effector (gripper)
2	Wrist joint	Raises and lowers the end effector (gripper)
3	Elbow joint	Raises and lowers the forearm
4	Shoulder joint	Raises and lowers the upper arm
5	Body joint	Rotates the body

Kinematics Model

Kinematics is the science of motion that treats the subject without regard to the forces that cause it. In this paper, the forward kinematics was implied in the principal role to analyse the motion of the robotic arm. The forward kinematics is process of determination the position and orientation of end effector giver values for joints variable of the manipulators. For studying this problem, method based on Denavit-Hartenberg (DH) convention is used to determine modelling robot links and joints. To solve the kinematics problem, we have to assign frame to each link by starting from base frame to end-effector frame. The frame assignment is shown in Fig. 2. Then we define the D-H parameters obtained in Table 2.

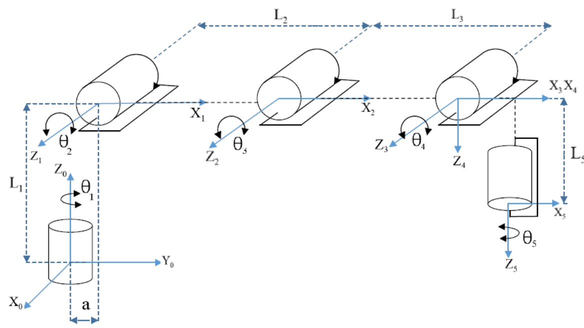


Fig. 2 Frame assignment to the robotic arm

Table 2 Denavit-Hartenberg parameters

Joint i	a_i (cm)	α_i (rad)	d_i (cm)	θ_i (rad)
1	a =1.20	$\pi/2$	L_1 =35	θ_1
2	L_2 =22	0	0	θ_2
3	L_3 =22	0	0	θ_3
4	0	$\pi/2$	0	θ_4
5	0	0	L_5 =15	θ_5

The D-H representation above depends on four link parameters, the following definitions of the four link parameters are valid:

- a_i (Link length) = the distance from Z_{i-1} to Z_i measured along X_i
- α_i (Link Twist) = the angle from Z_{i-1} to Z_i measured about X_i
- d_i (Joint Distance) = the distance from X_{i-1} to X_i measured along Z_{i-1}
- θ_i (Joint angle) = the angle from X_{i-1} to X_i measured about Z_{i-1}

The 4x4 homogeneous transformation matrix is used to determine the forward kinematics in this section. It can be easily developed by considering frame {i-1} and frame {i}. This transformation consists of four basic transformations.

$$^{i\text{-}1}T_i = \begin{bmatrix} C\theta_i & -S\theta_i C\alpha_i & S\theta_i S\alpha_i & a_i C\theta_i \\ S\theta_i & C\theta_i & -C\theta_i S\alpha_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Where $S\theta_i = \sin\theta_i$, $C\theta_i = \cos\theta_i$, $S\alpha_i = \sin\alpha_i$, $C\alpha_i = \cos\alpha_i$

Then, we substitute the D-H parameters from Table 2 into Equation (1), the transform matrix of each link are as the following:

$$^{0}T_{1} = \begin{bmatrix} C_1 & 0 & S_1 & aC_1 \\ S_1 & 0 & -C_1 & aS_1 \\ 0 & 1 & C\alpha_i & L_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2)$$

$$^{1}T_{2} = \begin{bmatrix} C_2 & -S_2 & 0 & L_2C_2 \\ S_1 & C_2 & -C_1 & L_2S_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (3)$$

$$^{2}T_{3} = \begin{bmatrix} C_3 & -S_3 & 0 & L_3C_3 \\ S_3 & C_3 & 0 & L_3S_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (4)$$

$$^{3}T_{4} = \begin{bmatrix} C_4 & 0 & S_4 & 0 \\ S_4 & 0 & -C_4 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (5)$$

$$^{4}T_{5} = \begin{bmatrix} C_5 & -S_5 & 0 & 0 \\ S_1 & C_5 & 0 & 0 \\ 0 & 0 & 1 & L_5 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (6)$$

To determine the end effector transformation matrix T_e. where $T_e = {}^{0}T_5$, we multiply the Equation (2), (3), (4), (5) and (6) together as the following:

$$^{0}T_{5} = {}^{0}T_{1} * {}^{1}T_{2} * {}^{2}T_{3} * {}^{3}T_{4} * {}^{4}T_{5} \qquad (7)$$

$$^{0}T_{5} = \begin{bmatrix} K_1 & K_4 & K_7 & p_x \\ K_2 & K_5 & K_8 & p_y \\ K_3 & K_6 & K_9 & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (8)$$

Where

$K_1 = C_1C_5C_{234} + S_1S_5$

$K_2 = -C_1S_5 + S_1C_{234}C_5$

$K_3 = C_5S_{234}$

$K_4 = S_1C_5 + C_1C_{234}S_5$

$K_5 = -C_1C_5 - S_1C_{234}S_5$

$K_6 = -S_{234}S_5$

$K_7 = C_1S_{234}$

$K_8 = S_1S_{234}$

$K_9 = -C_{234}$

We can get the value of the end-effector coordinate in cartesian space of this robotic arm as:

$$\begin{bmatrix} \square_{\square} \\ \square_{\square} \\ \square_{\square} \end{bmatrix} = \begin{bmatrix} C_1(a+L_3C_{23}+L_5S_{234}+L_2C_2) \\ S_1(a+L_3S_{23}+L_5C_{234}+L_2C_2) \\ L_1+L_3S_{23}-L_5C_{234}+L_2S_2 \end{bmatrix} \tag{9}$$

Where also

$$S_x = sin\theta_x,\ C_x = cos\theta_x,\ S_{xy} = sin(\theta_x+\theta_z),$$
$$C_{xy} = cos(\theta_x+\theta_y),\ S_{xyz} = sin(\theta_x+\theta_y+\theta_z),$$
$$C_{xyz} = cos(\theta_x+\theta_y+\theta_z)$$

Forward kinematics validation

The forward kinematics model of this robotics arm has been validated by using robotics toolbox in MATLAB. To examine the accuracy of the mathematics model in Equation (8), we have made the comparison between the results from matrix and MATLAB. Given the various angle set as input to the developed forward kinematics model and MATLAB toolbox, corresponding results have been compared and plotted. Assuming joint angle configuration [θ_1 θ_2 θ_3 θ_4 θ_5] as [0 0 0 0 0]; the position and orientation of the end-effector as computed from using Equation (8) is as the following:

$$\begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} = \begin{bmatrix} 45.2 \\ 0 \\ 20 \end{bmatrix}$$

Assuming joint angle configuration [θ_1 θ_2 θ_3 θ_4 θ_5] as [0 45° 0 45° 0]; the position and orientation of the end-effector as also computed from using Equation (8) is as the following:

$$\begin{bmatrix} \square_{\square} \\ \square_{\square} \\ \square_{\square} \end{bmatrix} = \begin{bmatrix} 47.31270 \\ 0 \\ 66.11270 \end{bmatrix}$$

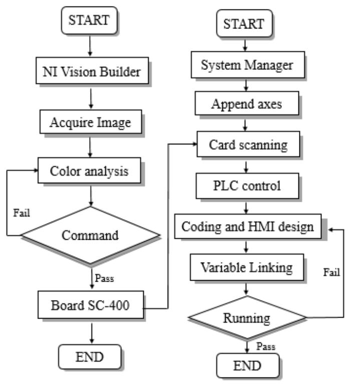
By using the command “Rob.fkine” in MATLAB, we obtained the same result, as shown in Fig. 3.

```
>> Rob.fkine([0 0 0 0 0])

ans =

    1.0000         0         0   45.2000
         0   -1.0000   -0.0000   -0.0000
         0    0.0000   -1.0000   20.0000
         0         0         0    1.0000

>> Rob.fkine([0 pi/4 0 pi/4 0])

ans =

    0.0000   -0.0000    1.0000   47.3127
    0.0000   -1.0000   -0.0000    0.0000
    1.0000    0.0000   -0.0000   66.1127
         0         0         0    1.0000
```

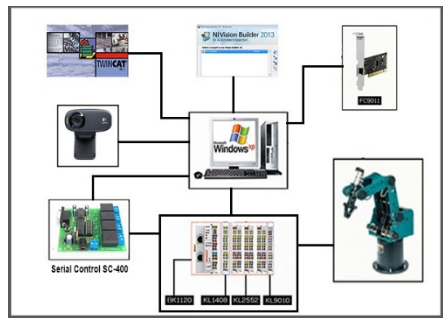
Fig. 3 Using command “Rob.fkine” in Matlab

Software development

In software development, there are two parts of software in the research. First, Twincat NC is used to program the robotic arm for expressing pick and place task with PC-and EtherCAT based control. In Twincat NC, there are two parts such as system manager and PLC control. System manager is used for appending each axis or motor and determining parameter value of its motor and optical encoder such as reference velocity and scaling factor. Moreover, system manager is also used to scan for the Beckhoff cards as used like KL2408 and KL2552.



a) PC flowchart



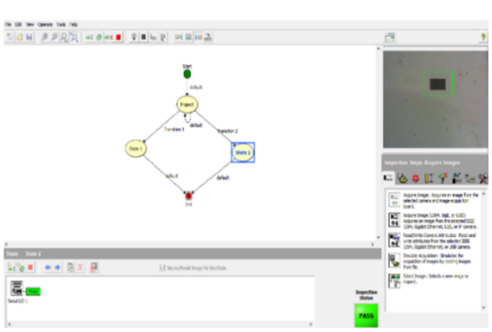
b) Applications of the EtherCAT technology

Fig. 4 PC and EtherCAT based control and image processing merging operation flowchart

And another parts of TwinCAT NC is PLC control where the researchers code the robotics arm and design HMI to control it, after the code and HMI is already done. The code is required to link its variables to the used cards in system manager. The second part is the image processing in NI Vison Builder. This software acquires image of the object from the webcam camera then inspects the object color. After the inspection and determining the conditions of the object color, NI Vision Builder is run, whenever the inspection status passes, the command is sent to Serial Control SC-400 board as the output of the image processing. With the command from NI Vision Builder, the channels of SC-400 changes its status from normal open (NO) to normal close (NC) and the electrical signal can reach the digital card KL2408 through electrical wire as input of PC and EtherCAT based control. The operation can also be describe by the flowchart in Fig. 4.

3. Results and discussion

In the experiment, the robotics arm is tested to express pick and place task with sorting object color by using image processing and PC and EtherCAT based control method described in section 3 and 4. At the moment of test, NI Vision builder and Twincat NC lso run together. The testing of image processing in NI Vision Builder to inspection black color is shown in Fig. 5.



a) Vision builder software

b) Robot and webcam camera

Fig. 5 Vision builder running and inspecting black color

Besides coding the robotics arm, the researchers designed a control displayed screen or HMI in TwinCAT NC as shown in Fig. 6 to facilitate for the user to control the robotics arm. On the displayed control screen, the user can jog each axis of the robotics arm, be aware of its all encoder values, run the full program for expressing the pick and place task with object color sorting and also object color status as shown on the screen.

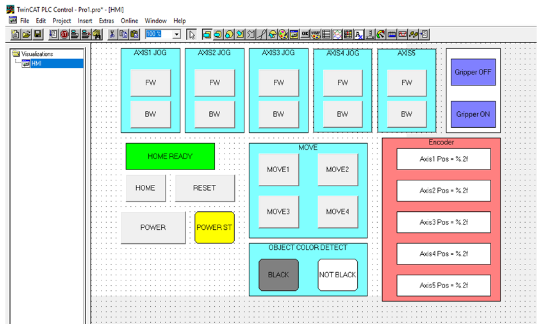


Fig. 6 An on Screen Control Panel

In this section, the researchers also tested on the accuracy of movement of each axis of the robotics arm. The researchers coded to move each axis to the desired position and make comparison between the positions that determined in the code with the position of its encoder value where each axis reached. By this way, the researchers tested each axis for 50 times, and observed that there were error values occurred in the 100 times test. These error values are shown in Fig. 7 – 11.

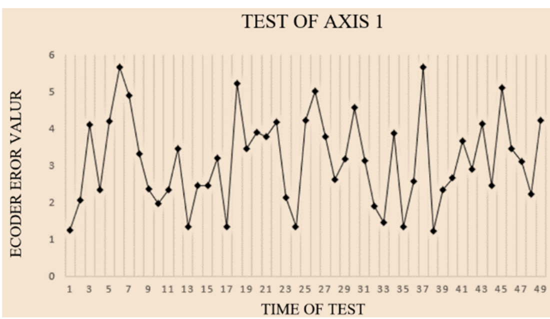


Fig. 7 Error value of Axis 1

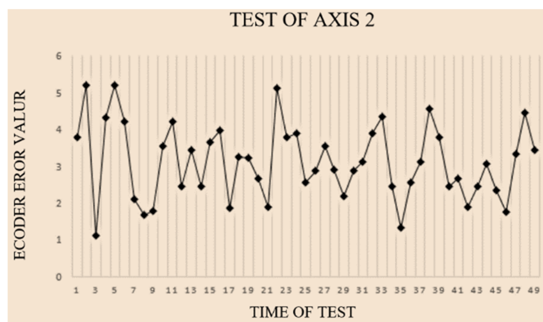


Fig. 8 Error value of Axis 2

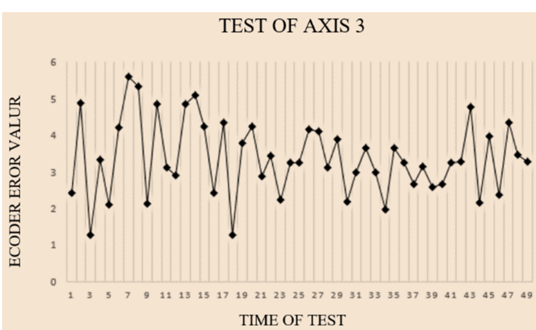


Fig. 9 Error value of Axis 3

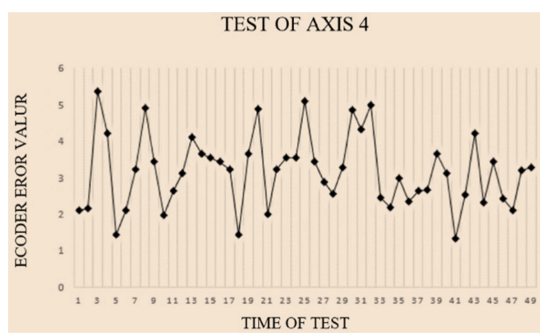


Fig. 10 Error value of Axis 4

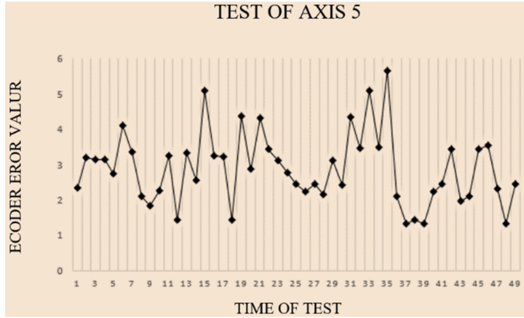


Fig. 11 Error value of Axis 5

4. Conclusion

This research described about merging between PC and EtherCAT based control which is the technology from new automation control method invented by Beckhoff with image processing by using NI Vision Builder. This merging method was used to control the robotic arm called Scorbot-ER 4U presented in section 2 to express pick and place with object color sorting. With image processing of NI Vision Builder, the acquired image from the webcam camera can be inspected its color and gain the output signal from Serial control SC-400 board potentially. On the other hand, the authors have tested the accuracy of each axis of the robotics arm 50 times, then made the comparison between the encoder values determined in the code with the encoder values that the robotic arm reached exactly. In this 50 times, we got the different error values of each axis as shown in Fig. 7-11. The average error values of axis1 is ±3.13143 mm, axis2 is ±3.12143 mm, axis3 is ±3.38208 mm, axis4 is ±3.17224 mm and axis5 is ±2.88347 mm. These average values of each axis is very little that we can run the robotic arm to pick and place the object effectively. And the forward kinematics of this robotics arm is modelled and analyzed. It may be applicable to get the end effector coordinate of this robotics arm and of other similar types of robotics arm.

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