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Trajectory Analysis for SCARA Manipulator with Industrial Application

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Abstract: The system included an Associate in the Nursing elbow, kaleidoscopic, and a wrist joint was joint to works within the vertical plane for real positioning of the work half that's referred to as Selective Compliance Assembly mechanism Arm (SCARA). It provides an acceptable alternative for obtaining along with missions principally. to urge higher accuracy in the industrial application, several researchers are visible on management and displaying of SCARA reasonably robot. Linear quadratic controller (LQG-controller) provides perfect control of the live and detective work vulnerability to operating a robot sideways a determined system. This paper shows the best technique to addressing SCARA 4-DOF robot movement ordering that considering the controller and the sensors will be operated during the implementation of the robot's mode. This transportation can be used to adjust the kind of the route, for an explanation by calculating the chance of maintaining a planned space from crashes. The usage of a virtual model for SCARA robot-based virtual reality (VR) with LQG controller takes into consideration improving the control frameworks of modern robots, notwithstanding proposing and approving new control frameworks. In the same direction, this paper presents the technique of plan and expansion of a robot with a SCARA proposal, which has strange application in the current-day industry. A future mode of LQG controller with SCARA robot was designed and realized in computer-created certainty condition, and it presently contains a physical stage where the assortment of control approaches can be strained and measured. The enhancement of the controller's invention, as to the electronic interface, in spite of the complexity of its structure and execution, permitted an ideal working of the total framework. This produce, many different capacities, similarly empowers the age of numerous directions for the robot. The work executes by utilizing MATLAB/SIMULINK var. 2019b, a suitable conclusion is developed which confirmed the dependence of this model as the right down-to-earth perceptive mechanical autonomy framework.

Keywords: SCARA manipulator, Inverse kinematic solutions, Virtual Reality Model, Linear quadratic controller.

1. Introduction

SCARA changes of the time execute errands, such as distortion clearing, brushing, determination, fixing, pinhole, mechanical get collected, and circuit load up meeting, all of which need careful next and fast moving of the last transponder. Usual fast robots can't manage huge payloads (10 kg-20 kg), whereas robots that handle huge payloads can't reach at high speeds. Servo water powered parts make high speeds and payloads conceivable. Kinematic systems are frequently delivered corresponding to fast fixed engines [1]-[4]. There are some robots may be growing the velocities more than 785 ms-2 (about several times the moving up of gravity), enormous payloads that employed packaging was limited and not practical yet, and not realistic for level actions. To overcome the inactivity matter, the force transmission parts and occupied framework pieces with actuator separated by belt drives from moving parts. This gives grinding to the framework and a violent response. A limited study suggests choices, such as, wire-driven FALCON robot. 3-DOF M.I.T. Direct plant controller was introduced by Kuo and Toumi. Next velocity was 3 m/s, and it can accelerate up to 3.8 times the moving up of gravity (min someplace in the variety of 0.050 mm and 0.10 mm) [5]-[7].

Level doings were operated by SCARA controllers in general. Normal business SCARA actuators were forced by brushless DC machine, that could create extremely high torque in addition to framework dormancy yet. The joints looking up to the devices or belt drives were called defeating the issue, they existing subjects of deferral yet, grinding and slippage. The treatment of huge problem in an electric machine SCARA gets unbelievable at very high speeds. Researches were done on servo pressure driven frameworks just on associated high torque / quality requests. To drive sequential controllers a couple of water powered servo machine was used. About direct machines were used to drive changeable joints, constraining execution, and vary the torque through the packaging. There wasn't enough research on turning machines. Additional check thought about rotating machines for high torque requests. Without servo water driven parts have been used to make high speeds in prearrangement moves [8]-[11].

The transmission control agreement was one of the most famous vehicle conventions, that provides a scheme to control began to end objection [12,13]. In this covenant, the typical objection gap size increases when the pack are conveyed to the receiver. Instead, the standard size of the objection gap reduces during the futile data change. May be, this plant has important disadvantages, for example, the poor operation of plant property and global flow concurrence [14-16]. To avoid these deficiencies, AQAP has been introduced at entrances to progress their exhibition. An insufficient kind of Al Qaeda on the earth was introduced in the closed TCP systems control in last years. In Random Early Detection (RED) is introduced that randomly released the pack at an exact probability before the line frame flood. Organizer gotten electronic

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transient behavior for AQM/TCP switches [17]. So, the representative has an unbelievable occupation in understanding and breaking down unlike plant closed dodging plans. In [18] the linearity was used by Hollot et al. For lately learnt non-direct system checkup of AQM/TCP switches. The PI controller was introduced in [19] Based on the conventional plant and control hypothesis, the provision obtainable better properties done the RED controller. In [20] a linear quadratic controller (LQ) was introduced and the control parameter was chosen by testing. The result constructed up a useful AQM-based neural model, and confirmed a great implementation that was proposed by [21,22].

This paper proposed the building up a controller for a 4-degree level of opportunity SCARA robot (4-DOFs) with D-H detailing, and unraveling the kinematic and kinematic conditions in front of the SCARA. Motor attributes; The DC servo engines driving each mechanical joint are concentrated in detail. Straight Quadratic Linear Control (LQG) application with a pragmatic way based streamlining way for SCARA mechanical automated application in modern and biomedical applications. The incorporated methodology that has been applied through VRML is a four-hub SCARA framework for managing MATLAB 2019b/Simulink. The controller structure to be proposed depends on the standards of strong body displaying with computer generated reality innovation. The outcomes are compelling, the reaction (dependability) is speedy and the application progressively is conceivable through the interface cards.

2. Solution of Inverse and forward kinematics for SCARA 4-DOF robot

The kinematics solution depends upon the presentation of D_H parameters for transformation matrix for the robot joints. In this case study for SCARA 4-DOF robot is shown in Fig. 1, the D_H parameters explain by Table 1 as follow:

Table1: The SCARA robot 4-DOF D-H formula

j	Dj	θj	mj	Aj
1m	0	θ_{1m}	L_{1m}	0
2m	0	θ_{2m}	L_{2m}	0
3m	d_{3m}	0	0	0
4m	d_{4m}	0	0	0

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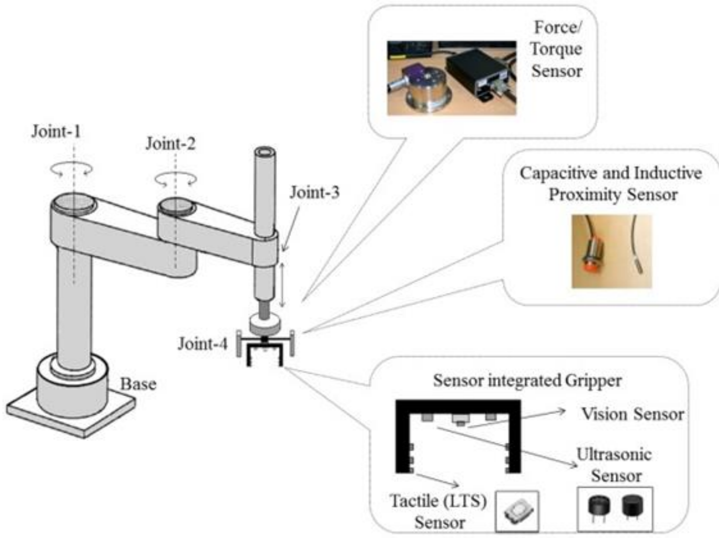

Fig. 1. Structure of SCARA robot with 4-DOF [23]

According to table 1, we can construction the transformation matrix for each joint as:

$$T_{1m}^{00} = B_{1m} = \begin{bmatrix} c_{1m} & s_{1m} & 0 & L_{1m} \\ -s_{1m} & c_{1m} & 0 & L_{1m}c_{1m} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(1)

$$T_{2m}^{1m} = B_{2m} = \begin{bmatrix} c_{2m} & s_{2m} & 0 & L_{2m}s_{2m} \\ -s_{2m} & c_{2m} & 0 & L_{2m}c_{2m} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(2)

$$T_{3m}^{2m} = B_{3m} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -d_{3m} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(3)

$$T_{4m}^{3m} = B_{4m} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -d_{4m} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(4)

At final, the overall transformation matrix can be written as:

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$$T_{4m}^{00} = \begin{bmatrix} c_{1m2m4m} & s_{1m2m4m} & 0 & L_{2m}s_{1m} + L_{1m}s_{1m} \\ -s_{1m2m4m} & c_{1m2m4m} & 0 & L_{2m}c_{1m2m} + L_{1m}c_{1m} \\ 0 & 0 & 1 & -d_{3m} - d_{4m} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(5)

The location of target posture for SCARA robot can be described by:

$$T_{Hj}^{Rj} = \begin{bmatrix} n_{xj} & o_{xj} & a_{xj} & p_{xf} \\ n_{yj} & o_{yj} & a_{yj} & p_{yf} \\ n_{zj} & o_{zj} & a_{zj} & p_{zf} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(6)

The series transformation matrices that are presented the SCARA robot with 4-DOF as:

$$T_{Hj}^{Rj} = B_{1j}B_{2j}B_{3j}B_{4j} = T_{4m}^{00}$$

(7)

The final solution must be written the form of B4, which can be presents as:

$$B_{3m}^{-1m}B_{2m}^{-1m}B_{1m}^{-1m}T_{Hj}^{Rj} = B_{4m}$$

$$B_{4m} = \begin{bmatrix} n_{xj}c_{1m2m} + n_{yj}s_{1m2m} & o_{xj}c_{1m2m} + o_{yj}s_{1m2m} & m_{xj}c_{1m2m} + m_{yj}s_{1m2m} & p_{xj}c_{1m2m} + p_{yj}s_{1m2m} - L_{1m}c_{2m} - L_{2m} \\ -n_{xj}s_{1m2m} + n_{yj}c_{1m2m} & o_{xj}s_{1m2m} + o_{yj}c_{1m2m} & -m_{xj}s_{1m2m} + m_{yj}c_{1m2m} & -p_{xj}s_{1m2m} + p_{yj}c_{1m2m} - L_{1m}s_{2m} \\ n_{zj} & o_{zj} & a_{zj} & p_{zj} + d_{33} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The final position can be gotten when compare the Eqn's (4) and (8)

$$p_{xj} = L_{1m}s_{1m} + L_{2m}s_{1m2m} \quad (9)$$

$$p_{yj} = L_{1m}c_{1m} + L_{2m}c_{1m2m}$$

(10)

By rearrange the Eqn's (9) and (10) we get:

$$s_{2m} = \frac{1}{2L_{1m}L_{2m}}\left(p_{xj}^{2m} + p_{yj}^{2m} - L_{1m}^{2m} - L_{2m}^{2m}\right)$$

(11)

$$c_{2m} = \pm\sqrt{1 - s_{2m}^2}$$

(12)

$\theta_{2m2} = tan^{-1}\frac{c_{2m}}{s_{2m}}$
(13)

Now, we can formulate the Eqn's (9) and (10) with final form as:

$p_{xj} = (L_{1m} + L_{2m}s_{2m})s_{1m} - L_{2m}c_{2m}c_{1m}$
(14)

$p_{yj} = L_{2m}c_{2m}s_{1m} + (L_{1m} + L_{2m}s_{2m})c_{1m}$
(15)

The final form of joints angle can be get by using kramer's formulae with Eqn's (14) and (15) as:

$\theta_{1m} = tan^{-1}\frac{s_{1m}}{c_{1m}} = tan^{-1}\frac{(L_{1m}+L_{2m}c_{2m})p_y - L_{2m}s_{2m}p_{xj}}{(L_{1m}+L_{2m}c_{2m})p_{xj} - L_{2m}s_{2m}p_{yj}}$
(16)

In Eqm's (5) and (6) by compare the two elements by cell (4,4) we get as:

$d_{3m} = -p_{zj} - d_{4m}$
(17)

Then

$\theta_{3m} = 0$
(18)

In Eqm's (4) and (8) by compare the two elements by cells (1,1) and (2,1) we get as:

$s_{4m} = n_{xj}s_{1m2m} + n_{yj}c_{1m2m}$
(19)

$c_{4m} = -n_{xj}c_{1m2m} + n_{yj}s_{1m2m}$
(20)

$\theta_{4m} = tan^{-1}\frac{-n_{xj}\, sin(\theta_{1m}+\theta_{2m}) + n_{yj}\, cos(\theta_{1m}+\theta_{2m})}{n_{xj}\, cos(\theta_{1m}+\theta_{2m}) + n_{yj}\, sin(\theta_{1m}+\theta_{2m})}$
(21)

3. Linear Quadratic Controller Design

In this section, the LQG-servo controller was introduced to provide the output (optimum value) stabilized to the wanted joint angle in minimum steady-state error (e_{ss}) for network congestion avoidance [24].

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a. Servo Formula for SCARA Model

When the robot system doesn't include a mix unit this called the primary typical of the servo SCARA robot, (for example, a SCARA system) a front integrator must be entered as looked in Figure 2 to complete the zero objective control unit in the robot response [25]. The state-space model description for the control model with LQG technique can be defined as:

$$x_n(\mathrm{k+1}) = \varphi_{LQ} x_n(k) + \Gamma_{LQ} u_n(k), \quad \mathrm{k} = 0,1,2,...$$
$$y_n(k) = G_{LQ} x_n(k)$$
(22)

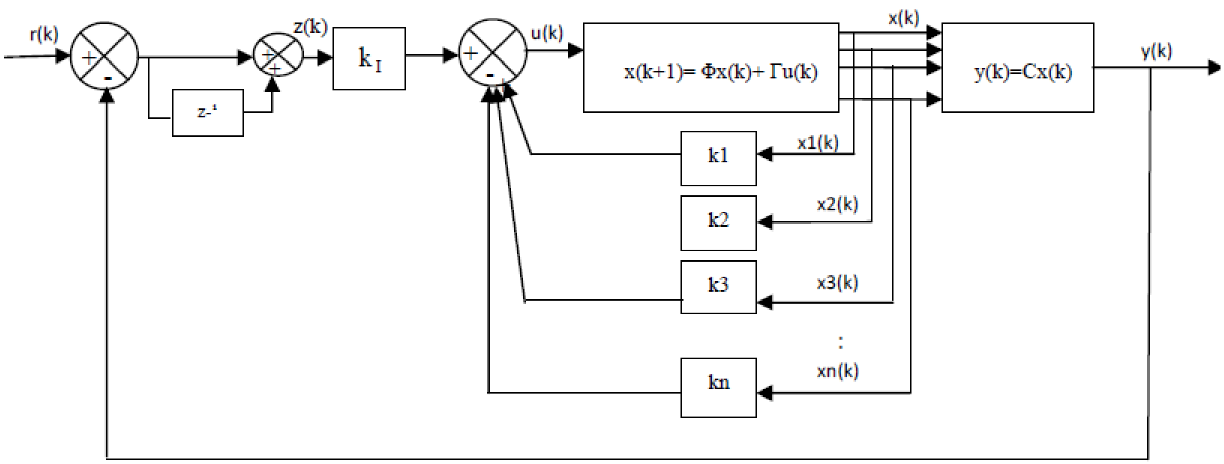

Fig. 2. Servo system of SCARA robot with state space representation [26]

The detail definition of the system in (22) as:

$$\varphi_{LQ} = \begin{bmatrix} \varphi_h & 0 \\ -G\varphi_h & 1 \end{bmatrix}, \Gamma_{LQ} \begin{bmatrix} \Gamma_h \\ -G\Gamma_j \end{bmatrix} \text{ ; also } \quad K_h{}^* = [K_h \quad -K_I] \,,$$

$$\xi(k) = \begin{bmatrix} x_{eh}(k) \\ h(k) \end{bmatrix} = [x_{e1} \quad x_{e2} \quad x_{e3} \quad x_{e4}]^T,$$

$$u^*(k) = -K_h{}^* \xi(k)$$
(23)

u*(k) presents the optimal (LCG) control law and K^* is according control gain matrix.

b. Optimal LQG-servo Controller

The chief difficulties with an optimum LQG-servo is the calculation of the gain state feedback matrix (K^*) [27]. The goal of this matrix is decreasing the input ($u^*(k)$) according to the suitable cost function (performance index), is shown in Fig. 3.

$$J = \sum_{0}^{\infty}(\xi^{T}(k)Qx_j(k) \rightleftarrows +u^{*T}(k)Ru^{*}(k)) \rightleftarrows \quad (24)$$

Where

$k = (R + \Gamma_j^{T} P_j \Gamma_j)^{-1} \Gamma_j^{T} P \varphi_{LQ}$; $P_j = P_j^{T}$ a solution matrix for discrete algebraic Riccatti's equation:

$$\varphi_{LQ}^{T} P \varphi_{LQ} - P + Q - \varphi_{LQ}^{T} P \Gamma S^{-1} \Gamma^{T} P \varphi_{LQ} = 0 \quad (25)$$

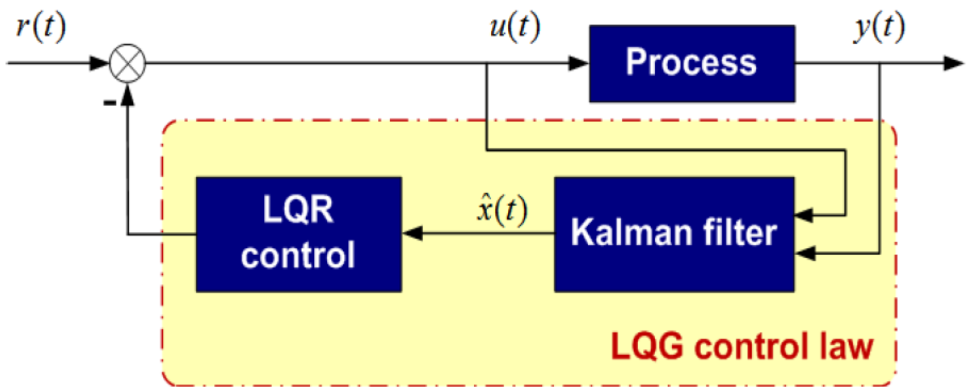

Fig. 3. The overall structure of optimal LQG controller [28]

4. Design SCARA robot based on virtual reality

The VRML strategy necessities are explained in constrained and allowed preparing assignments, measurement of power and dependable self-enlistment. The idea in VRML count on the article creative mind and originator's data. VR construction selections are typical designs (cone, circle, drum, and so on.) and freestyle (listed face mapping button is determined, for numerous arrangements with focuses that can be modified). Each original construction is a free-form plan, that can start with building squares alone and checks the shape against a related genuine controller part. In this, robot parts can't be re-formed in computer created reality when using the normal arrangement from an amplified simulation library, as its form isn't uniform. The proposal operates the ordered face set-in computer-generated reality. The following structure step is to interface all parts to deliver the object and decide the item's source. This assignment was performed by setting the primary shape (for instance the base) and afterward associating the following shape (the subsequent joint) in the "Kids" button; a similar methodology is rehashed with different parts. Figure 4 is the plan, in full VR, for a SCARA robot with a wrist.

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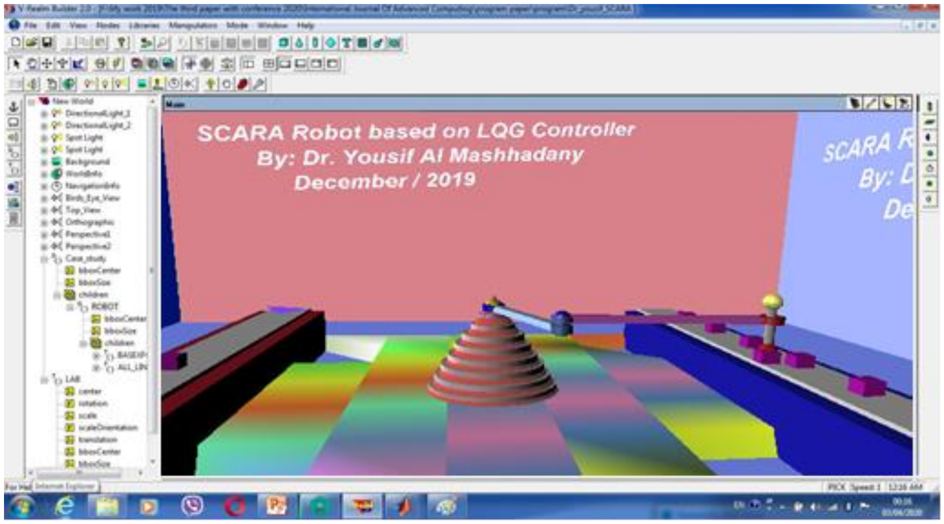

Fig.4. A SCARA 4-DOF model based on VR with practical limitation installation

5. Simulation results and analysis based on VR model

Figure 3illusterates the VR model with Matlab 2019b /Simulink with SCARA way LQG controller. Beginning the reenactment is to summon the converse and forward kinematics figuring for the SCARA robot from the Matlab order window; The arrangement document opens where the guidelines are composed utilizing a genuine useful control procedure. The order record (yousif_LQG_Des) is imported through the order window from the source, and afterward opened (by means of the document open order) in the LQG control box. Figs. 5, Open initiated record shows up, information is sent out to the workspace, and reproduction is run for instance, 60s. The Base Display order empowers the presentation of perfect composed preparing rules. It is a pictorial base watcher for 4 sources of info and 1 yield.

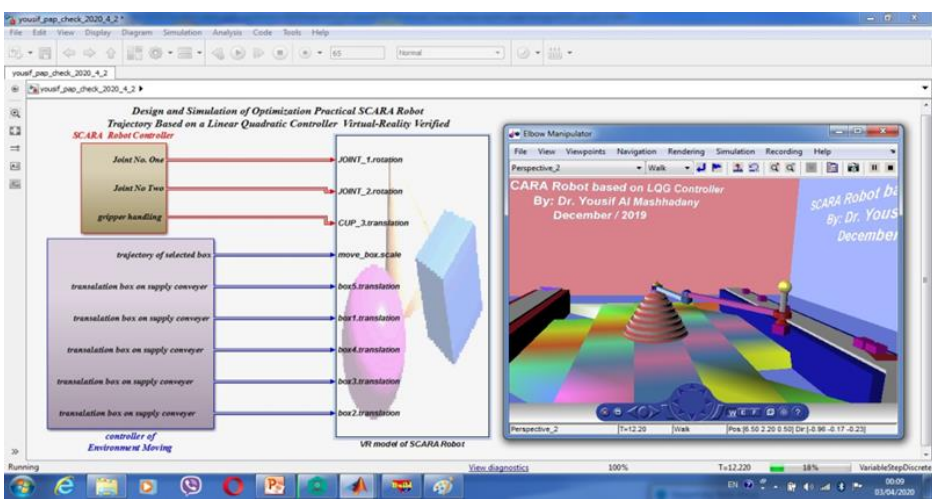

Fig. 5. Simulation for LQG Controller of SCARA Robot by VR model Verified on Industrial-Application

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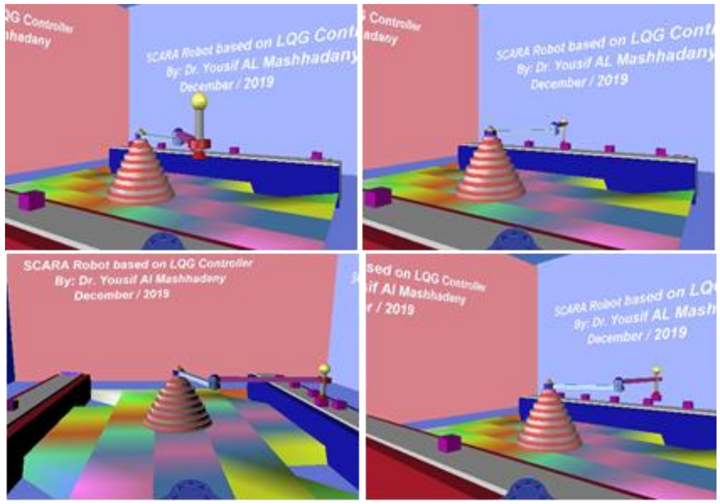

Figs. 6: Optimal trajectory of SCARA 4-DOF based on LQG controller

After the underlying activities, the VR model is called by the interface obstruct among it and Matlab. Figure 5 shows opening the support account in the order window. Workspace factors are stacked on the LQG comfort square. At that point the prepared information is sent out to the workspace, by means of the Export Files order. Figure 6 is the test yield for the four-joint example of a SCARA robot.

Note that the LQG controller upgrades the framework reaction, and therefore, it gives better blockage shirking contrasted with the PI controller, and LQG_servo-based execution improvement gives preferred capacity to maintain a strategic distance from clog over the LQG_servo controller, as appeared in Figure 7 rise time a period is recorded Override and introduce to think about execution, we can see preferable LQG controller results over PID controller and this is induced from Figure 7. At Final, the exhibition of the LQG-servo comfort under augmented experience situations like Variable Path and Industrial Robot Functions was broke down. The framework reaction is appeared in Figure 6,7, and the outcomes show that an improvement-based LQG-servo can get the objective with the ideal way

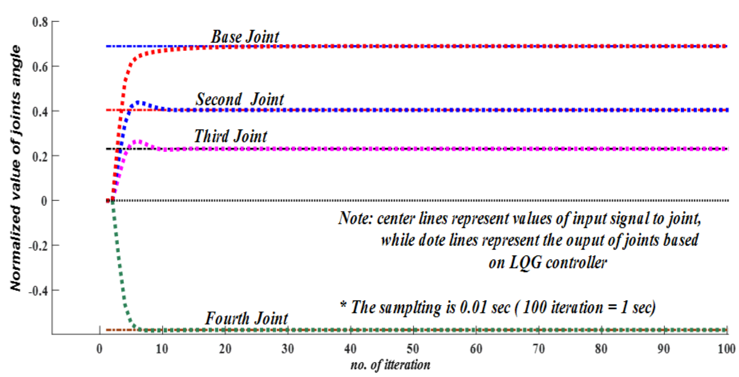

Fig. 7. Sample of testing of joint angle in optimal trajectory of SCARA with LQG controller

6. Conclusions

Optimization of the practical path for SCARA mechanism designed in Matlab Var. 2019b. The simulation of the computer game model to implement prophetical management to use the sensible function. Kalman estimation was applied to see system output and digital optimization. The tactic was wont to improve the value function, which permits a trade-off between performance regulation and control effort. The parameters of this LQG-servo controller were gotten by the improvement calculation addicted to checking the presentation file. At that point, LQG computation with SCARA 4-DOF by VR model was dead in MATLAB 2019b. The outcomes incontestable the viability of the proposed managementler and show that it's additional powerful than the PID in inbound at zero consistent state mistakes and higher blockage evasion underneath the dynamic system condition. In addition, the planned controller accomplishes a littler postponement and quicker subsiding time. The outcomes ensure effective scientific displaying of the robot. LQG controller procedure has viable calculations and functions commendable with straight, enhancement, and versatile strategies. Contrasted and different control systems, it works tons quicker. The LQG controller created here settles and balances out apace and has a superb distinctive reaction. The employment of physical phenomenon sensors as a police investigation element in the management framework enlarged adequacy. This device has adequate real explicit for its realistic usage within the control framework proposed.

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