International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 24 (2015) pp 44049-44056

Computer Aided Modelling And Simulation Of A Generic Robot For Inspection

G. ShanmugaSundar* [1]

Research Scholar Department of Production Technology, Madras institute of technology,
Anna University, Chennai, Tamilnadu, India
shasunrobo@gmail.com, gshanmugasundar@gmail.com
**Corresponding Author: shasunrobo@gmail.com*

R. Sivaramakrishnan[2]

Associate professor, Department of Production Technology, Madras institute of technology,
Anna University, Chennai, Tamilnadu, India

Abstract
Robots are successful as an essential substitute in the field of inspection technology with nondestructive testing (NDT) techniques at hazardous environment. Inspection robots are essential components of today's factory and even more of the factory of the future. Robots can perform inspection tasks with the aid of NDT methods causes a high degree of inspection quality for longer periods of time. In this research work we carried out a newly designed robot arm expected to carry out the inspection tasks. With a view to meet such the above demands, this paper features the computer aided modelling, simulation and analysis of a generic robot which specially designed for identifying the weld defects on the circumference of the cylindrical storage steel canisters. The end use of these kind of robot arm is utilized to inspect the defects with the help of the NDT inspection camera this can also use to hold the weld gun for complete the weld operations. In this work we also focused the mechanical design of the proposed robot arm with required degrees of freedom calculations and also the computer aided modelling and simulation work done using multibody simulation software. The End effector or gripper position analysis explained with the aids the computer simulation.

Keywords: Computer Aided modelling, Multibody Simulation, forward kinematics, degree of freedom.

Introduction
A robot arm is usually called a robot manipulator, generally programmable, with similar functions to a human arm. In general the links of a robot manipulator are connected by means of joints performing either rotational motion or translational displacement depending upon the task to be completed. (3), (5).
The links of the robot manipulator can be considered to form a perfect kinematic chain. The end of the kinematic chain of the manipulator is called the end effector of the robot arm and it is equivalent to the human hand (4).
The end effector can be designed to perform any desired task like as Spray painting, welding, gripping, grinding, etc., depends on the field application.

A. NDT inspection of weldments presents on steel canisters
In many industries the stainless steel canisters, are very much used to store liquefied gases, vitrified intermediate level wastes, hazardous gases and liquids, etc. These tanks are prone to defects at the weldments which were present on the outer surfaces of the canisters. These welds need to be inspected throughout their service life for signs of damage. Many independent robotic systems have been developed by using the wall climbing technique comprising of pneumatic and magnetically operated actuators. These climbing robots carry the NDT scanning probes for inspection (6). A very special inspection situation involves the tanks used to store nuclear fuels and waste. This research aims to implement the robot with specially designed mechanical configurations of articulating arms for inspecting the weld seams present in the outer surface of the large storage tanks. A newly designed articulated robot with seven degrees of freedom is proposed to carry out the above mentioned tasks. This robot system can effectively serve as a substitute for a human worker, who would otherwise expose to dangerous and hazardous environments.

Background of the research work
With the advances in technology, the demands for Inspection Robots are also greater than before. Researchers continue to meet such demand. A review of similar researches is done to understand the recent trends in inspection technology. Formerly Bing L. Luk et al.(6) have developed three climbing robots namely WIC, SADIE and Robug III, which were used for inspecting tile-Walls of high-rise buildings, for carrying out ultrasonic inspection and surface preparation inside reactor cooling gas ducts and for working in an unstructured environment respectively.
Their robots are all climbing robots which require some clamping mechanisms to fix them to accomplish their tasks.
Fei Yanqiong et al.(7) have developed a modular wall-climbing mobile robot with magnetic wheels, which can move on the vertical steel vessel and inspect the weld seam. Their work is found applicable in the ferrous background only. X.G. Fu et al. Have introduced new auto-inspection robot system

for weld inspection in nuclear pipes. This system also performs trajectory planning, 3D simulation, auto-operation, ultrasonic signal analysis and 3D reconstruction according to the measured flow data.
Jayarajan. K, et al. (8) has developed the tele manipulator in which a master slave arrangement is provided. The master is assembled in a non-hazardous area. The slave is made to work in the unstructured environment. The slave would exactly reproduce the motions performed by the master in the remote locations. There is only electrical contact between the master and the slave robot. This technology is a milestone in the inspection robots, as it provides cent percent safety to the operator.
The slave is provided with a vision camera which allows the accurate motions in the unsafe area. These manipulators are provided with actuators, sensors and force transmission mechanisms. This manipulator system is being successfully installed in the BARC (Bhabha Atomic Research Centre) for the Waste management Project Division. It's performed is evaluated for the intended tasks. These researches paved the way to design the new mobile articulated robots which can perform all the desired tasks in a single system. The new robot with arms coupled by double universal coupling for maximum flexibility is designed. The screw-jack lifting mechanism provides the maximum reach to the end-effector. This robot system can effectively serve as a substitute for a human worker, who would have otherwise exposed to dangerous and hazardous environments.Gigi Naidin et al, have made a workspace drawing of a six Degrees of freedom of a manipulator with RRRRRR configuration. The authors made performance analysis of this industrial, manufacturing robot. They have used many types of software to do their research work, like Autodesk for preliminary design, mathematical model using Sim Mechanics for the mechanical structure and Sim Hydraulics for hydraulic drive,
Simulink for entire mechanical modeling, MATLAB 2007 software to analyze the results and Workspace to spatial evolution. Workspace V5 software is used to realize the robot model and maximum workspace calculation.

Methodology
The entire work is divided into stages and is accomplished accordingly (11). The simple flowchart is shown below, which depicts the flow of research work. In this paper modelling, simulation and kinematics analysis were discussedbriefly.

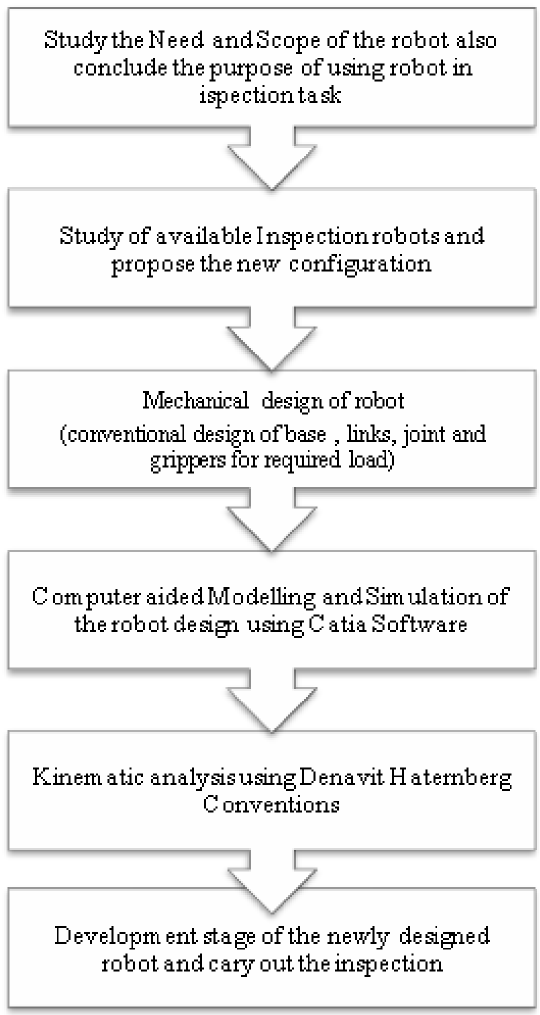


Fig.1. Work Methodology of the research work

Mechanical design procedures of Robot
A. Design of robot arm as a serial manipulator
Robots can be classified according to various robot selection measures, such as overall degrees of freedom, kinematic structure of the robot, drive technology for actuating the joints, workspace geometry, motion characteristics, type of control system.
In the above types the kinematics structural topologies deal about the serial and parallel kind of robot configuration. A serial manipulator consists of several links connected in a series manner by means of various types of mechanical joints, typically prismatic (Linear) and revolute (4), (5).
In this type of configuration generally one part of the robot is attached to the ground and the other part is free to move in space. The fixed link of the robot is called as base, and the free end where gripper or mechanical fingers is attached, the end effector. For serial robot positional analysis problems the direct or forward kinematics is fairly simple, whereasinverse or reverse kinematics becomes very difficult.

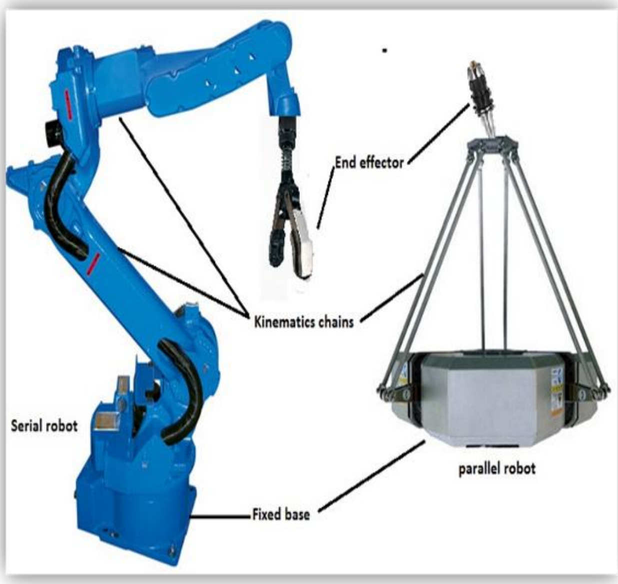


Fig.2. Serial vs parallel manipulators

The term Degrees of freedom or mobility in any mechanism framework, are specific, defined modes in which a mechanical device or machine can move. In general the number of degrees of freedom depends on the total number of independent movements in a mechanism. The term is commonly used to define the motion capabilities of the robot arm in 2D or 3D space.

The robot as a whole is made up of several components. The robot mainly consists of two sections viz. Base and the Arm. The base of the robot comprises of lifting mechanisms (10). The arms are stable, which carries the weldsinspecting sensors.

The essential components of robot are,

a) Base of the robot.
b) Screw jack mechanism.
c) Arms.
d) Universal Coupling.
e) End Effector.

The total degrees of freedom in a robot are calculated mainly consider the number of mobility between the ground link and the end-effector link. Usually the degree-of-freedom between two links in a robot is called as connectivity [Phillips, 1984]. In this research work the serial link robot arm was suggested for complete the inspection task on the outer surface of the cylinder.

The designed robot arm has totally seven degrees of freedom as mentioned in the figure 4. The Grubler-Kutzbach criterion equation was applied for calculating the degree of freedom (dof) as given in equation 1.

The proposed robot is considered as a simple open chain consists of n number of moving links which are connected end to end by j no of joints, with one end connected to a ground link (Base).

Thus, in this case the mobility of the open chain is

$$Dof = \sum_{i=1}^{j} \text{fi} \quad (1)$$

Dof = 1 (base rotation) + 1 (up&down motion) +2 (ist universal joint motion)+2 (2nd universal joint motion+ 1(end knuckle motion) = 7

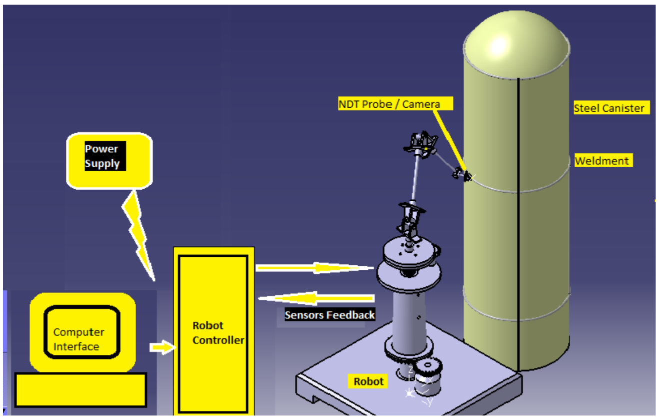


Fig.3. Overall system view of the proposed robot performing the inspection task

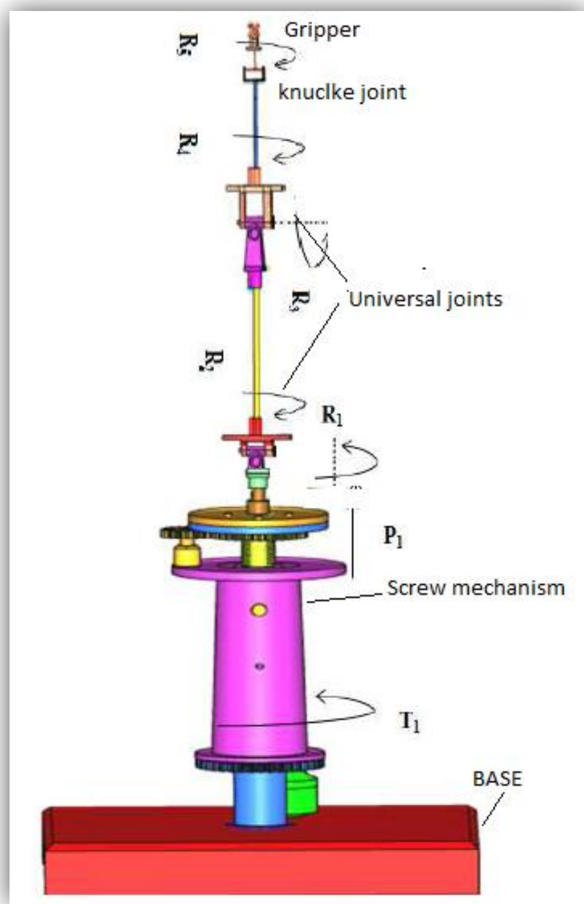


Fig.4. The robot manipulator diagram shows the Joint types and its nature of degrees of freedom

Mild steel is used for constructing the components of the robot.

The robot system must be designed to bear the load exerted on it. The design of lifting mechanisms and the design of the coupling are considered important from a design point of view (13), (14). The Base, Arms and End Effector are designed as per the design of screw jack and universal coupling. The following table shows the robot parts and its D.o.f and functional behaviour.

B. Selection of lifting mechanism for linear up and down motion in robot

When compared to the different lifting mechanisms, screw jack mechanism is found well suited for the inspection tasks in hazardous environment. A survey of lifting mechanisms is done and due to some of the disadvantages in them

They are neglected. The rack and pinion method could not withstand the expected load. The telescopic mechanism also fails to operate in heavy load condition (15), (16).

The chain mechanism gives more flexibility, but it is more expensive and is so complex in controlling. Thus the screw jack mechanism in selected as it can withstand the load and simple to operate and moreover it is economical when compared to other methods.

i. Design criteria for screw jack

For designing the new screw jack for a specified purpose there is a need to analyze the stability of the design through theoretical calculation. These are lifting devices and should be capable to lift the desired load. So the input variable for designing the screw jack is the load applied, the material used and their properties (23). Design of screw jack is done as follows;

ii. Design of screw for spindle

Consider the outer diameter of the spindle as 30mm.For the spindle of diameter 30mm the pitch should be 6mm. To find mean diameter, d, which is the mean diameter of the core and outer diameter

d_0 = 30 mm and p = 6

$$d = d_0 - \frac{p}{2} \qquad (2)$$

= 27 mm

Therefore, mean diameter d = 27 mm

To find the core diameter of the screw spindle, mean and outer diameter values are needed

$$d = (d_0 - d_c) / 2 \qquad (3)$$

d_c = 24 mm

Then the torque required to rotate the screw in the nut has to be found

$$T = P \times \frac{d}{2} \qquad (4)$$

Therefore, by substituting tan α = 0.070, then φ = 0.25 values and the load 490 N, the P value is found at 159.59 N Substituting the P value and mean diameter value in the torque equation, torque value is obtained

$T = P \times \frac{d}{2}$ = 2154.5 N-mm

= 2.15 N-m

iii. Design of the nut

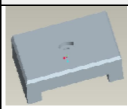
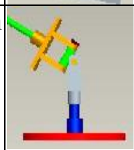
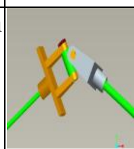
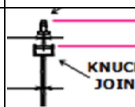
The design of the nut should be suitable to fit the screw spindle for the easy lifting process. The suitable bearing pressure is incorporated between the screw and nut as P_b = 18 N

Considering the number of teeth in the nut to be 15

Height = (n x p) (5)

= 90 mm

TABLE 1. Robot part description with motion type, degrees of freedom and range.

S l n o	Part Description	CAD model-Diagram	Joint motion type	No. of Degrees of freedom	Notation & Range	Functional behaviour
1	Robot Base		Twisting (T)	1 (either Clockwise or Anticlockwise)	θ_1 = -270° to +270°	Mechanical stability
2	Screw mechanism		Prismatic (P)	1 (either Up or Down)	d = 0 to 240 mm	Raise or lower the manipulator.
3	Universal Coupling 1		Rotational (R)	2 (Separate X & Y axis)	θ_3 = -90° to +60° & θ_4 = -90° to +60°	To Provide more flexibility in link movement.
4	Universal Coupling 2		Rotational (R)	2 (Separate X & Y axis)	θ_5 = -60° to +90° & θ_6 = -60° to +90°	To Provide more flexibility in link movement.
5	Knuckle Joint 1		Rotational (R)	1 (either In or Out)	θ_7 = -120° to +120°	To hold the End effector.

Iv.The design of the outer casing

By considering the diameters of the spindle and nut, the diameter of the casing is designed as if it hosts the lifting mechanism. The base with a little larger diameter as 150 mm and tubular stem to be 98 mm isselected.

v. Stress calculations

The robot system must be capable to bear the stress applied by the loads upon it. The calculated stress should be less than the maximum stress for the safer designs.

Compressive stress due to axial load:
Load, W = 490 N, d_c =24mm

$\theta_c = W/A_c$ (6)

$= 1.083\ N/mm^2$ (6)

Shear stress due to torque:

$\tau = (16T_1/\ \pi d_c^3) = 0.793\ N/mm^2$ (7)

Maximum principal stress:

$\theta_{c\ (max)} = \frac{1}{2}[\theta_c + \sqrt{\theta c^2 + 4\tau^2}]$ (8)

$= 1.5017\ N/mm^2$

Maximum shear stress:

$\tau_{(max)} = \frac{1}{2}[\sqrt{\theta c^2 + 4\tau^2}] = 0.96\ N/mm^2$ (9)

The maximum stress is much below the limits, therefore the design is safe.

C. Design of flexible coupling

To make the robot flexible some of the joint components should be used. By analyzing the available joints, the universal joint is selected for our robot.
Universal joint consists of two degrees of freedom it gives more flexibility to the robots. Two universal joints have been installed for better flexibility.
The design calculations for the joint are as follows,Design of universal joint consists of design of both shaft and pin.

i. Design of shaft:

To design the shaft one should find the diameter of the shaft. The diameter should be designed in such a way to bear the torque transmitted. Assume the 50kg (490 N) to be applied, and then the torque transmitted is found as follows
The torque transmitted = force x distance between point of load to axis of the joint

T = F x perpendicular distance (10)

= 490 x (290+180+45)

$T = 0.252 \times 10^6\ N\text{-}mm^2$

$T = \frac{\pi}{16} \times \tau \times d^3$ (11)

The shear stress of the shaft material is considered to be τ = 60 MPa, which is equal to 60 N/mm^2 and d = 27.759 mm

ii. Design of the pin

The pin is designed to withstand the load exerted by the shaft. The diameter of the pin should be suitably designed to withstand the stress. Since the pin experiences the double shear stress, therefore the torque transmitted will be

$T = 2 \times \frac{\pi}{4} \times d_p^2 \times \tau \times d$ (12)

By substituting the known values, the d_p is found, d_p= 14.36 mm
The mechanical configuration of the robot is modeled using 3D modeling software CATIA as presented in Figure 5.

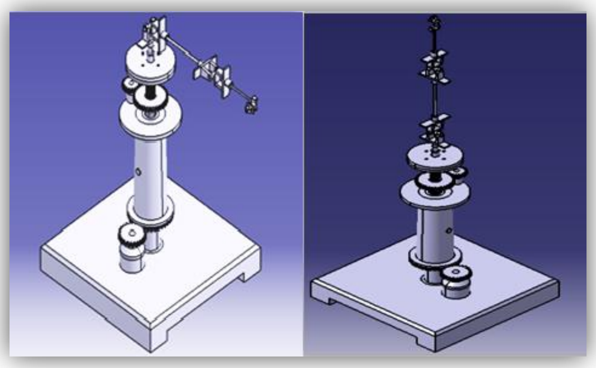


Fig. 5. Images of Computer aided modeling of robot using modeling software.

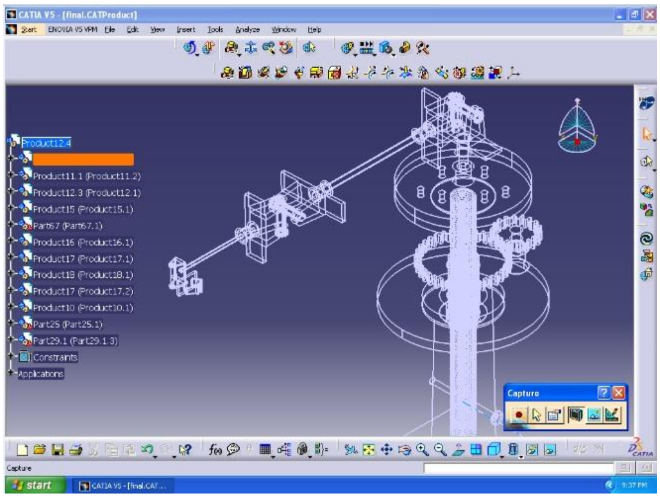


Fig.6.Wireframe Images of Computer aided modeling of robot

1. Simulation of robot maniputor

The simulation of the robot arm is done in the multibody dynamics simulation software (RecurDyn) to demonstrate the actual practical application in the real time environment created by the software. This type of simulation before the real practical application is very useful to fabricate the robot and make changes as per the rectifications.
RecurDyn is Computer aided engineering motion analysis software that is mainly focused on Multi-Body Dynamics (MBD). The RecurDyn technology has higher calculation efficiency because it is based on a recursive formulation through this the robot linkage actuation with a high degree of displacement, velocity and torque are easily predicted after completion of the simulation process (30).
The position in X, Y and Z axis and orientations of the end effector has accurately traced by means of these kinds of simulation techniques.

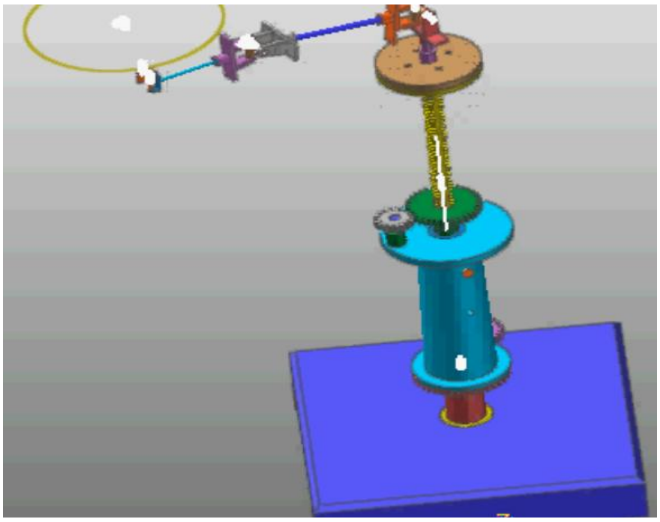


Fig.7.1 Robot joint motion simulation in the upper weldment of the canister.

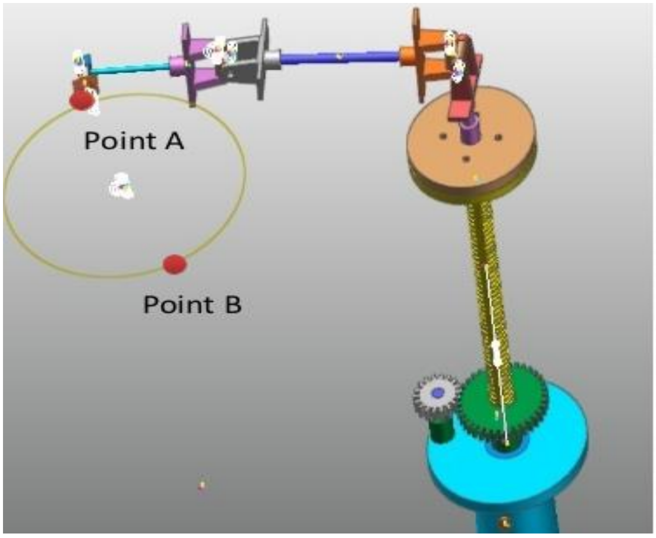


Fig.7.2 Robot joint motion simulation in the upper weldment of the canister.

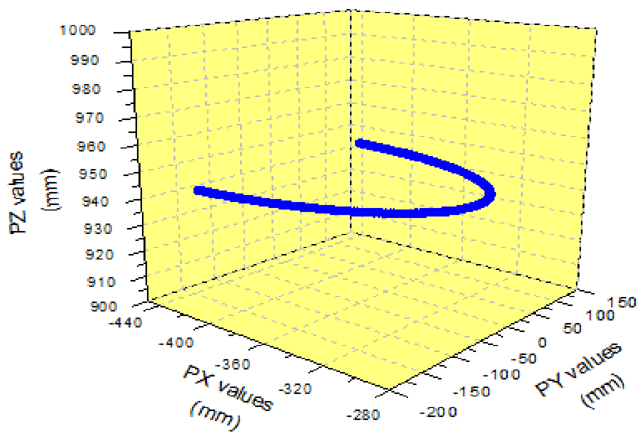


Fig.8. the Values of Px, Py, and Pz values of the robot end effector after upper weldment simulation on the canister.

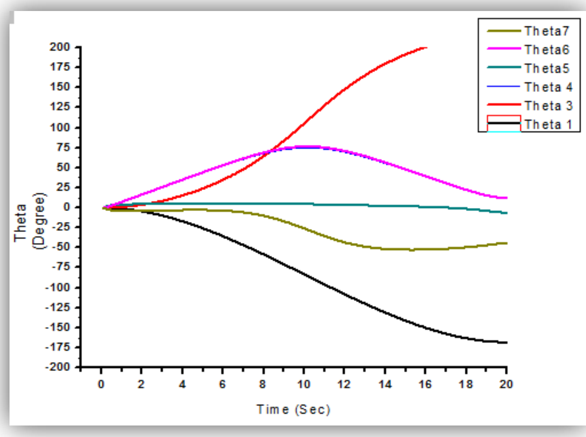


Fig.9. the variation in joint angles with respect to the simulation time.

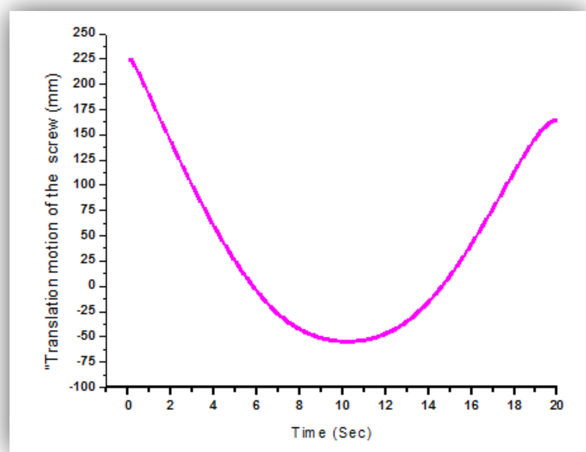


Fig. 10. The variation in Screw jack linear displacement vs. the simulation time

The table.2shows the values of the X, Y and Z coordinates of the robot end effector with respect to the simulation time.From the above software simulation, it was clearly observed that all the joint angles are within the designed range and the robot has performed the inspection task clearly without any damage of joints (18), (22).

Conclusions and future work

Thus, in this paper the mechanical design, Computer aided modeling and multibody simulations of a proposed robot arm are well explained. The uniqueness of the seven DOF robots, its flexibility and ability of positioning is demonstrated. The idea of selection of the components is well justified.
The design parameters and their stability are demonstrated. The designed robot with seven degrees of freedom robot suggested in this paper is theoretically stable to identify the weld defect in the steel storage tanks in industry in future As

the researchers continue in the world, there will be increased demand for robots in the future.

To conclude the newly developed robot system developed now are going to have a great demand in the near future. From the software simulation the maximum joint limits were easily found as $\theta_1 = -270^\circ$ to $+270^\circ$, the translation motion(d) = 0 to 240 mm, $\theta_3 = -90^\circ$ to $+60^\circ$, $\theta_4 = -90^\circ$ to $+60^\circ$, $\theta_5 = -60^\circ$ to $+90^\circ$, $\theta_6 = -60^\circ$ to $+90^\circ$ and $\theta_7 = -120^\circ$ to $+120^\circ$. In the stage step the inspection robot is completely fabricated and selection of control system is going to achieve complete the task fully in the future.

TABLE 2. Values of the Joint parameter corresponding simulation time

Sl no	Simulation Time (Sec)	Px (mm)	Py (mm)	PZ (mm)	Theta 1	Translation (mm)	Theta 3	Theta 4	Theta 5	Theta 6	Theta 7
1	0.00	-438.19	139.17	943.30	0.00	224.81	0.00	0.00	0.00	0.00	0.00
2	0.20	-437.46	139.15	943.30	-0.05	219.56	0.00	1.05	1.93	1.04	-1.86
3	0.40	-436.75	139.11	943.30	-0.20	211.50	0.12	2.65	3.04	2.65	-2.91
4	1.01	-433.12	138.85	943.30	-1.24	184.14	1.04	8.11	4.12	8.13	-3.75
5	2.01	-422.59	137.60	943.30	-4.74	138.76	4.16	17.35	4.64	17.43	-3.68
6	2.94	-408.29	134.77	943.30	-9.81	98.68	8.76	25.90	4.90	26.07	-3.27
7	3.01	-407.25	134.46	943.30	-10.26	95.78	9.17	26.54	4.91	26.72	-3.23
8	4.01	-388.25	128.19	943.30	-17.54	56.41	16.06	35.64	5.11	35.97	-2.80
9	4.07	-386.82	127.60	943.30	-18.02	54.19	16.54	36.19	5.12	36.52	-2.79
10	5.01	-367.11	117.58	943.30	-26.32	21.83	24.91	44.60	5.25	45.12	-2.77
11	6.01	-345.71	101.72	943.30	-36.37	-6.80	35.92	53.24	5.35	54.01	-3.60
12	6.07	-344.26	100.41	943.30	-37.01	-8.30	36.66	53.74	5.35	54.52	-3.69
13	7.01	-326.17	80.30	943.30	-47.42	-28.55	49.44	61.24	5.38	62.30	-5.91
14	7.07	-324.93	78.60	943.30	-48.11	-29.63	50.34	61.69	5.37	62.76	-6.11
15	8.01	-310.60	53.73	943.30	-59.23	-43.13	65.89	68.06	5.29	69.42	-10.38
16	9.01	-300.76	23.19	943.30	-71.54	-51.15	85.40	72.86	5.04	74.51	-17.45
17	10.07	-297.87	-11.81	943.30	-84.86	-53.92	108.56	74.80	4.59	76.62	-27.17
18	11.01	-302.03	-42.16	943.30	-96.66	-52.20	129.32	73.38	4.08	75.18	-36.01
19	12.01	-312.82	-72.63	943.30	-108.96	-45.47	149.50	69.00	3.53	70.63	-43.70
20	13.01	-328.80	-99.15	943.30	-120.76	-32.48	166.68	62.53	3.01	63.91	-48.79
21	14.01	-348.05	-120.59	943.30	-131.80	-12.58	180.84	54.82	2.50	55.95	-51.51
22	15.01	-368.44	-136.57	943.30	-141.82	13.84	192.34	46.50	1.92	47.40	-52.46
23	16.01	-387.91	-147.44	943.30	-150.59	45.66	201.55	37.96	1.19	38.67	-52.19
24	16.54	-397.40	-151.41	943.30	-154.64	64.15	205.59	33.44	0.70	34.08	-51.68
25	17.01	-404.69	-154.08	943.30	-157.84	81.16	208.70	29.49	0.16	30.07	-51.06
26	17.54	-412.11	-156.27	943.30	-160.99	100.65	211.70	25.14	-0.60	25.67	-50.15
27	18.01	-417.36	-157.62	943.30	-163.33	117.77	213.90	21.45	-1.46	21.95	-49.15
28	18.54	-422.10	-158.63	943.30	-165.44	136.10	215.88	17.59	-2.69	18.07	-47.78
29	19.01	-424.85	-159.18	943.30	-166.80	150.37	217.16	14.65	-4.01	15.13	-46.38
30	19.54	-426.44	-159.46	943.30	-167.74	161.98	218.05	12.28	-5.47	12.77	-44.88
31	20.00	-426.50	-159.54	943.30	-168.00	165.69	218.31	11.52	-6.03	12.03	-44.31

ACKNOWLEDGEMENT

G. Shanmugasundar is very thankful to his research supervisor, Dr. R. Sivaramakrishnan, Associate Professor, Department of Production Technology, MIT, Chennai for his constant guidance and motivation throughout this research work. This work was supported by Dr. S. Venugopal, Head / Remote Handling, Irradiation Experiments and Robotics Division, Indira Gandhi Centre for Atomic Research, Government of India. Also last but not least for the author's thanks HEXDOF Engineering Services Pvt. Ltd. Chennai for software supports and suggestions. The authors thank the anonymous reviewers for their helpful comments.

REFERENCES

[1] X.G.Fu, G.Z.Yan, B.Yan, H. Liu, 2006, "A new robot system for auto-inspection of intersected welds of pipes used in nuclear power stations" International Journal of Advanced Manufacturing Technology, vol. 28, pp. 596-601.

[2] Baki Koyuncu, Mehmet Guzel, 2007 "Software development for the kinematic analysis of a Lynx 6 Robotic Arm " world Academy of Science, engineering and technology, Vol. 30, pp. 252-257.

[3] Saeed B. Niku, 2008, " Introduction To Robotics", Prentice Hall. Upper Saddle River, New Jersey, USA. pp 67-76.

[4] John J. Craig, 2005, "Introduction To Robotics Mechanics and Control ", Prentice Hall, pp. 109-114.

[5] Saha, S.K., 2008, Introduction to Robotics, Tata McGraw-Hill, New Delhi, India.

[6] Bing L Luk, Louis K P, Liu and Arthur ACollie, 2007, "Climbing Service Robots for Improving Safety in Building Maintenance Industry", Bio inspiration and Robotics Walking and Climbing Robots, ISBN: 978-3-902613-15-8.

[7] Fei Yanqiong and Song Libo, 2008,"Design and Analysis of Modular Mobile Robot with Magnetic Wheels", WSEASTransactions on Applied and Theoretical Mechanics, Vol. 3, No. 12.

[8] Jayarajan K, Dutta A, Kar D, C, Sahu R, Zende D, G, Bhaumik T, K, Venkatesh D and Ramakumar M S (1998), "Design of a Tele manipulator for Radioactive Waste Management", Division of Remote Handling and Robotics, BARC, Mumbai, India.

[9] Choong W. H, Yeo K. B, (2007), "Structural Design for a 3DOF Robot Lower-Arm via Computer Aided Engineering, the Journal of Science and Technology, Volume 20.pp. 123-134.

[10] R. K. Mittal, I. J. Nagrath, 2003, " Robotics and Control", New Delhi, Tata McGraw-Hill Publishing Company Limited,. ISBN 0-07-048293-4, pp 25-39.

[11] T.C. Manjunath, 2007, " Kinematic Modelling and Manoeuvring of A 5-Axes Articulated Robot Arm ", World Academy of Science, Engineering and Technology International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering Vol:1, No:4, pp 216-222.

[12] Adrian George, 2010, "Optimization design for the structure of an RRR type industrial robot", Series D, Vol. 72, Iss. 4, pp 121-134.

[13] Monica Enescu, Catalin Alexandru, 2011, "Modeling and Simulation of a 6 DOF Robot", Proceedings of 2011 International Conference on Optimization of the Robots and Manipulators (OPTIROB 2011), pp 20-25.

[14] Elias Eliot, B.B.V.LDeepak, D.R.Parhi., and J.Srinivas, 2012, "Design& Kinematic Analysis of an Articulated Robotic Manipulator", International Conference on Mechanical and Industrial Engineering (ICMIE-2012).

[15] G. Shanmugasundar, R. Sivaramakrishnan, 2012, "Modelling, Design and Static Analysis of Seven Degree of Freedom Articulated Inspection Robot ", Applied Materials Research, Vol. 655-657, pp 1053-1056.

[16] G. Shanmugasundar, R. Sivaramakrishnan, 2012, “A Survey of Development of Inspection Robots: Kinematics Analysis, Workspace Simulation and Software Development”, International Review Of Mechanical Engineering, Vol 6. N 7, pp. 1493-1507.

[17] J.W. Jeong, I.S. Kim, R.R. Chand, J.H. Lee, 2012,” A study on simulation model and kinematic model of welding robot”, Journal of Achievements in Materials and Manufacturing Engineering, Vol. 55, Issue 1, pp. 66-73.

[18] Luo Haitao, Liu Yuwang, Chen Zhengcang and, Leng Yuquan, 2013, “Co-Simulation Control of Robot Arm Dynamics in ADAMS and MATLAB”, Research Journal of Applied Sciences,Engineering and Technology, Vol. 20, Iss 6, pp. 3778-3783.

[19] Jian Zhou, Zhimin Yang, and Songlin Chen, 2014, “Analysis of the harvesting robot arm modal based on CAE “Journal of Chemical and Pharmaceutical Research, Vol 6 (11), pp. 669-673.

[20] B. O. Omijeh, R. Uhunmwangho, M. Ehikhamenle, 2014,“ Design Analysis of a Remote Controlled “Pick and Place” Robotic Vehicle”, International Journal of Engineering Research and Development, Volume 10, Issue 5, pp. 57-68.

[21] Vivek Deshpande & P M George, 2014, “ Kinematic modelling and analysis of 5 of robotic arm”, International Journal of Robotics Research and Development, Vol. 4, Issue 2, pp. 17-24.

[22] PVS Subhashini, N.V.S. Raju and G. Venkata Rao, 2014,” Modelling, simulation and analysis of a scara robot for deburring of circular components”, ARPN Journal of Engineering and Applied Sciences, VOL. 9, NO. 4, pp. 398-404.

[23] Shanmugasundar, G.; Sivaramakrishnan, R.; Rajmohan, M., 2014, “Computer aided simulation for workspace plot of a newly designed inspection robot”, IEEE International Conference on Computational Intelligence and Computing Research (ICCIC), pp. 1-6.

[24] B.S.K.K Ibrahim, Ahamed M.A zargoun, 2014, “ Modelling and control of SCARA manipulator”, procedia computer science, Elsevier, International conference on robot-PRIDE 2013-2014, pp. 106-113.

[25] Sudhakar Ramasamy,, Sivasubramanian.R, Krishnakumar.M, Prakashpandian.M.D, 2014, Design, Development and Kinematic Analysis of a Low Cost 3 Axis Robot Manipulator, proceedings of international conference on interdisciplinary research in engineering & technology, pp 77-81.

[26] Nur Afiqah Binti Haji Yahya, Negin Ashrafi, Ali Hussein Humod, 2014, “ Development and Adaptability of In-Pipe Inspection Robots”, IOSR Journal of Mechanical and Civil Engineering, Volume 11, Issue 4 Ver. VII, pp. 01-08.

[27] Mohamed Aburaia, Erich Markl, Kemajl Stuja, 2015, “New Concept for Design and Control of 4 Axis Robot Using the Additive Manufacturing Technology, Procedia Engineering, Elsevier, 25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014, pp. 1364-1369.

[28] Carmelo Mineo, StephenGarethPierce, PascualIanNicholson, Ian Cooper, 2015, “Robotic path planning for non-destructive testing-A custom MATLAB toolbox approach, Elsevier, Robotics and Computer-Integrated Manufacturing, Volume 37, PP.1-12.

[29] G. Shanmugasundar, Sivaramakrishnan. R, R. Sridhar, M. Rajmohan, 2015, “Computer aided modelling and static analysis of an inspection robot” Applied Mechanics and Materials, Vols 766-767, pp. 1055-1060.

[30] Jie Han, Zhen An ; Lina Hao, 2015, “ Research on modeling and simulation of tracked robot on RecurDyn”, IEEE International Conference on Information and Automation, pp. 856-860.