Indonesian Journal of Electrical Engineering and Computer Science
Vol. 21, No. 2, February 2021, pp. 1238~1246
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v21.i2. pp1238-1246

Recursive least square and control for PUMA robotics

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Article Info

Article history:

Received Jul 17, 2020
Revised Sep 19, 2020
Accepted Oct 3, 2020

Keywords:

Joints 6-dof
Kinematics system
PI controller
PUMA robotics
Recursive least square

ABSTRACT

The solution of inverse kinematics system based on recursive least square (RLS) theorem is improved this paper. The task in joints of robotics is inverse kinematics for PUMA robotics. The design the manipulator of robotics is not simple if due to model of algebraic method. I suggested a method of RLS method to get predicts the positions of robot and it is comfortable the applications in real-time. The RLS is used to find the solution of the inverse kinematics for the joints 6-dof of the robotics. This technique is important to compute the joints of each arm space with Cartesian axes in the end-effector. The identification will be in each joint for PUMA by RLS and applied PI controller on each joint to get the response follows the reference input by tuning the values of coefficients of PI.

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1. INTRODUCTION

The objective of this work suggests an algorithm for predicting the robot position from reading measuringof the sensoes some feature of framework. This algorithm is prepared for implementations when readings the sensor are not cheap or is limited so that just comparatively few can get, the noise and errors of readings that are taken. The algorithm suggested enable of approaching to predict the position with high precision by using alittle measurments than other algorithms for implementations. This algorithm is validated by using a PUMA robotic toget information of position with using a controller to ensuare the stability without problems or mistakes.

Zhu and Dai [1] proposed a method to deal with data of missing are in the process of fusion, so its accuracy of fusion is decreased. Two algorithms the recursive least square and datch ae suggested to develop the precision the prediction of fusion. The performance of calculation is bad because the the first suggested theory focused on the performs fitting of least square at the same time. The simulation and analysis display that the algorithms of suggested to deal with missing data case and the prediction of fusion is accuracy.

Wen *et al.* [2] proposed a technique of analytic and method of fuzzy logic are put into dynamic modeling for robotic fish with swimming control. The method of fuzzy control is focused on the behavior of the robotic fish dynamic knowledge. The smaller steady state error and fast acceleration are got from fuzzy controller. The method of conventional control is the trust efficiency through the steady. Cabré *et al.* [3] described a method of learning of project from control of robotics and vision of computer. The target of learning was to evolve a system of computer vision that must to discover the object that located on surface of target and control arm of computer to move it and turn it to destination. The results that be seen that evolution a case of learning focused on vision of computer and motivation of computer has increased.

Leibrandt *et al.* [4] presented the strategy of kinematic that required for manipulator and permit control to detect the spaces. A model of nonlinear is used to join the map to reach the space and develop the accuracy the motion of instrument. This improvement is driven by intervention accessing of surgical during orifices on natural such as anus or mouth. This technique is measured with tests of bench of the system is determined by requirements the task of realistic surgical.

Giataganas *et al.* [5] designed a robotic device for imaging of large area endomicroscopy with high accuracy, indicated a quick, and machine of scanning with control of motion. This design involves endomicroscopy of robotic assisted, the ability to eradication tissue without required for an extra instrument. The results showed that the device attains trajectories of pre-programmed with precision of position for than 30 μm, as approach of image indicated that the disturbances of motion up to 1.25 mms^{-1}. This method displays a necessary alternative to current, decreasing time of tissue assessment.

Faria *et al.* [6] introduced an idea of stereotaxy and represent a neurosurgery of standard stereotactic. Expectations of neurosurgery relating the function of robots as tools of assistive are addressed. They improved a system of robotic to execute a neurosurgery of stereotactic. Excel of robots at information of handling spatial and are clear nominees in the directing of trajectories. A system with robotic permit workflow of structure in spite the difference in technique.

Faessler *et al.* [7] presented a controller for a body-rate and an iterative schem for thrust-mixing and that improve the performance the trajectory-tracking without needing learning and decrease the error of yaw control for robotic. They applied algorithm with saturation of motor by prioritizing control input by LQR method for trajectory tracking and stabilizing. The method of LQR for dynamic of motor and body-rate to decrease the error of the overall trajectory-tracking. They improved the robustness, stability of saturation for motor, yaw control, and trajectory tracking.

Lee and Jung [8] poposed a recursive least square to obsorv the distance of model that is second order the filtering of input-output. The observer of disturbance has been a method of robust control to reject the noises. The technique to design Q filters is important for observer of disturbance to compensate the inverse model improperness for the plant. The studies of experiment the performance of balancing control of robot are very suitable and accuracy.

Incremona *et al.* [9] proposed approach of compassable and modular depending on featuring of basic modules involving a couple of hybrid force/position control and supervisor correlated with manipulators of robotic. The controllers of force and position are type of supervisory sliding mode to be comfortable for tracking of trajectory in existence the external disturbances and modeling uncertainties. Ciullo *et al.* [10] presented results of preliminary with regard to system of supernumerary hand. The system includes robotic of active soft hand and mechanism of gravity compensation. The problem of this design is to place the arm of robotic because of effects of dynamics and kinematics. The results of experimental and analytical recognize the positions as nearest to hand of human.

Peng *et al.* [11] presented the art state for dancing robots. This work has importance to robotics and humans. Dance of robotic is sorted to four parts: robotics choreography creation, music with synchronization, robot dance for cooperative human and motions for human dancing. Wang *et al.* [12] proposed approach of precision-aware diffusion by using sensors of aquatic mobile such as robotic fish. In this design, the sensors of robotics collaboratively profile the properties of process the diffusion involving amount of discharge substance and location of source. They in formulate the accuracy of profiling of robotic and problem movements scheduling that goals to get the accuracy of profiling at maximum to make the sensor energy and mobility. The results display that their method can precisely the processes of profile dynamic diffusion with budgets of tight energy.

Selvaggio *et al.* [13] proposed a technique to use the assistance of virtual fixtures in tasks of invasive robotics in surgery departments. Adaptations of geometry and pose of the virtual fixtures are examined. Both parameters of the constraint enforcements and geometry of virtual fixtures must be adapted. This technique is substantiated through experiments the kit of the da Vinici Research. Rodr´ıguez *et al.* [14] proposed and submitted two plans to decrease times of research. They checked of feasibility of plan of assembly for robotic system and this will carry out the plant for the system. The execution feasibility needs the system simulation to make the system decelerate to execute the system. The errors in the system are spread as rules of symbolic to cut back the search tree.

Kimble *et al.* [15] presented a group of matrices, methods of test, and artificial of associated to aid advance the deployment and improvement of assembly of robotic system. The three designs reproduce operations of fastening and insertion of small part such as meshing, snap fitting and threading with wiring, drivers of belt, and connectors of electric. Protocols of benchmarking and matrices of performance are presented that vigor these boards of tasks to support robotics assembly evaluation.

Allan *et al.* [16] proposed to estimate the pose of 3D of tools is to be necessary in robotic invasive for main procedures automation as features of providing safety as fixture of virtual. They predicting pose of

rigid 3D with flow of optimal and silhouette focused with DOF or instruments of robotic within framework of optimization. The technique validation is supplied with study of ex-vivo from system of robotics. The experiments indicated that their method is totally precise as depending on data of image.

Xia *et al.* [17] designed a controller for suppression the error propagation of seam boundary is suggested for robotic. The process of welding is worked out as design the control of closed loop with controller of low gain feedback in baseline loop. The controller of non-causal feed forward is optimized by using the robust control technique such that the value of error affected by disturbances of non-repetitive in one pass is revoked. The results of experiment on system of robotic welding display the suggested control revoke the error affected by disturbances of non-repetitive within passes and decrease in error in response of the system.

Wortman *et al.* [18] proposed to reduce the surgery invasiveness by approaching the cavity of abdominal through single split with surgery of laparoendoscopic. The surgery by robotic is demonstrating to be good choice to defeat these restriction. The results of experiments of the single incision in surgery with robot is capable to do tasks of surgery as conquering the issues related with operations of LESS manual. The test results in experiment with vivo robotic colectomy using robotic with cavity of abdominal.

Johansen *et al.* [19] presented a model of dual control of robotic hands for multi-grasp incoroporating EMG with an inductive tongue control system. The control of inductive tongue control system performance was assessed in a comparative study. They did experiments with 10 healthy subjects that utilized both the control of EMG and the control inductive tongue control system to finish the experiments with hand of Azzurra robotic. The results were important when they obtained differences when comparing the both controllers with performance for each control. The results found that when used the control of EMG is lowest compared with control of inductive tongue control system

Nierhoff *et al.* [20] proposed a model in the areas of sensing and control in robotic system to communicate with humans. They used a pool to be as a reoresenative secenario to manage the model of plan and control the framework in the opponent that is considered. An optimized policy is derived by a human model and the game of pool as Markov process. When planning is stroke, it makes a robot to involove the style of typical game. The results with simulations are validated with playing pool in robot is comparative to human.

DiFilippo and Jouaneh [21] designed a robot of incorporation of sensing of force and vision to eliminate bolts the laptops back. The system of robotic utilizes two webcams, the first one is mounted on the robot and the second one is fixed over the robot. The studies of experiment were managed to test the performance the system of vision and sensor equipped. The values of study were diversed comprised the setting of brightness on the webcam and source of localized light and setting of higher brightness as the case of laptop became darker made the greatest results.

Xu *et al.* [22] proposed task of assembly is conceived as algorithm through the policy of learned without the states analyzing. In this algorithm, the process of learning is managed by control of simple force. The strategy of feedback is suggested to avoid actions of risky and be an optimal assembly policy, that can choose tha data to ensuare the stability. The results of simulations for the algorithm indicated the effective of this method for the strategy of feedback of the system.

Formosa *et al.* [23] proposed to design a multi sensor in robotic capsula endoscopes for colonoscopies and assessed the performance ex vivo and in vivo. They design includes drive of double worm to remove the forces of axial gear as momoents of decreasing radial. The used two controllers for motors to drive micro pillared below and above the insturments permitting for 2-DOF in robotic. The results enable the feedback controller with validation, algorithms of mapping and localization in environment of vivo.

Desai *et al.* [24] proposed a technique of printing with 3-DOF that satisfied requirements of stringent for surgical robot. They presented the achivements in development surgical robots with 3-DOF for interventions of cardiovascular and neurosurgical due to the benefits of improved scaling of motion, capabilities of sensing, reduction of tremor and precision.

Hou *et al.* [25] proposed a 6-DOF platform the parallel for packaging of optoelectronic. This platform is a type structure of parallel layout, that utilizes the motors of piezoelectric the jloints are active and hinges of large stroke flexture are joints to be passive. An analysis of elastokinematic is deduced and analyzed by using modeling of inverse kinematic. The model of finite element and compliant prototype are expanded. They supplied a date of experimental and reference of theoretical for analysis of inverse kinematic of 6-DOF with hings of large-stroke flexture.

2. RESEARCH METHOD

The joint of manipulator of puma robotics can be modeled and calculated in an articulated chain of open-loop with numerous rigid links that is coupled in series by either prismatic or revolute links, which are

impelled by actuators. The analytical study of robot kinematics deals the reference coordinates system as a related to moments or time that not requiring the forces for movement with respect to geometry for the motion of a puma robot. Consequently, it cares with the mathematic description of analytic for the puma robot that will be as a time function, in specific, relations are between the orientation and position for puma with manipulator of end-effector the joint-variable. Figure 1 shows the robotics manipulator's structure in this paper.

The analysis of kinematics for puma robotics is done in two manners: inverse kinematics and forward kinematics task, that is mostly explained in this work, includes the calculation of the-orientation of effectors and position and their alterations, as a concern of given speed and positions the axes of the motion. Denavit and Hartenberg suggested a method in establishing in a system of coordinate axes to articulated chain joint to get a rundown of rotational and translational association between adjoining joints. Forward kinematics method bargains with motion of the end effector for the puma relating to a system with coordinate axes. A system with axes (W_x, W_y, W_z) is colonized with the immoral of the link as be seen in Figure 1.

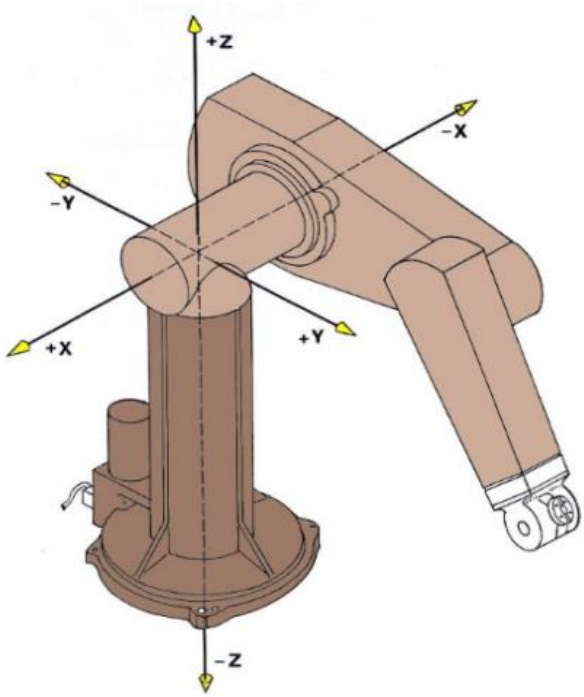

Figure 1. The structured of the 6-dof of PUMA robotics

The manipulator of puma robotics link is structured and this modeling gives a rundown of the 'A' homogenous transformation matrix that uses four parameters for link. This transformation in modeling of robotics is known as the Denvit-hartenberge notation. To get the solution of forward kinematics for a puma robotics manipulator, we use the following is used (1).

$$\text{Aend-effector} = \text{T6} = \text{A1A2A3A4A5A6} = \begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

The manipulator of puma robotics has 6 joints is utilized in this work. Each link consists one degree of freedom. The manipulator links have a 6-degree of freedom of axes of Cartesian distance of for axes (Z,Y,X), that is calculated through the matrix T6 and hand orientation is discussed relating to the RPY rotations.

$$RPY(\emptyset x, \emptyset y, \emptyset z) = Rot(Z_w, \emptyset_z)Rot(Y_w, \emptyset y)Rot(X_w, \emptyset x) \quad (2)$$

If T6 matrix is calculated, we get

$$\emptyset z = A\tan 2(ny, nx), \tag{3}$$

$$\emptyset y = Atan\ (-nz, ny\sin\emptyset z + nx\cos\emptyset z) \tag{4}$$

$$\emptyset z = A\tan 2(-ay\cos\emptyset z + ax\sin\emptyset z \quad , oy\cos\emptyset z, -ox\sin\emptyset z) \tag{5}$$

The information of the orientation and position for puma that is relating to the frame the coordinate of real-world that got from questions above and the frame of coordinate axes for each link are utilized to discuss the orientation and position for puma robot system. The forward kinematics can be utilized to calculate the coordinate of Cartesian axes for puma robot system when the angles of joint are known. While, the applications of industrial for the angles of link with real-world the coordinates of Cartesian axes. The solution of kinematics if it is inverse in manipulator of puma robot will be in next equation. The parameters of twelve, that describe the end effector for orientation and position of in (6).

$$\begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = A_1A_2A_3A_4A_5A_6 \tag{6}$$

Such as mentioned earlier in this paper, the solution methods iterative of traditional inverse kinematics, algebraic and geometric, are insufficient if the dsign of manipulator's joint is intricate. Neural network with this method makes it very successfully to calculate the solution of kinematics if it is inverse. The parameters of models of the Denatvit-Henatrberg utilized to find the solution.

The end effectors of orientation and position from basic trigonometry can be rewritten in terms of the coordinate's axes for joints in the following pattern. The angles of link have been scaled in counter clockwise and the joint longitudes are supposed to be positive giving from one joint axis to the promptly distal joint axis. In (7) is savings of three equations that depict the relationship between joint coordinates and effectors coordinates end. Notice that we have evident equations of the end-effectors for coordinates axes in terms of link coordinates axes. while, to find the link coordinates axes for a given group of end-effectors for coordinates axes $(\varphi, x, y,)$, one requires to find the solution of this problem with equations if they are nonlinear equations for $\theta 1, \theta 2, and\ \theta 3)$. The manipulator of planner R-P for kinematics of is simple to subedit.

The axes of end-effector are clearly given in terms of coordinates axes for the joint. while, because the equations are easier in (7), it is clear the algebra included in solving the axes for the joint in terms coordinates axes for the end effector to be simpler. Notice that in disparity to (7), now there are only two joint axes in three equation, $\theta 1\ and\ d2$. Consequently, in general, the solution for axes of the joint can't find it for a qualitative set of axes of end effector. The axes of the end effector tool point or trajectory set poin of the end effector depict by (x,y) by two equations.

Notice that the limited $d2$ to values to be positive. A values of $d2$ to be negative may physically completed permitting the trajectory at end effector point to pass the system through the axes of coordinate x-y over to another quadrant. If we become shoter $\theta 1$ to the range value $0<\theta 1<2\pi$, there is a single value of $\theta 1$ that is proportionate with the given (x,y) and the calculated $d2$. The present of multiple solutions is examplary when we solve nonlinear equations. The equations for kinematic analysis are direct and inverse kinemtics for PUMA robotics. And calculating the Cartesian axes, $x, y\ and\ \varphi$. The joint positions or coordinates are the lengths of the three telescopeing link $(q1, q2, q3)$ and the end effectors coordinates (x, y, φ). The analysis of a planar 3-R manipulator in inverse kinematics for shows to be difficult. However, we find the solutions of analytic. The direct kinematics are as shown in (7).

$$\theta 1 = \gamma + \sigma cos^{-1}\left[\frac{-\left(y'^2 + x'^2 + l1^2 - l2^2\right)}{2l1\sqrt{y'^2 + x'^2}}\right] \tag{7}$$

Where,

$$\gamma = atan2(\left[\frac{-y\prime}{\sqrt{y'^2 + x'^2}}, \frac{-x\prime}{\sqrt{y'^2 + x'^2}}\right]$$

$$\cos(\theta 1 + \theta 2) = \frac{x' - l1 cos\theta 1}{l2}$$

$$\sin(\theta + \theta 2) = \frac{y' - l1 sin\theta 1}{l2}$$

$$\theta 2 = atan\left[\frac{y' - l1 sin\theta 1}{l2}, \frac{x' - l1 sin\theta 1}{l2}\right] - \theta 1 \quad (8)$$

$$\theta 3 = \varphi - \theta 1 - \theta 2 \quad (9)$$

3. RECURSIVE LEAST SQUARE (RLS) AND CONTROL OF PUMA

The RLS is mostly used in the applications of engineering for identification the parameters of a system. The equation of linear with parameters $\theta(t)$ can be explained as (10).

$$z(t) = R^T \theta(t) \quad (10)$$

Where,

$$R^T = [r(t), r(t-1), \dots \dots, r(t-k)] \quad (11)$$

$$\theta^T = [c(0), c(1), \dots \dots \dots, c(k)] \quad (12)$$

The parameters of predicted can be explained as,

$$z(t) = R^T \hat{\theta}(t) + \hat{e}(t) \quad (13)$$

where, $\hat{\theta}(t)$ are parameters of predicted system and $\hat{e}(t)$is an error between the true value and predicted value

$$\hat{e}(t) = z(t) - R^T \hat{\theta}(t) \quad (14)$$

Can be rewrite (18) as,

$$\hat{e}(t) = R^T(\theta - \hat{\theta}(t)) \quad (15)$$

To be minimized with objective function is as,

$$J = \sum_{t=1}^{P} \hat{e}^2 = \hat{e}^T \hat{e} \quad (16)$$

The parameters of optimal solution will be zero,

$$\frac{\partial}{\partial \hat{\theta}} J = 0 \quad (17)$$

The solution of (21) will be,

$$\hat{\theta}(t) = [R^T(t) R(t)]^{-1} [R^T(t) z(t)] \quad (18)$$

The matrix of covariance is,

$$P(t) = [R^T(t) R(t)]^{-1} \quad (19)$$

By using a Matrix Inversion Lemma and can be get the equation,

$$P(t+1) = P(t)\left[I - \frac{R(t+1) R^T(t+1) P(t)}{1 + R^T(t+1) P(t) R(t+1)}\right] \quad (20)$$

$$\hat{\theta}(t+1) = \hat{\theta}(t) + P(t+1) R(t+1)(z(t+1) - R^T(t+1)\hat{\theta}(t)) \quad (21)$$

The forgetting factor γ with (24) and (25) can be as,

$$P(t+1) = \frac{1}{\gamma}\left[P(t)\left[I - \frac{R(t+1)R^T(t+1)P(t)}{\gamma + R^T(t+1)P(t)R(t+1)}\right]\right] \quad (22)$$

4. PID CONTROL OF PUMA ROBOTICS

The control of PUMA robotics is very necessary to move the joint of manipulator to make the stability with with the setting point. In this paper, we applied PI controller with RLS to make the optput to be inputh the PUMA robotic system to control each position of manipulator. The PI controller with S-domain can be described in (23).

$$y(s) = K_p e(s) + \frac{K_i}{s} e(s) \quad (23)$$

By tuning the values of K_p , K_i , we will get the best response of each link of manipulator that is according to setting point with fast response, minimum settling time, and minimum zero steady state error as shown in Figures 2-7.

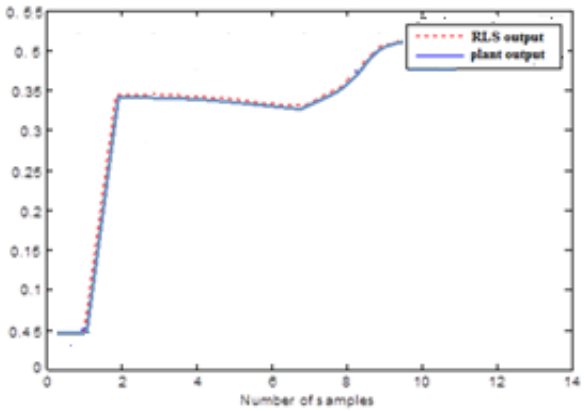

Figure 2. The output from RLS (learning stage) with PI controller (y) and (y,) reference position for y_1

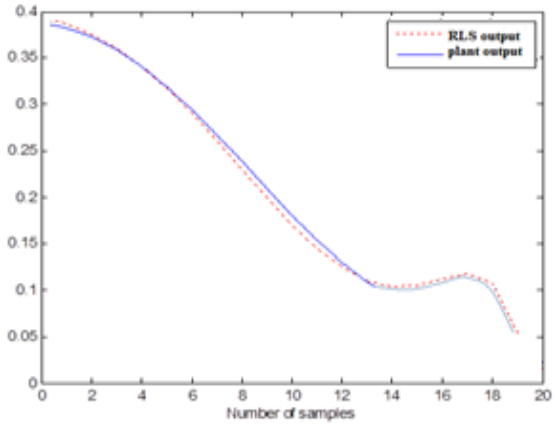

Figure 3. The output from RLS (learning stage) with PI controller (y) and (y,) reference position for y_2

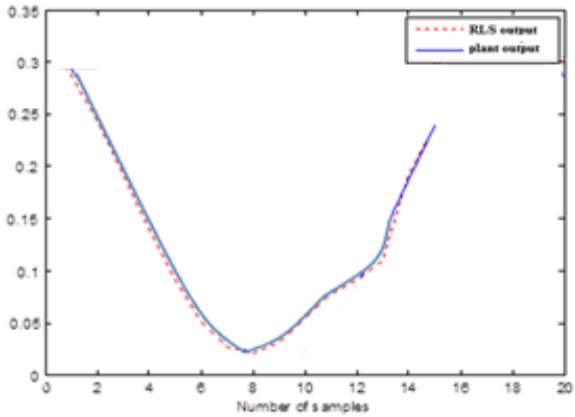

Figure 4. The output from RLS (learning stage) with PI controller (y) and (y,) reference position for y_3

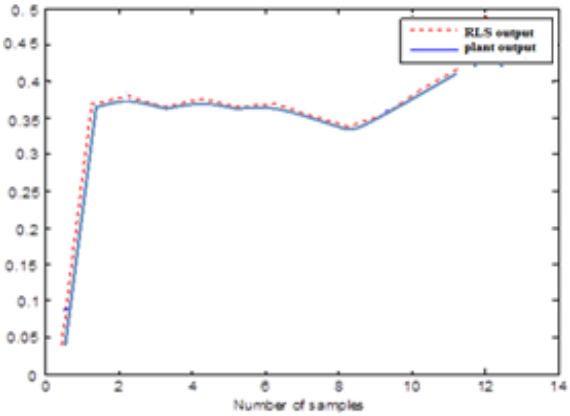

Figure 5. The output from RLS (learning stage) with PI controller (y) and (y,) reference position for y_4

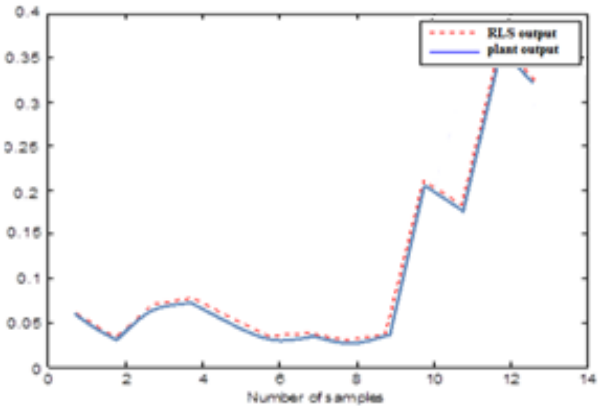

Figure 6. The output from RLS (learning stage) with PI controller (y) and (y,) reference position for y_5

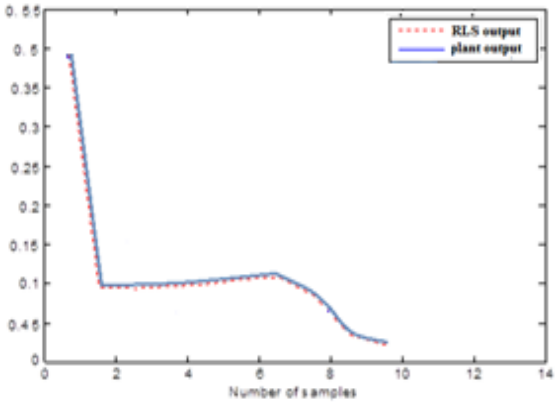

Figure 7. The output from RLS (learning stage) with PI controller (y) and (y,) reference position for y_6

5. CONCLUSION

In this work, we have suggested three parts: the first part for modeling the PUMA robotics with inverse kinematic, identification with recursive lease square (RLS) filter, and using PI controller with RLS to make stability and follow the reference input. The modeling of PUMA robotics of manipulators to move the positions and angles and the mathematic modeling is very close to movements of robotics. The filter of RLS does not need estimate with initial state, avoid errors of modeling inserted by the extended filter by Kalman to reduce in robot uncertainty. The method illustrated with simulation to be an actual robot to be run. It is indicated the RLS can be accurate predicts the same robotic position and angles but there are an errors between the actual and predicted response. In order to reduce the errors between the actual and predicted response, the PI controller is applied to decrease the error when tuning the values of K_p and K_i. The responses of positions and angles are very close between the actual and predicted for PUMA robotics.

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