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Kinematic Analysis of 4-DOF Teleoperated SCARA

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Abstract
Tele-operated robots are a class of robots that can be controlled from a remote location. They do not require the actual physical presence of the controller at the area of interest. This characteristic of tele-robots makes them highly useful in applications where the physical presence of the operator is either not viable or is dangerous, such as handling of toxic wastes or in medical applications. This project uses an augmented video interface and haptic feedback for slip detection to develop a 4-DOF SCARA robot that can be used as a tele robot. SCARA robots have the advantage of high degree of precision and reliability and hence are ideal for use as tele-robots. They have both linear as well as rotary joints, which results in a cylindrical configuration. This makes them well suited for almost any applications. The initial design of the robot was performed using Solidworks software. This provides the static workspace analysis of the robot and enables the setting of the material specifications required by the robot. In this paper, the derivation of the forward kinematics of the robot using Denavit-Hartenberg parameters and Inverse kinematics using Jacobian analysis have been presented. The Jacobian is a partial derivative analysis used to determine the inverse kinematics of the robot. The parameters were manually calculated and later compared using the robotics toolbox available in MATLAB (Mathematics Laboratory). A detailed description of the robot, including the materials used is also attached to enable a thorough understanding of the robot.

Keywords: *Tele-robots, haptics, SCARA, Denavit-Hartenberg, Solidworks, MATLAB, Jacobian*

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INTRODUCTION

A SCARA robot is typically used for applications requiring a quick and reliable response. Due to their unique structure and configuration, they excel in pick-and-place applications. However, they can also be modified to suit various other applications. One such application is in assembly lines of electronics parts where the favorable characteristics of SCARA such as high accuracy and fast cycle time are used for good effect. SCARA robotic arms have also been employed in various other industrial areas such as pick and place type operations, automated palletizing, and de-palletizing operations[1]. We have developed a, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

Modified model of the SCARA consists of a vertical axis, rotates about the Z-axis and translates in the XY-plane. Such a model enables the robot to be fully enclosed if necessary, and provides an inherent protection to the robot in destructive environments such as in industries performing metal works such as welding, milling etc. The design of the SCARA is such that it is able to move freely in the x-y plane and hence can accomplish tasks that require manipulation in the same plane more efficiently. Professor Hiroshi Makino was the first to develop the SCARA at the University of Yamanashi in 1979.

Simulation and modelling are a crucial part in the design of any robot. Performing a simulation of the robot enables us to get a clear picture of the expected workings of the robot and also enables us to calculate the various parameters associated with the robot. For performing the simulation of our robot, we have initially calculated the Denavit-Hartenberg parameters manually and then simulated it using the Robotics toolbox (an add-on toolbox) in MATLAB. Modelling the robot increases the quality of control that can be affected on the robot by displaying the areas that require a greater degree of control.

Yang Si *et al.* have performed a complete inverse kinematics for a 4-dof manipulator robot[2], which has four revolute joints: the first stands vertically while the other three are horizontal and parallel. They have calculated all possible solutions and configurations for their robot. The design we have fabricated consists of a prismatic joint for the body and three rotary joints. This limits the possible configurations of the robot, and hence simplifies the calculations.

MANIPULATOR DESCRIPTION

Design Details

In this section, we provide a detailed description of the structural design of our robot. The image of the basic design of the robot is shown in the Figures 1 and 2 below.

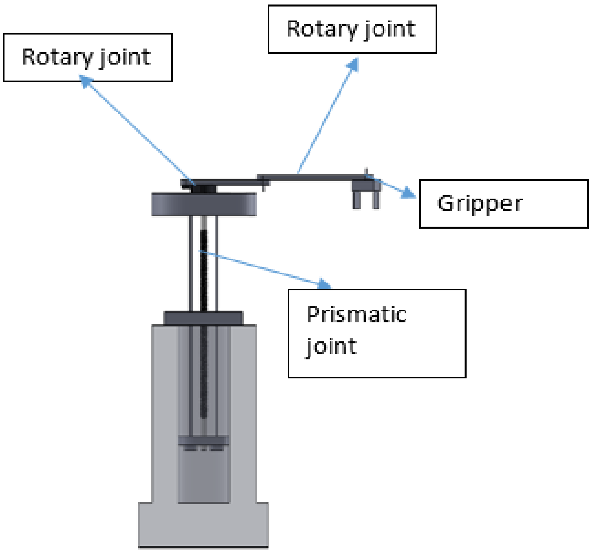

Fig. 1: *Front View of ROBOT.*

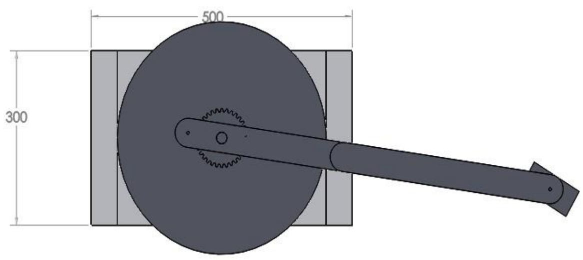

Fig. 2: *Top View of ROBOT.*

The robot consists of the following parts:

1. Body,
2. Lead screw (Prismatic joint),
3. Nut,
4. Guide rods,
5. Arms,
6. Sun and Planet gears (Rotary Joint),
7. Gear base,
8. Gripper,
9. Bearings (Linear and Roller),
10. Couplings,
11. Motors.

The robot is a 4-dof SCARA robot. The first joint is a prismatic joint. The lead screw rotates about a fixed nut to form the prismatic joint. A servomotor at the base facilitates the rotation of the lead screw. The guide rods act as guides to ensure that the lead screw moves along the correct path. The planet gear runs along the sun gear to form the first rotary joint. Both the gears rest on the gear base. The first arm is attached to the planet gear and hence is provided with nearly 360° rotation. The second arm is provided with a longer length than the first arm to facilitate better reach of the robot. Another servomotor is used to actuate the arm joint.

The simulated model of the robot in MATLAB is shown below:

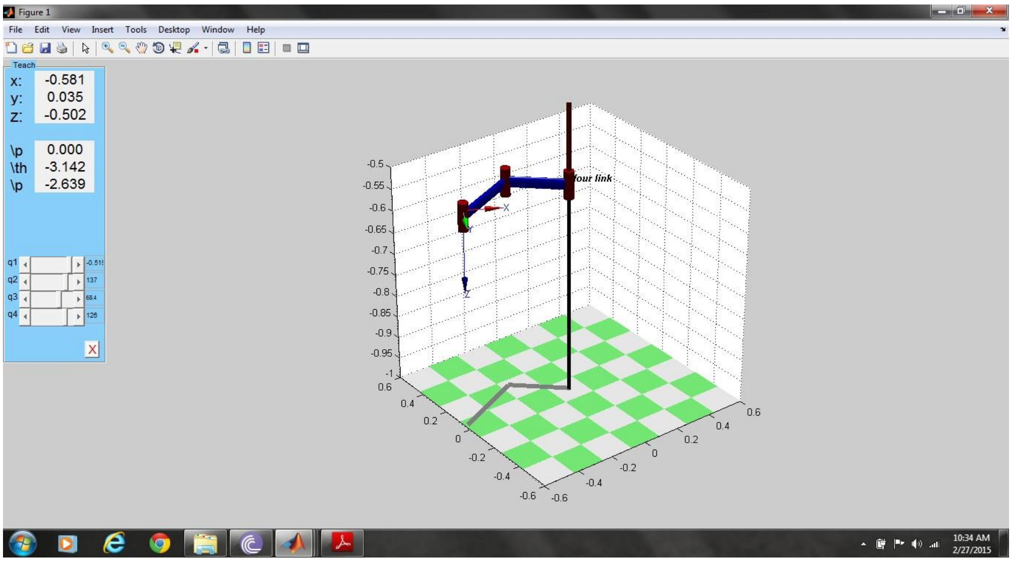

Fig. 3: *MATLAB Simulation.*

Forward Kinematics

A manipulator is composed of serial links, which are fixed to each other through revolute or prismatic joints. Calculating the position and orientation of the end-effectors in terms of the joint variables is called as forward kinematics [3].

The Denavit-Hartenberg (D-H) parameters for SCARA robot via simulation in MATLAB and theoretically are shown below (Table 1 and Figure 4).

Table 1: *Theoretical DH Parameters.*

Joints (j)	Θ (deg)	d (m)	a (m)	α (degs)
1	0	q_1	0	0
2	q_2	0	0.3	0
3	q_3	0	0.4	0
4	q_4	0.013	0	π

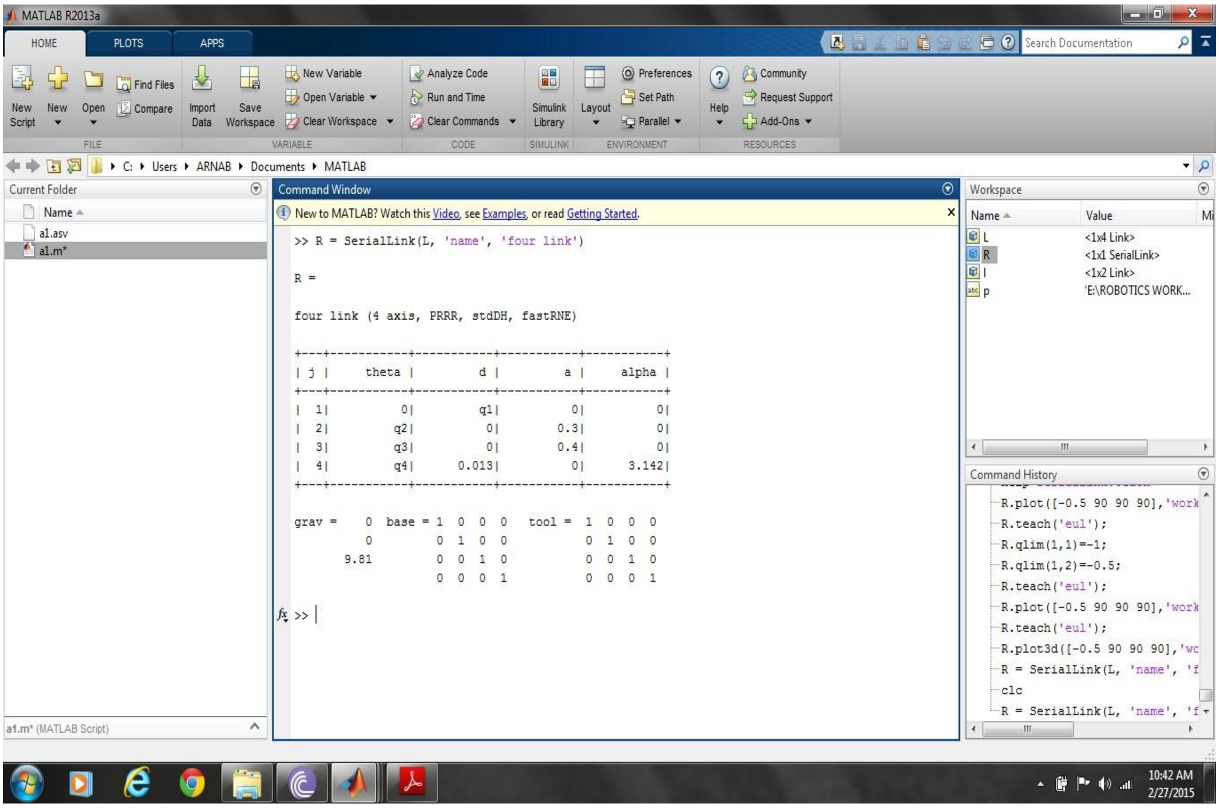

Fig. 4: *Simulated DH Parameters.*

Transformation matrices for each joints specified as T_1, T_2, T_3, and T_4 are given by the following equations:

$$T_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & q_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \text{Eq. (1)}$$

$$T_2 = \begin{bmatrix} \cos q_2 & -\sin q_2 & 0 & l_1 \cos q_2 \\ \sin q_2 & \cos q_2 & 0 & l_1 \sin q_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \text{Eq. (2)}$$

$$T_3 = \begin{bmatrix} \cos q_3 & -\sin q_3 & 0 & l_2 \cos q_3 \\ \sin q_3 & \cos q_3 & 0 & l_2 \sin q_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \text{Eq. (3)}$$

$$T_4 = \begin{bmatrix} \cos q_4 & \sin q_4 & 0 & 0 \\ \sin q_4 & -\cos q_4 & 0 & 0 \\ 0 & 0 & -1 & d \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \text{Eq. (4)}$$

$$T=T_1*T_2*T_3*T_4=\begin{bmatrix} \cos(q_2+q_3+q_4) & -\sin(q_2+q_3+q_4) & 0 & l_2\cos(q_2+q_3)+l_1\cos q_2 \\ \sin(q_2+q_3+q_4) & \cos(q_2+q_3+q_4) & 0 & l_2\sin(q_2+q_3)+l_1\sin q2 \\ 0 & 0 & -1 & d+q_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \text{Eq. (5)}$$

Simulated Forward Kinematics for joint parameters is: q=[0.25π/2π/2π/2]

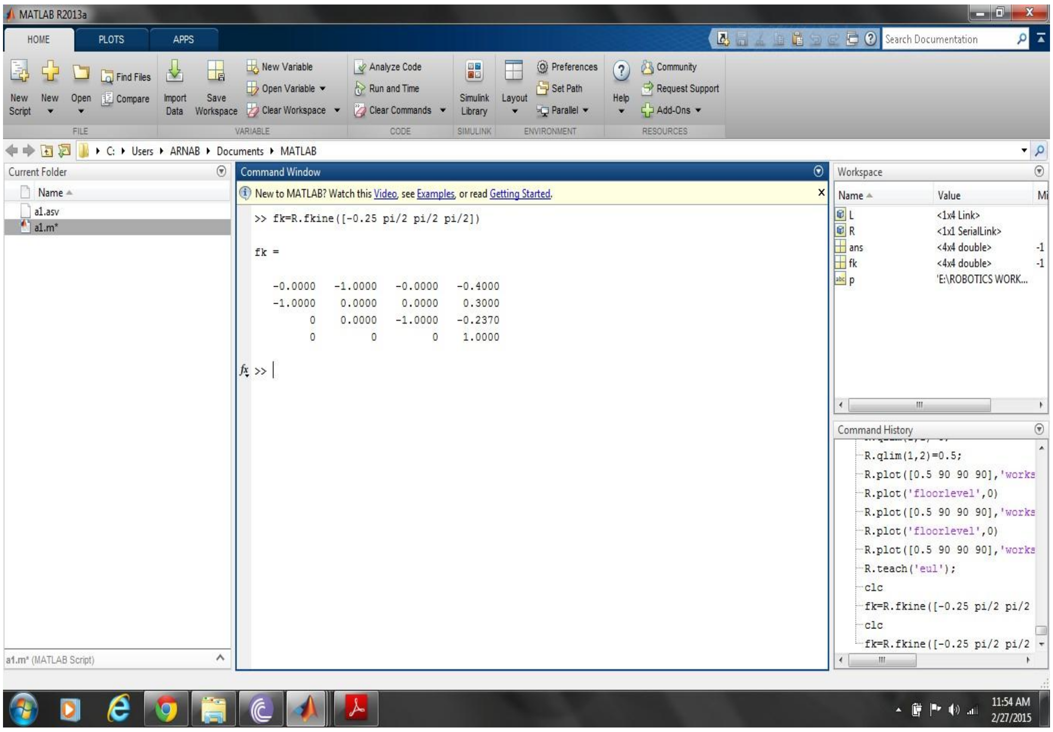

Fig. 5: MATLAB Output for Inverse Kinematics.

Inverse Kinematics

The two important terminologies associated with kinematics are Cartesian space and Joint space. Cartesian space represents the orientation matrix and position vector whereas Joint space is represented by joint angles. Cartesian space is used by the manipulators to perform their tasks whereas actuators work in Joint space. The conversion from Cartesian to Joint space is called inverse kinematics. The problem associated with inverse kinematics is that it is computationally expensive and hence, in real world takes a long time to affect control of the manipulator. Work has been carried out in this field for decades and two approaches for solving the problem have been derived namely, geometric and algebraic methods.

The mathematical calculations for inverse kinematics involves the following equations:

$$x=l_2\cos(q_2+q_3)+l_1\cos q_2 \qquad \text{Eq. (6)}$$

$$y=l_2\sin(q_2+q_3)+l_1\sin q_2 \qquad \text{Eq. (7)}$$

$$z=d+q_1 \qquad \text{Eq. (8)}$$

$$\gamma=q_2+q_3+q_4 \qquad \text{Eq. (9)}$$

$$\frac{dx}{dt}=-l_2\sin(q_2+q_3)*\left(\frac{dq_2}{dt}+\frac{dq_3}{dt}\right)-l_1\sin q2*\frac{dq_2}{dt} \qquad \text{Eq. (10)}$$

$$\frac{dy}{dt} = l_2\cos(q_2+q_3)*\left(\frac{dq_2}{dt}+\frac{dq_3}{dt}\right)+l_1\cos q2*\frac{dq_2}{dt} \qquad \text{Eq. (11)}$$

$$\frac{dz}{dt} = \frac{dq_1}{dt} \qquad \text{Eq. (12)}$$

$$\frac{d\gamma}{dt} = \frac{dq_2}{dt}+\frac{dq_3}{dt}+\frac{dq_4}{dt} \qquad \text{Eq. (13)}$$

$$\begin{bmatrix} \frac{dx}{dt} \\ \frac{dy}{dt} \\ \frac{dz}{dt} \\ \frac{d\gamma}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -l_1\sin q_2 - l_2\sin(q_2+q_3) & -l_2\sin(q_2+q_3) & 0 \\ 0 & l_1\cos q_2 + l_2\cos(q_2+q_3) & l_2\cos(q_2+q_3) & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 \end{bmatrix} * \begin{bmatrix} \frac{dq_1}{dt} \\ \frac{dq_2}{dt} \\ \frac{dq_3}{dt} \\ \frac{dq_4}{dt} \end{bmatrix} \qquad \text{Eq. (14)}$$

ÞR=J*Q, Eq. (15)

where,

$$R=\begin{bmatrix} \frac{dx}{dt} \\ \frac{dy}{dt} \\ \frac{dz}{dt} \\ \frac{d\gamma}{dt} \end{bmatrix}$$

$$J=\begin{bmatrix} 0 & -l_1\sin q_2 - l_2\sin(q_2+q_3) & -l_2\sin(q_2+q_3) & 0 \\ 0 & l_1\cos q_2 + l_2\cos(q_2+q_3) & l_2\cos(q_2+q_3) & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 \end{bmatrix}$$

$$Q=\begin{bmatrix} \frac{dq_1}{dt} \\ \frac{dq_2}{dt} \\ \frac{dq_3}{dt} \\ \frac{dq_4}{dt} \end{bmatrix}$$

The simulation for 4-DOF robot using RVC toolbox in MATLAB is difficult therefore to ease the calculations, the final joint of the robot is merged with the end effector and therefore joint angle corresponding to that joint is added to the joint angles of the previous joints making the robot a 3-DOF robot.

The simulation is shown below with the input homogeneous transformation matrix obtained from forward kinematics.

EQUATIONS

Forward Kinematics

The Eqs. (1-4) are the transformation matrices for joints 1, 2, 3, and 4 respectively.

Eq. (5) corresponds to the final transformation matrix for the above four equations which gives us the study of forward kinematics.

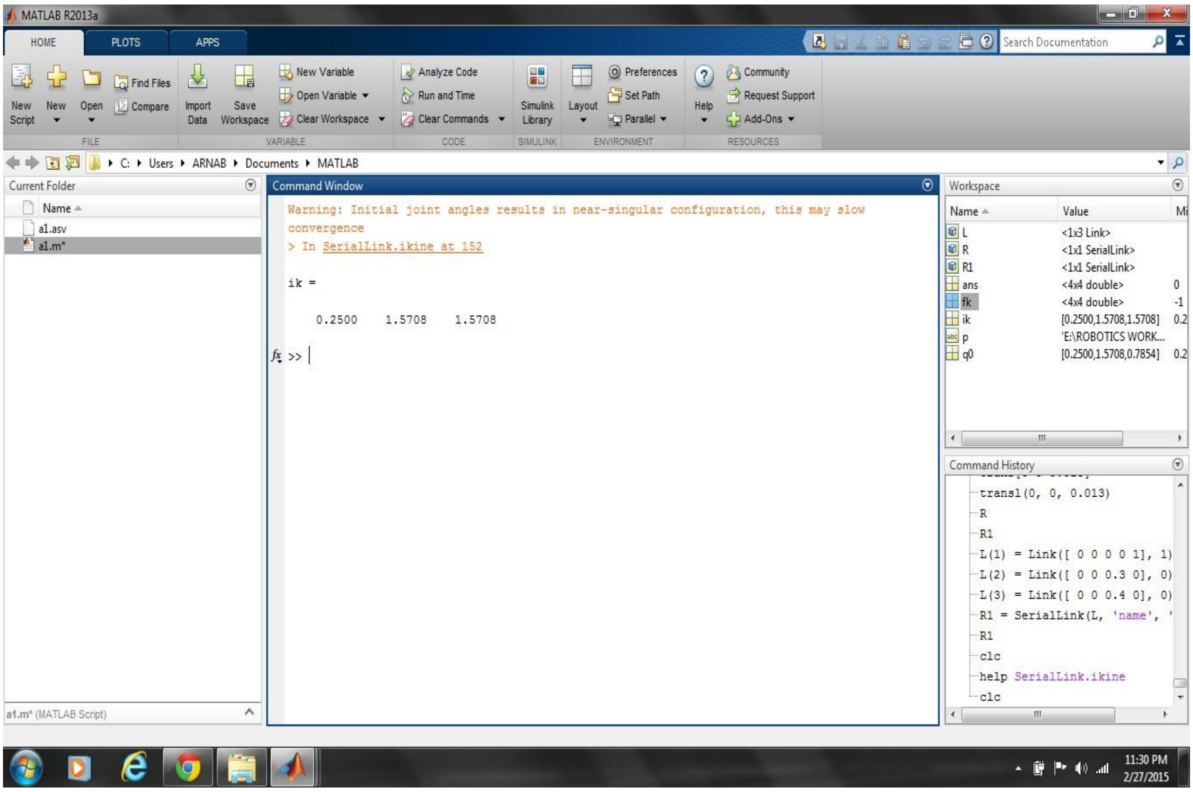

Fig. 6: MATLAB Output for Forward Kinematics.

Inverse Kinematics

Eqs. (6-9) gives us the world coordinates for x, y, z and γ. (Since α and β are zero in this case) Thus the world coordinate system (6x1 Matrix) has to be mapped with the joint coordinate system (4x1 Matrix). Therefore, to find a relation, we take the derivative of the above equations with respect to time.

Eq. (10) provides us the relation between world coordinate and the joint coordinate systems using a matrix J called the Jacobian. Now if we take the inverse of Jacobian matrix and multiply both sides with it in Eq. (10), we get the corresponding joint coordinates in terms of world coordinates.

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REFERENCES

1. Subhashini PVS, Raju NVS, Venkata Rao G. Modelling, Simulation and Analysis of SCARA Robot for Deburring of Circular Components. *ARPN Journal of Engineering and Applied Sciences (JEAS)*. Apr 2014; 9(4).
2. Yang Si, Qingxuan Jia, Gang Chen, *et al. A Complete Solution to the Inverse Kinematics Problem for the 4-dof Manipulator Robot.* Beijing University

of Posts and Telecommunications. Unpublished.

3. Serdar Kucuk, Zafer Bingul. *Industrial Robotics: Theory, Modelling and Control*. (Ed.) Sam Cubero. Germany. Dec 2006; ARS/p lV: 964p. ISBN 3-86611-285-8.
4. Khairul Salleh Mohamed Sahari, *et al*. Design and Development of a 4-dof SCARA Robot for Educational Purposes. *Jurnal Teknologi*, 54(sans & khej), keluaran khas. Universiti Teknologi, Malaysia. Jan 2011; 193-215p.