KINEMATIC ANALYSIS OF PLANAR ROBOTS USING ARTIFICIAL INTELLIGENCE BASED EXTENDED JACOBIAN

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Abstract— *In the recent years,industrial robots are remodeling fabricating industriesas it is used for automatic working in various applications, specifically soldering, packaging, stacking, and machine parts installation. Particularly, planar robots, a typical optimal form of robot which is impacted in standard Cartesian plane is used for high efficiency and productivity. As working like human arm, it is connected in series with stable divisions and connectors. However, the position of any one end of robot arm is fixed, whereas the other arm of the robot travels through the Cartesian plane by changing the structure of arm joints. The manipulator with absence of design and fault tolerant task is analytical for remote applications and risk conditions as theperiodic management and developments are not available.Generally, the most advanced architecture and working flexibility of robots possessnovel probability and development in a large scale of manufacture process. Accordingly, this paper proposes inverse kinematic analysis of PUMA 560 robotic arm to achieve long range of fault tolerance. In the proposed work Jacobian is combined with the Firefly algorithm to determinethe inverse kinematics forredundant robots.*

Keywords— *Planar robots, Cartesian plane, kinematic analysis, fault tolerance, PUMA 560 robot manipulator, idle robots, Jacobian and firefly algorithm.*

1. Introduction

ROBOTS is a mechanical system has the capacity for carrying various kind of task in controlled automatic manner. Generally robots are computerized programmed system assigned for complex operations where human operators unable to perform. The robots are utilized in fields such as minute manufacturing of products, and it incorporates tasks includes radioactive where human not able to carried out. By considering the following factors robots take a step forward and regards as servers to the users.

The term kinematics refers to the field of study related to the motion of objects. The kinematic of robots is defined as the study carried out in the mechanical motion of robots. The analysis of robots includes the position, velocity and acceleration of mechanical links and joints of robots. The kinematic analysis is carried out by utilizing the above factors which tends to cause motion. The relativity between the robotic motion, force and torque is analysed during the kinematic analysis. The robotic design and fault tolerance for certain remote and threated environments where periodic maintenance and improvements are not achievable. The fault rates in products considering threated environments are comparatively high (Ben-Gharbia K. M.et al. 2014).

The robotic systems generally consists of a mechanical manipulator, end-effector, microprocessor and controller based user interface computer. A mechanical manipulator constitute number of links and joints to form a kinematic chain. The joints in the manipulator can be actuated while some of them are not possible. The actuated joints in a typical robot equals to the degree of freedom (Simas H., et al. 2012). In recent times some attempts has undergone towards the research in alternative design of manipulator based on the perception of kinematic chain, because of the following advantages which is compared with traditional open kinematic chain manipulators which offers more rigidity and accuracy (Lee,KM and Shah DK. 1988).

The research on kinematics of mechanical system advance imminent to the configuration regards to singular problems. The configuration are defined as the Jacobian matrix, Theses matrices related with input and output speeds became insufficient (Gosselin C and Angeles J, 1990). The manipulator configuration can be analysed using numerical techniques that will position and adapt the end effector in an appetite manner in the research for typical geometry arms simultaneously (Golden-berg, Benhabib, and Fenton 1985; Goldenberg and Lawrence 1985; Angeles 1985, 1986).

The analysis of numerical method uses multidimensional Newton-Raphson or the same techniques induced for finding solutions. The computational efficiency is validated by evaluating the inverse Jacobian of manipulator at different periods (Manseur R and Doty KL, 1988). The hybrid manipulation is a combined model of open and closed chain mechanism or a flow of parallel mechanism. These type manipulator gives limited efficiency to serial and parallel manipulators and offers applications from flexibility of work space efficiency (Tanio TK, 2000). Precisely, more researches on the dexterity optimization or flexibility ratio are relevant to the kinematic accuracy (Sefrioui J and Gosselin CM, 1992).

The key contributions of the proposed methodology is summarized as follows:

- Deriving the manipulator Jacobian with the desired property (fault tolerance).
- Select the best configuration by firefly algorithm.
- Check for fault tolerance before and after joint failure.
- Comparison of the kinematic analyses of the proposed system with the existing works.

The rest of the paper is organized as follows: the related research work on the industrial robot fault tolerance is given in section 2. The problem for the proposed work is derived in the section 3. The proposed system for the error minimization is described in the section 4. The implementation results and discussion is given in section 5 and in the subsequent section the conclusion and reference to the paper is given.

2. Related Work

Some of the recent research related to the fault location in distribution system is listed below:

Ben-Gharbia, K. M. et al (Ben-Gharbia KM et al.,2013) had proposed a strategy for distinguishing all the kinematic plans of spatial positioning manipulators that are ideally fault tolerant in a nearby sense. By utilizing a typical meaning of adaptation to internal failure, i.e., the post-failure jacobian has the biggest conceivable least solitary esteem over all conceivable single bolted joint disappointments. The substantial group of physical controllers that could accomplish this ideally disappointment tolerant arrangement was then parameterized and sorted. In which a general computational method to assess the subsequent manipulators as far as their worldwide kinematic properties, with an accentuation on disappointment resistance was produced. A few manipulators with a scope of alluring kinematic properties are exhibited and examined, with a particular case of advancing over a given class of controllers that have a predefined kinematic limitation.

Reppa, V. et al (ReppaV et al. 2012) introduced the design and investigation of a strategy for recognizing and segregating numerous sensor failures in vast scale interconnected nonlinear frameworks. The foundation of the proposed decentralized approach was the design of a nearby sensor failures determination operator devoted to each interconnected subsystem, without the need to speak with neighboring agents. Every nearby sensor failures determination operator was in charge of recognizing and disconnecting various failures in the nearby set of sensors. The nearby sensor failure analysis operator comprises of a bank of modules that screen littler gatherings of sensors in the comparing nearby sensor set. The discovery of failures in each of the sensor gatherings is led utilizing logical excess relations, defined by organized residuals and versatile edges. The different sensor failures confinement in every nearby sensor failure analysis was acknowledged by collecting the decision of the modules and applying demonstrative thinking based decision inference. The execution of the proposed analytic plan was broke down as for sensor failure perceptibility and different sensor failure reclusion. A simulation case of two interconnected robot manipulators was utilized to represent the use of the various sensor failure discovery and confinement strategy.

Ben-Gharbia et al (Ben-Gharbia KM et al. 2015) proposed a strategy to produce physically feasible Jacobians that are near being ideal. It was further demonstrated that there exist 7 unique manipulators, from a solitary Jacobian, that have a similar nearby adaptation to non-critical failure properties. To assess the worldwide properties of these distinctive manipulators, a system for figuring six-dimensional failure tolerant workspaces was exhibited. The span of these workspaces change essentially among these 7 manipulators.

To clarify non dreary issues, Xiao, L et al (Xiao L and Zhang Y ,2013) proposed and researched a novel Repetitive Motion Planning (RMP) plot (named speeding up level RMP conspire), which was settled at the joint-quickening level instead of at the joint-speed level. The plan was then reformulated as a quadratic program (QP) subject to balance and bound requirements. For the reasons for experimentation, a discrete-time QP solver was created for the arrangement of the resultant QP. By extension, the worldwide joining of such a discrete-time QP solver is displayed and researched. Comparison between the non-repetitive motion and REP approve the adequacy and predominance of the proposed plot. All the more vitally, the proposed plot and the comparing discrete-time QP solver are actualized on a six-connect planar robot controller. The trial comes about further substantiate their physical unwavering quality, productivity, and precision.

Peng Qi et al (Qi P et al, 2016) exhibited an experiment on kinematic control of continuum controllers utilizing a fluffy model-based approach. A fuzzy manipulator was proposed for self-sufficient execution of end-effector direction tracing function for a continuum manipulator. Especially, participation capacities were utilized to consolidate the linearized state-space models, to accomplish, generally speaking, a fuzzy model. The fuzzy model can outline the fuzzy controller; in this approach procedure is upheld by an exhaustive security investigation. This control system empowers an answer with low computational prerequisites to this movement control issue - there was no compelling reason to ceaselessly overhaul the Jacobian of the continuum controller. The exceptional execution of this controller was approved in MATLAB simulations and contrasted with those of established controllers found in the research. The validations on a quick prototyped continuum controller additionally confirm the practicality and the benefits of this fuzzy controller within the sight of displaying disparities and equipment errors.

3. KINEMATIC MODEL OF 6-DOF PUMA 560 ROBOTIC MANIPULATOR

In this paper, a six degree-of-freedom (6-DOF) planar robot arm is taken as the experimental platform to check the efficiency of the proposed method for the inverse kinematic problem of redundant manipulators. The PUMA (Programmable Universal Machine for Assembly) 560 machine is designed with 6 degree of freedom (DOF) having 6 joints and links. However, it has an arm for performing movement, also a wrist for agility and an end effector to execute a task. An appropriate example for serial chain machine is PUMA 560 robot which is designed for using in industries manufactured by Unimation.Inc., described in fig 1 [13]. The truck of the robot is stationary and fixed on a table or floor. However, PUMA 560 robotic arm is analyzed by the Jacobian matrix $a \times b$, here a is the task space dimension and b is the total number of DOFs which is the axes quantity of independent movement. Moreover, the inverse kinematic redundant manipulator should retains more DOF than it is required to execute the allotted task (i.e. $a < b$).

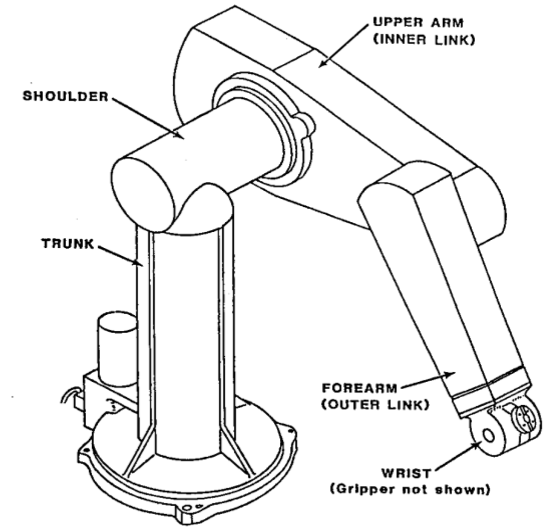

Fig.1. Structural diagram of six degree-of-freedom PUMA 560 robot manipulator

The shoulder portion of the robot rotates about a vertical axis with respect to the trunk of the robot. The robot upper arm rotates around horizontal axis with respect to the shoulder and these kind of rotation is termed as shoulder joint rotation. The forearm of robot revolves around horizontal direction with respect to upper arm. The robot wrist constitutes of three fixed bodies with three other rotations. Thus the robot arm consists of seven fixed bodies and six joints connecting the fixed bodie

***Inverse Kinematics*: -** The inverse process that estimate the joint parameters which accomplish a quantified position of the end effector is termed as inverse kinematics. In other words, an inverse kinematic problem [17] is atransformation from the end effector point of a kinematic chain to the joint coordinate's area. Accordingly, the inverse kinematic problem is stated as: determine the point of joints r_s that will be $x(r_s) = z_s$.Conversely, the forward kinematics utilizes the joint parameters to calculate the chain configuration. The forward and inverse kinematic problem definition is diagrammatically represented in **fig. 2.**

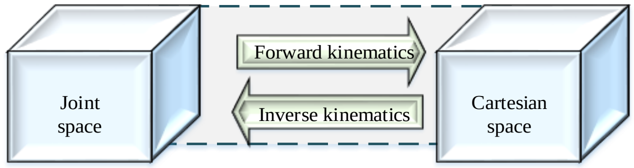

Fig. 2. Forward and inverse kinematic problem

Motion planning is processed for the specification of the robotic movement to facilitate its end-effector to reach the desired task. Further, the inverse kinematics converts the motion plan into joint actuator paths for the robot. Here, the motion of a kinematic chain of robot is demonstrated by the kinematics equations of the chain. However, these kinematic equations describe the chain configuration in terms of its joint spaces. Instantly, inverse kinematic equations permit the estimation of joint parameters that points a robot arm to pick up a portion.

4. Modelling Of Extended Jacobian Optimization Problem

A methodology for the kinematic analysis of robot manipulator is proposed in this work. Here the method of extended Jacobian and firefly algorithm is used for designing the manipulator of planar robots with high degree of fault tolerance. The extended Jacobian method is computationally fast and robust also it provides control of over arm configuration. The firefly algorithm is used for the finding of better configuration of the manipulator. The correctness of the method is checked before and after the joint failure occurrence in the manipulator. The work is illustrated with single locked joint failure and two joint failures. Here the manipulator taken is the robot arm.The main criteria discussed throughout this paper is to design and fabricate the manipulator of robot with high grade of fault tolerance. The kinematic analysis of robot is undergone using a prototype of Puma 560 robot with six degree of freedom. The manipulator is taken for the kinematic analysis incorporates robotic arm. The analysis is carried out by using Extended Jacobian and firefly algorithm. The inverse kinematics of robot arm is utilized for obtain high grade of fault tolerance is analysed by firefly algorithm. In the inverse analysis the output of the robot joint angles is the coordinates of end effector.

A.Preliminaries

The estimation of coordinates in robot kinematics of a static redundancy manipulator is defined in equation (1)

$$x : F^d \to F^t, \quad z = x(r) \tag{1}$$

where; 'd' is the degrees of freedom in manipulator and 't' is the spatial task field. In the static redundancy manipulators $d > t$ and the number 'n' ($n = d - t$) is defined as the redundancy degree of the kinematics.

Let $J(r) = \frac{\partial x(r)}{\partial r}$ be the Jacobian analysis of manipulators. The equation (1) derives the kinematics of manipulator and the point of inclination be z_s in task field. Thus the inverse kinematic problem is determining the position of joints r_s that will be $x(r_s) = z_s$. The Jacobian Inverse Kinematics (JIK) algorithm is induced to obtain a remedy for the problems regarding inverse kinematics. A continuation method is utilized for deriving JIK algorithm [5]. The fundamental composition be r_0, by defining a curve $r(u)$ in joint fields which pass through a medium as r_0 and the correlative error of task field along this curve $w(u) = x(r(u)) - z_s$ decreases aggressively with extinction rate $\delta > 0$, then

$$\frac{\mathrm{d}w(u)}{\mathrm{d}u} = -\delta w(u) \tag{2}$$

Thus the Wazewski–Davidenko equation is induced in the below equation to evaluate the error rate.

$$J(r(u))\frac{\mathrm{d}w(u)}{\mathrm{d}u} = -\delta(\mathrm{x}(\mathrm{r}(\mathrm{u})) - z_s) \qquad (3)$$

If the right inverse of the Jacobian be $J*(r)$ and $(J(r)J*(u) = g_t)$ then it offers a dynamic system

$$\dot{r}(u) = -\delta J*(r)w(u) \quad (4)$$

Where, the result of the inverse kinematic problem arise with a limit range be

$$z_s = \lim_{u\to\alpha} r(u) \quad (5)$$

Frequently, the JIK algorithms utilize JI pseudo at routine manipulator joint points, which is defined in the below equation.

$$J^{q*}(r) = J^{I}(r)\left(J(r)J^{I}(r)\right)^{-1} \qquad (6)$$

The Extended Jacobian Inverse (EJI) offers in the following way. Thus by implementing the kinematic map in the following equation.

$$y : F^{d} \to F^{h}, \quad \tilde{k} = p(r), \quad n = d - h \qquad (7)$$

By the implementation of map in equation (2) the extended kinematics is defined as below.

$$M = (z,k) : F^{d} \to F^{d}, \quad \bar{z} = M(r) \qquad (8)$$

where, extended Jacobian $\bar{J}(r) = \frac{\partial M(r)}{\partial r}$ and mutate the joint fields which gives structure to the EJK.

$$J^{o*}(r) = \bar{J}^{-1}(r)\Big|_{v \text{ first columns}} \qquad (9)$$

By outline, the EJK is a correct converse of the Jacobian and has the destruction property. In structure savvy, the extended Jacobian is an opposite of Jacobian with a property of extinction.

$$J(r)J^{o*}(r) = G_t \qquad (10)$$

$$\frac{\partial k(r)}{\partial r} J^{0*}(r) = 0 \qquad (11)$$

Dynamically stable Jacobian inverse: -It is strongly explained that the extended JIK algorithm is repeatable. A substitute to the Jacobian inverse be changed logically Jacobian inverse is defined by Oussama Khatib in [14]. The following equation define the joint field direction.

$$N(r)\ddot{r} + B(r,\hat{r})\hat{r} + X(r) = \psi \qquad (12)$$

Where $N(r) = N^{o}(r)$ is the inertia matrix with vector be $B(r,\hat{r})\hat{r}$ defines the impact of the centrifugal and Coriolis forces, $X(r)$ be the gravity force vector and ψ is the vector of generic joint exaction. Condition such as non-redundant manipulators the basic relationship between end-effector exaction S and joint torques ψ is defined in the following equation below.

$$\psi = J^{o}(r)S \qquad (13)$$

The relative identity between the essential tasks collaborate with joint and task field. The quality become fragmented for the dynamic redundant manipulators. Generally the redundant manipulator are not static and attains an eternity of joint torque vector which employ without the resulting force at the end effector. By considering the above features the end effector and joint torques defines as in the following equations.

$$\psi = J^{o}(r)S + \left(G_d - J^{o}(r)J^{o*}(r)\right)\psi_0 \qquad (14)$$

where, ψ_0 is the normal arbitrary joint torque vector and J^{o*} be the normal inverse of J^{o}. From the equation (14) it clearly shows it depends on J^{o*}. The below equation defines the joint torque to the movement of manipulator.

$$N(r)\ddot{r} + B(r,\dot{r})\dot{r} + X(r) = J^{o}(r)S + \left(G_d - J^{O}(r)J^{o*}(r)\right)\psi_0 \tag{15}$$

For the evaluation of acceleration of process and force, the equation (15) multiplied by the matrix $J(r)N^{-1}(r)$. By utilizing the differential $\ddot{x} = \dot{J}(r)\dot{r} + J(r)\ddot{r}$ and the computational equation is derived as below.

$$\begin{pmatrix} \ddot{x} + \left(J(r)N^{-1}(r)B(r,\dot{r})\dot{r} - \dot{J}(r)\dot{r}\right) \\ + \\ J(r)N^{-1}(r)X(r) \end{pmatrix} = \begin{pmatrix} \left(J(r)N^{-1}(r)J^{o}(r)\right)S \\ + \\ J(r)N^{-1}(r)\left(1 - J^{o}(r)J^{o*}(r)\right)\psi_0 \end{pmatrix} \tag{16}$$

From equation (16) which communicates the relation between the operational increasing velocities $\ddot{x}$ and the force S. It can be seen that the length of the term $J(r)N^{-1}(r)\left(G - J^{o}(r)J^{o*}(r)\right)\psi_0$ is non–zero the operational point is influenced by ψ_0. All together for the joint torques connected with the invalid space in (14) to not deliver any speeding up at end-effector, it is important that

$$J(r)N^{-1}(r)\left(G - J^{o}(r)J^{o*}(r)\right)\psi_0 = 0 \tag{17}$$

$$J(r)N^{-1}(r) = J(r)N^{-1}(r)E^{o}(r)J^{o*}(r) \tag{18}$$

$$N^{-1}(r)J^{o}(r) = J^{*}(r)\left(J(r)N^{-1}(r)J^{o}(r)\right)^{o} \tag{19}$$

$$J^{*}(r) = N^{-1}(r)J^{o}(r)\left(J(r)N^{-1}(r)J^{o}(r)\right)^{-1} \tag{20}$$

From the above equation (17) it defines the regular Jacobian inverse and it is said to be progressive steady Jacobian inverse.

$$J^{BX*}(r) = N^{-1}(r)J^{o}(r)\left(J(r)N^{-1}(r)J^{o}(r)\right)^{-1} \tag{21}$$

Approximation problem: **-**For obtain a novel extended Jacobian which is similar to the progressive steady Jacobian. The main factor is to determine relative issues and to find an EJK $J^{Q*}(r)$ that relates in an ideal path to the progressive steady inverse $J^{XC*}(r)$. Solicit the approach commenced in [17], offer a couple of matrices.

$$Q_1(r) = \begin{bmatrix} J(r) \\ Xk(r) \end{bmatrix}^{-1} = \begin{bmatrix} J^{Q*}(r) & P(r) \end{bmatrix} \tag{22}$$

$$Q_2(r) = \begin{bmatrix} J(r) \\ L^{o}(r) \end{bmatrix}^{-1} = \begin{bmatrix} J^{BX*}(r) & N^{-1}(r)L(r) \end{bmatrix} \tag{23}$$

where $k(r)$ is defined as the enhanced kinematics map, $Xk(r) = \dfrac{\partial k(r)}{\partial r}$ and matrix $L(r)$ has the subsequent properties such as

$$J(r)N^{-1}(r)L(r) = 0 \tag{24}$$

$$L^{o}(r)N^{-1}(r)L(r) = G_n \tag{25}$$

where, $P \in F^{d}$ inferred as the arrangement of routine designs, from the conditions (22) and (23) the error rate is characterized as the Frobenius standard of relative measure between $J^{BX}(r)$ and $J^{Qr}(r)$.

$$Q(k) = \int_L \left\| Q_1^{-1}(r)Q_2(r) - G_d \right\|_S^2 t(r)\mathrm{d}r \tag{26}$$

where, $t(r)\mathrm{d}r$ infers the volume shape with $t(r) = \det\left(J(r)N^{-1}(r)J^{o}(r)\right)$ [17]. Substituting the condition (22) and (23) into (26) the error rate function is characterized as

$$Q(k) = \int_L \mathrm{tr}\left(Xk(r)T^{BX}(r)\left(Xk(r)\right)^{o} - 2Xk(r)N^{-1}(r)L(r) + G_n\right)t(r)\mathrm{d}r \tag{27}$$

where;

$$T^{BX}(r) = J^{BX*}(r)\left(J^{BX*}(r)\right)^{o} + N^{-1}(r)L(r)L^{o}(r)N^{-1}(r)$$

The enhanced kinematics offer reduction of error function (27) and allow us to propose a firefly optimization algorithm to reduce the error function.

5. PROPOSED FIREFLY OPTIMIZATION FOR THE APPROXIMATION ERROR MINIMIZATION

Generally, the inverse kinematics of robot arm is developed to acquire high grade of fault tolerance and it is achieved by firefly algorithm. Accordingly, in the proposed work firefly algorithm is employed to determine the better configuration of the manipulator. The firefly is a metaheuristic algorithm was implemented by Xin She Yang [15] appreciated by the lightning property of fireflies. The firefly algorithm calculation is developed with the three optimal qualities of unique fireflies. These specific attributes are,

- The entire quantities of fire-flies are considered with same sort of sex. At that point just they pulled in towards the firefly which has more noteworthy lustre.
- If the separation between the fire-flies builds it naturally diminishes the lustre of the fireflies. There is no fire-fly having more noteworthy lustre than the specific one then it moves in an irregular way.
- The firefly lustre is recognized by the target capacity of the proposed work. In the event that the goal is the augmentation work then lustre is relative to the endpoint function.

The lighting of firefly is directly proportional to the fire-flies attractiveness. The given equation describes the luster of fireflies.

$$L = L_0 e^{-\eta d^2} \qquad (28)$$

The relation L_0 described as the firefly attractiveness, d is the distance between each fireflies. The Cartesian form is utilized for defining the distance,

$$d_{ij} = \left\| d_i - d_j \right\| \qquad (29)$$

where, d_{ij} be the relative distance of fireflies i and j.

Thus the firefly movement with respect to brightness of certain firefly can be estimated from the following equation.

$$f_r^{\,i} = f_r^{\,i-1} + L_0 e^{-\eta d_{ij}^{\,2}} \left(f_m^{\,i} - f_r^{\,i-1} \right) + \partial \varphi_i \qquad (30)$$

The equation describes the current position of firefly.In our proposed work, the values of $L = 1$and $\partial \in [0,1]$ are considered. The pseudo code of the proposed firefly algorithm is illustrated as Algorithm 1 as follows,

Algorithm 1 : Firefly optimization algorithm

Begin
Define
Objective function $f(p)$ // Error minimization
Light absorption coefficient η
Initialize the population of fireflies, $p_{i(i=1,2...n)}$
Light intensity L_i at p_i is determined by $f(p_i)$
While $(t < gen_{\max})$ // maximum generation
For $i = 1:n$, $\forall$ fireflies

For $j = 1 : i$, $\forall$ fireflies

If $(L_j > L_i)$

Move i^{th} firefly towards new position j in k-dimension through levy flights using eqn. (30)

End if

Attractiveness varies with respect to the d distance through $\exp[-\eta d]$

Evaluate the fitness function and update L_i

End For

End For

Rank the fireflies with best fitness value and find the current best value.

End while

Obtain the optimal solution by output the best firefly

End

6. Simulation Results and Discussion

This paper proposes firefly based extended Jacobian for the puma 560 robot. In this paper the robotic toolbox developed by Peter I. Corke [16] is used and then the performance is validated as below. The proposed work is carried out in the Mat Lab platform in terms of performance. The simulation parameters are given in Table 1

Table 1: Simulation parameters

	Parameter	***Value***
A. ***Firefly optimization***	Maximum number of iteration	100
	Population size N	50
	Light absorption coefficient L	1
	Attraction coefficient	2
	Mutation coefficient ∂	0.2

	Link No.	**Joint angle ϕ_i**	**Link twist (rad)**	**Link length (m)**	**Link offset (m)**
Puma 560 Robot	1	ϕ_1	1.570796	0	0
	2	ϕ_2	0	0.4318	0.15005
	3	ϕ_3	-1.570796	0.0203	0
	4	ϕ_4	1.570796	0	0.4318
	5	ϕ_5	-1.570796	0	0
	6	ϕ_6	0	0	0

The joint field direction is induced for angle and acceleration of the proposed PUMA 560 manipulator defined in figure 3 and 4. The trajectory of robot is defined as the movement of robot arm from the point A to B by deflect crash at an end time. In brief, the movement of robot is starts from the ready position, subsequently moves towards the target position which is allotted by the operator. After reaching the target position, it pauses for a few seconds to permit the end-effector to complete its task. Finally, the manipulator returns to its initial position and get prepared for another motion. This can be evaluated in terms of discrete and continuous methods. Trajectory planning is one of the dominant fields in robotics. The trajectory planning is utilized in robots to plan the motion such as velocity, kinematics and time. The simulation is done and it calculates the joint angle values and the figure 3 and 4 plotted below defines the trajectory of the proposed manipulator by changing each joint angle with respect to time. It is seen from the figure that the joints 2 rotates by larger angles than joint 3.

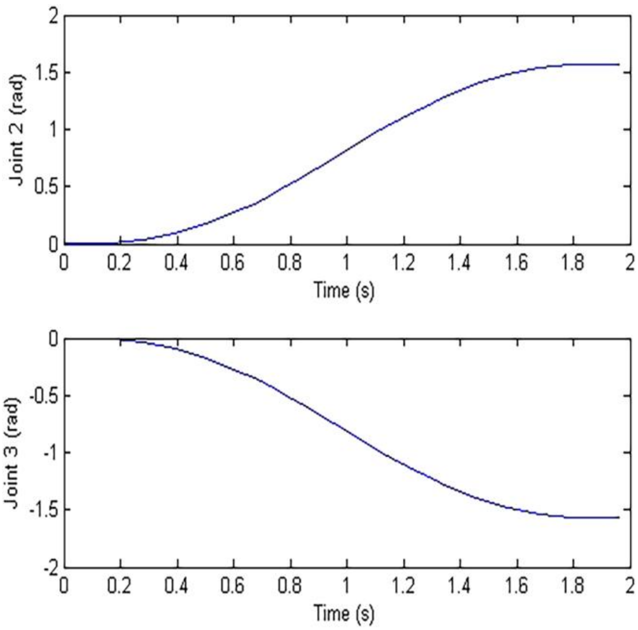

Fig.3. Generated Joint space trajectory of Angles

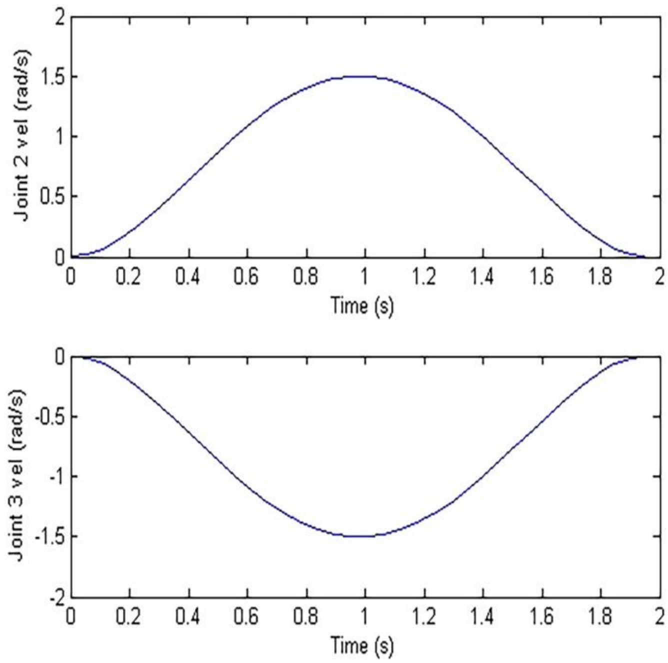

Fig.4. Generated Joint space trajectory of acceleration

The homogenous transform is utilized to perform the attitude, location and coordination of robot in Cartesian zone. The robots generally houses with trajectories which is continuity of Cartesian structure or the connected angles. For solving the trajectory, the coordinates of individual inverse kinematics is shared as the solution of the previous one. The given chart shows the trajectory of joint space is compared with time and shows the proposed approach is gradual and not relevant for the application in real robot controller by which inverse kinematics results needed in few milliseconds. The following figures 5 determines the trajectories related to Cartesian coordinates.

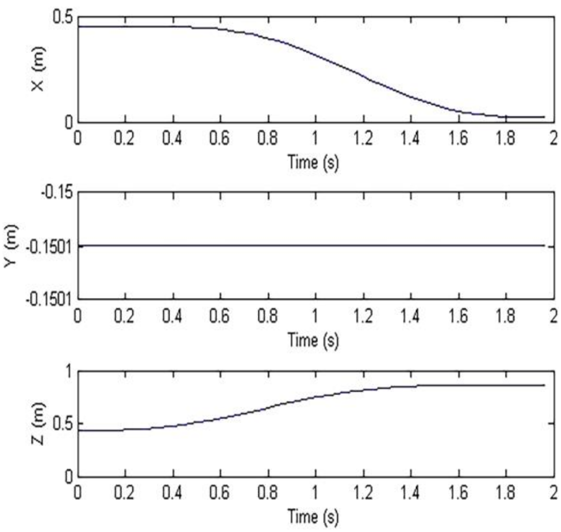

Fig.5. Cartesian coordinates of wrist for the trajectory

The figure 6 defines the proposed PUMA 560 robot plotted in 3D form. Here, a straight motion line is produced rather than a polynomial fitting curve for the application of inverse kinematics is to determine the fastest path to attain the target.

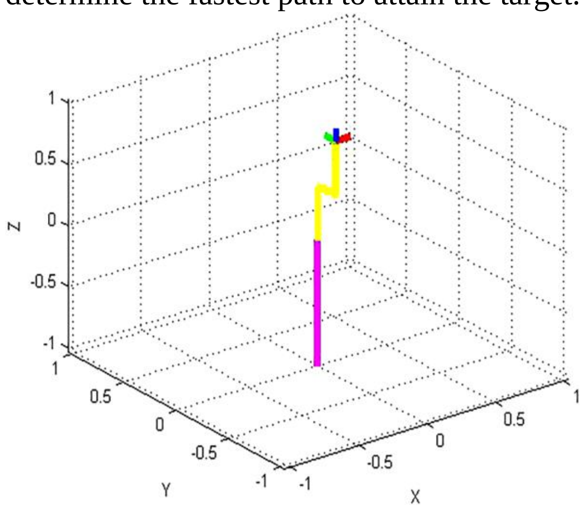

Fig.6. Proposed PUMA 560 Manipulator

The kinematics of robots related to the geometric study of robot movement with multi-DOF kinematic chains that offer the robot system to structure. The robot geometry is defined as the robot links designed as fixed bodies and the joints are estimated to contribute complete revolution. The kinematics of robot deals with the study of relation between the proportion and kinematic chains interconnection, location, velocity of each individual links of robot for planning and controlling and it is also estimates the robot actuator force and torque. The robot dynamics deals with the relation between properties such as mass and inertia.

In figure 7, figure 8, figure 9 and figure 10, it determines the time cognate of equations of kinematics produce the robot Jacobian which includes the end effector linear and angular velocity in terms of joint rates.

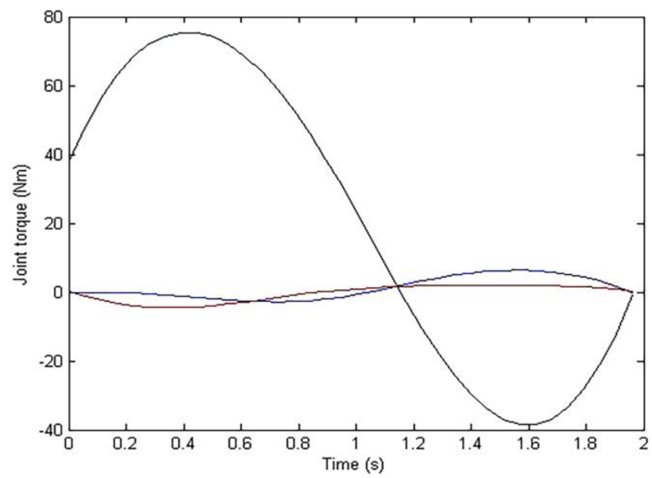

Fig.7. Joint torques

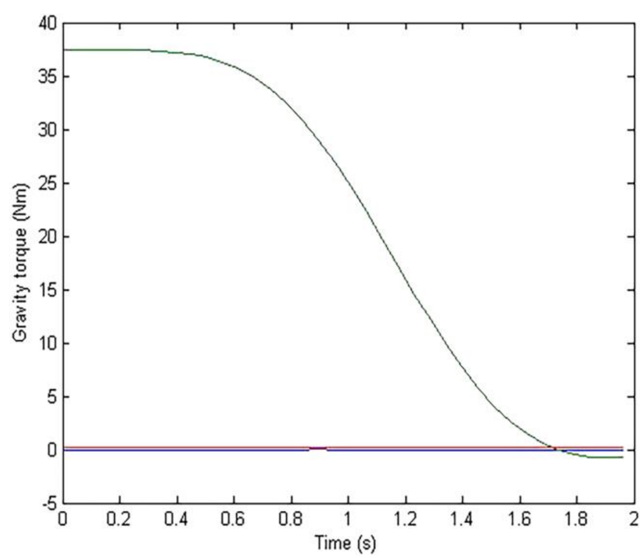

Fig.8. Gravity torques

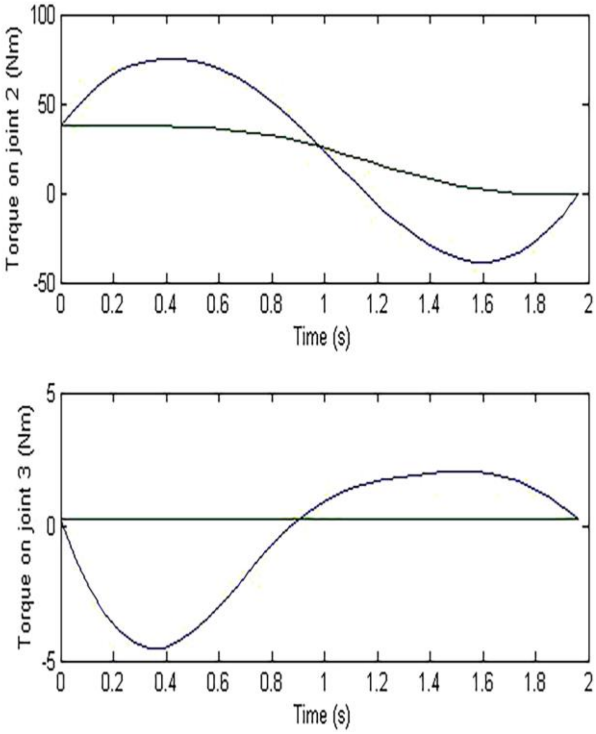

Fig.9. Comparison of gravity torque

The result obtained from the virtual work defines the relation between the torque and force induced in the end effector. Thus the torque, gravity and inertia are analysed and plotted in the figures below.The inverse kinematic function yields a figure 7 in which the joint torque is analyzed with respect to time. From that it is seen that the largest torque which achieves by joint 2 is around 75 Nm. Accordingly, while the operator needs to choose the motors for the arm, the motor torque should not be less than 75 Nm.

The link inertia parameters which are consider in the proposed work are link mass M_l, moments of inertia and link center of gravity. However, the link mass is supposed to be proportional to the link lengths l of the proposed Puma 560 robotic arm. The rotational inertia of the proposed system is derived using equation (31)

$$I_r = \frac{M_l * d^2}{\mu^2 * l} \quad (31)$$

where, d is the distance from each interruption wire to the axis of rotation and μ is the oscillation frequency (rad/sec). The computed inertia for joint 1 is plotted in figure 10 with respect to time.

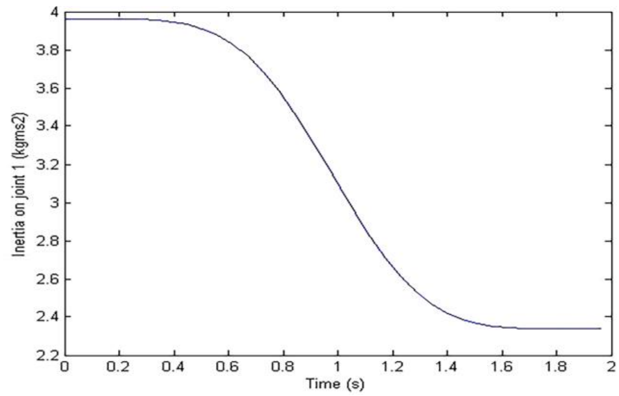

Fig.10. Inertia Plot

The robot manipulation is an essential task in case of industrial robot while designing an obtained fault tolerance level. So that the complicated operation of robot being reduced. This paper proposes firefly optimization algorithm which is extended by Jacobian for the reduction of error rate. The minimized error values are given in Table 2, it can be seen that the proposed Firefly shows accuracy in error minimization than existing Artificial Neural Network (ANN) and Fuzzy techniques.

Table 2**Comparison results for error minimization**

Joint angles	**Proposed Firefly**	**ANN**	**Fuzzy**
ϕ_1	0.0029	0.0100	0.0567
ϕ_2	0.0014	0.0178	0.0789
ϕ_3	0.0012	0.0167	0.0356
ϕ_4	0.0016	0.0198	0.0467
ϕ_5	0.0013	0.0245	0.0678
ϕ_6	0.0020	0.0145	0.0987

7. Conclusion and Future Work

The fault tolerance in industrial robot manipulation is the main criteria solved through this paper. The PUMA 560 robot is taken for the fault tolerant evaluation. The proposed protocol consists of firefly algorithm which is derived from the Jacobian is used for controlling fault tolerance. The firefly algorithm coupled with inverse Jacobian is induced for the optimization process for error rate minimization. The proposed firefly algorithm is tested and performance criteria such as trajectory, torque and inertia is evaluated in the Mat Lab robotic toolbox. The result shows the proposed algorithm has better performance in terms of trajectory, torque and inertia.

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