International Journal of Analytical, Experimental and Finite Element Analysis
Volume 9, Issue 2, June 2022, pp 20 - 25
https://doi.org/10.26706/ijaefea.2.9.arset1930

Prediction of Joint Acceleration of 2 DOF Robot Manipulator Using Supervised Learning

Dr M. K. Satyarthi[1]
mksssrewa@ipu.ac.in

Tirthankar Roy[2]
tirthankar.00616418720@ipu.ac.in

Sourabh Anand[3]
sourabh.17216490020@ipu.ac.in

[1]Assistant Professor, Department of Mechanical and Automation Engineering, USICT, Guru Gobind Singh Indraprastha University, Delhi, India

[2]Student, Department of Robotics and Automation Engineering, USICT, Guru Gobind Singh Indraprastha University, Delhi, India

[3]Research Scholar, Department of Mechanical and Automation Engineering, USICT, Guru Gobind Singh Indraprastha University, Delhi, India

***Abstract*— Robo-analyzer (RA) is open-source software that uses a 3D representation of a robot manipulator to carry out various analytical studies. It was created primarily to assist instructors and students in getting started with robotics teaching and learning utilizing framework-based skeleton models or computer aided design (CAD) software designs of serial robots i.e., articulated robot. The RA software is used in this work to simulate and examine a two-degree of freedom (DOF) robot with two link and two revolute joints respectively. The joint length is kept constant at 0.2m, and the joint velocity is varied from 0 to 180 degrees per second. The two-link manipulator is permitted tocarry out forward kinematics after generating and establishing the input parameters for the simulation of the 2DOF model, which results in simulating the joint acceleration values, and that is the primary prerequisite for the machine learning (ML) process. The model tends to deduce the relationship between the input and output parameters in this study, which further aids in the deduction of a linear relationship between the two parameters, especially input and output parameter i.e., link length coordinates, joint velocity, and joint acceleration. The experimentation was then carried out on the basis of RA data to apply linear regression machine learning technique (LRMLT), which will assist in the prediction of an output, namely joint acceleration. The model tends to pave way for future research which can be carried out for joint vibration which is solely based on the basis of the acceleration present at joint.**

***Keywords*—** Robot manipulator, Forward kinematics, Supervised learning, Linear regression

I. Introduction

Robotics is a field which has achieved a steep growth in the last two decades, among the numerous kinds of robots; serial-linked robots arethe ones which has the most usage in diverse application in multiple industries mainly in aeronautics, healthcare domain and automobile industry etc. Hence monitoring throughout the years has led to this conclusion that the most partof the introductory courses on robotics focuses on the mechanics of the serial robots. The studies of robotics are generally not very instinctual to teach or grasp, as these topics involve knowledge fromdomain consisting of linear algebraic co-ordinate transformation, and fundamentals of mechanics. Taking consideration of the geometry, the architecture and the motion of the robot with the sole help of textbooks can be a difficult task. These criteria highlight the need of having robot learning/teaching software that can be used in conjunction with any robotics textbook. An excellent learning tool can improve the efficiency of the learning/teaching process. With less or no work required to develop, visualize, and simulate a robot model in a CAD environment, more time may be spent

Research Paper – Peer Reviewed
Published online – 04 August 2022

Cite this article – Dr M. K. Satyarthi, Tirthankar Roy, Sourabh Anand, “Prediction of joint Acceleration of 2 DOF Robot Manipulator Using Supervised learning”, *International Journal of Analytical, Experimental and Finite Element Analysis,* RAME Publishers, vol. 9, issue 2, pp. 20-25, 2022.
https://doi.org/10.26706/ijaefea.2.9.arset1930

understanding its mechanics. This would also make it easier for the course instructors to show the principles and robot motion in a classroom setting. While carrying out the study on the topic of robot simulation software, it was observed that several good functionalities are required in teaching software. Some of the features have been applied by the developers while designing this software's, one of the main principles which had notbeen focused upon is the Denavit - Hartenberg (DH) parameter which is a fundamental requirement which is used to define the architecture of a robot. This feature was specifically worked upon in the AR teaching/Learning software. Hence, this software works on most of the important features which are specifically required to carry out the kinematics of Robot.

The RA design philosophy was as follows: When studying robot mechanics, the physics of the robot must not be buried by the fundamental mathematics, and should be plainly comprehended by a learner as if he or she were moving a real robot. It was createdwith the goal of teaching robotics using only a few standard link forms. Linear Regression can be defined as a planar approach for framing the relationship between a scalar response and one or more co-dependent variables. In case of a linear relationship of one dependent variable it is calleda simple linear regression, for more than one; the process is called multiple linear regressions. In Linear regression, the relationship is based on linear predictor function, whose unknown model parameters are estimated from the data. The mainpurpose for choosing this model for carrying out the research of the paper is because with the help of Linear regression we can satisfy the linear relationship between the link length and Joint acceleration which in the long run can help us to find insightful information from the present data and help us to study the multi faceted effects which might be caused by the joint acceleration. One of the biggest challenges ofusing the linear regression is that the correlation needs to be checked before applying the model onthe present data so that we can get the desired output. The most interesting part of using Machine Learning is that the input data may be inany format, including text, video, picture, sound,data, and so on.

One of the approaches used in this work was to train and deploy a linear regression model to predict joint acceleration on the basis of link-length using data obtained from the RA while simulating a 2-link Robot. The biggest advantage of applying Machine Learning in this experiment apart from the presence of basic Robot Kinematics knowledge is that the model helps to verify the solution which has been provided by the software and also the application of this model can be done for robots with higher degree of freedom.

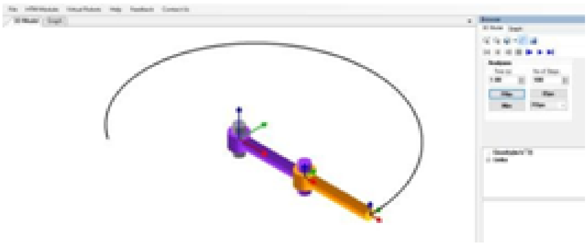

Figure 1: 2 DOF robot simulated on RoboAnalyzer Software

II. RELATED WORK

Since robots have become an indispensible element of modern organizations, there is a need for well-trained robot operators or technicians to operate and maintain them. Because the ideas of robotics are difficult to graspfrom a pure mathematical approach, various robot visualization software has been developed to aid in the comprehension of robot movements.One such programme is RoboAnalyzer. The characteristics of RoboAnalyzer and how they might be utilized to teach robotics principles to robot technicians were explored by Gupta et al. [1]. Liu et al. have proposed a method for determining the inertial parameters of robot manipulators with significantun-modeled joint friction and actuator dynamics [2]. Gautier and Poignetsuggested an efficient technique for nonlinear model predictive control in their work. Essentially, the model is first linearized through feedback, and then a model predictive control method was demonstrated, which is implemented using an optimized dynamic model and runs within a short sampling period [3]. Jacques [4] have introduced a novel class of adaptive robot controllers whose parameter modification is based on both tracking and prediction error. The implications of joint clearing in a robotic system were explored and investigated byErkaya [5]. The necessity for the end effector's trajectory has been considered while analyzing motion sensitivity. During the working process, he also employed a neural network to forecast trajectory deviations. He discovered that clearance plays an important role in the motion sensitivity of robotic manipulations in his study. A dynamic neural predictor with appropriate input variables likewise have been used to calculate trajectory errors [5]. Faroni [6] provides a predictive method for trajectory scaling that is constrained by joint velocity, acceleration, and torque. The parameterizations of inputs and outputs, as well as the repeated linearization of the optimum control problem around the prior outcome prediction, drastically reduce computational complexity [6]. The movement of a robot's manipulator is calculated by integrating kinematics, dynamics and trajectory computations. These calculations however are complicated and can only be utilizedin the case where the robot's design and theproperties of the joint trajectory are known. By resolving the non-linear function and altering theattributes of trajectories not known, Hong [7] discusses the utilization of Artificial Neural Network to find solution to this problem [7].The extensive usage of Machine Learning in the fieldof robotics is not new, and it has been done in thepast to increase robotics' functionality and highlight the industry's adaptability. Erick et al., describe ongoing research on one such Machine Learning technique, the Decision Tree learning system, and its application in real-time mobile robot navigation in the form of a discussion that caters to architecture that is self-configurable according to the problem statement under consideration. [8]. Ertugul [9] in his paper says thatmultiple and competing criteria, as well as their interdependencies, should be included in acomprehensive model developed for robot selection. The proposed technique uses Quality Function Deposition's emphasis on creating value by addressing customer demands and then utilizing that knowledge throughout the development phase to robot selection. When thereare unclear correlations among system characteristics, fuzzy linear regression is suggested as an alternate decision aid for robot selection issues. To demonstrate the suggested decision-making technique, an instance of robot selection issue has been discussed [9]. As a result of the preceding literature study, it wasdiscovered that very little research has been doneon the relationship between different attributes ofrobotic manipulators, making this a grey area toexamine. A robot simulation programme data isused in the current study to identify thecorrelation of different features with the help of a data visualization tool, and it can also be used to investigate industrial robotic manipulators infuture.

III. METHODOLOGY

The research in this paper is based on the principle of applying Machine Learning technique while analyzing data from the RoboAnalyzer software for a two link Robot. A two-link robot consisting of revolute joints was analyzed for this paper where the forward kinematics was carried out for the robot through simulation and the data was collected for a certain timeframe. The selection for the two revolute joint serial chain robot was done on the basis of relevancy of the revolute joint in the real world where these joints are used in most applications. After the completion of the experiment and collecting the experimental data which was stored in a digital format, the same data was analyzed through various data analytical techniques with the help of plotting various graphs such as scatter plot, histogram, bar graph while using Python Programming Language with importing various library modules such as Matplot, Seaborn, numpy, pandas which helps to visualize the data and helps in thecorrelation. Moreover, based on the experimental data a correlation was attempted with the help ofa confusion matrix which further strengthens theargument on which this research is based i.e, the linearity between the coordinates of Link Length and the Joint Acceleration. Now based on the theory until this point from the above-mentioneddiscussion it is quite clear that the Linear Regression requires mainly two things -Firstly an Independent variable and the next a dependent variable or the one whose results are found out. Hence following the same path we segregate the dataset present in two new dataframes depending on the correlation matrix which roughly has the link length in one and the joint acceleration in the other one.Before moving ontothe next step we recall those two dataframes to see whether both of them have been successfullysegregated or not.Now before moving onto the model design one final step is carried out which requires importing the sklinear module from which the linear model is imported as the Linear Regression model will be processed through thiscommand hence importing this model is a pivotalstep in taking preliminary step in designing the Machine Learning model.The next step involves the use of LRMLT where the model is now constructed and the dataset present at hand is now split into two categories mainly train and test to find out how the Machine Learning model fairs.Hence in this way the Machine Learning model is trained and now the logical step after training the model is the most vital step involved in the paper i.e, predicting the values.This is done with the help ofthe predict function that is present in the Python Library where it comes pre-loaded,Hencethrough the use of this function we find out the result whereas through the use of the coef() function we find the equation which satisfies thismodel.

IV. Result And Discussion

On the basis of the application of LRMLT model the prediction of Joint Acceleration has been achieved on the basis of the Experimental data that is present from the Robo Analyzer software. After the completion of the simulation and running the Experiment, it was allowed to accumulate data on the basis of which the Machine Learning Model was selected and trained. The data present in the form of tabular data was necessary to find the result of this work.As can be seen from the figure 4 that there is a linear relationship between the Link Length and the Joint Acceleration i.e., the graph plotting the input and output parameters tend to be linear for most part of time, which has also been visualized with the help of the scatter plot and moreover thisis a pivotal part of why the Linear Regression model was selected for the prediction of the model. Based on the same data the correlation matrix was formed for the dataset for which the heat map was generated as shown in the figure 5 & the heat map was thoroughly studied to find thescore of 1.00 which would represent a linear relation between the two component whereas -1.00 which would represent no relation was present at all, hence on the basis of the above said principle the heat map helps in explaining the dataset in a muchmore elaborate form as well as further strengthens the argument as to why Linear Regression Model should be selected for designing the Machine Learning model in this paper and not any other Machine Learning technique.

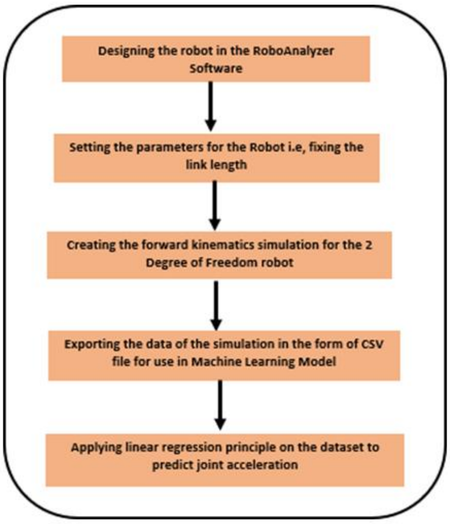

Figure 2 Data Acquisition and overview of work

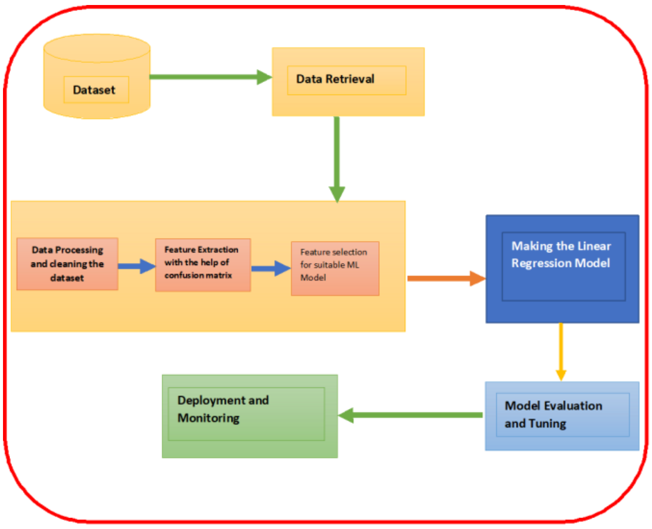

Figure 3: Flow Chart of Linear regression used in training the model

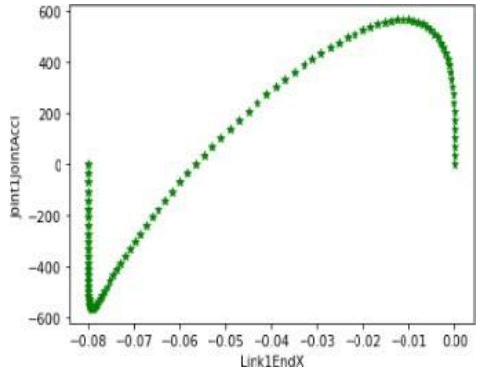

Figure 4: Link Length vs Joint Accelerationcodependency

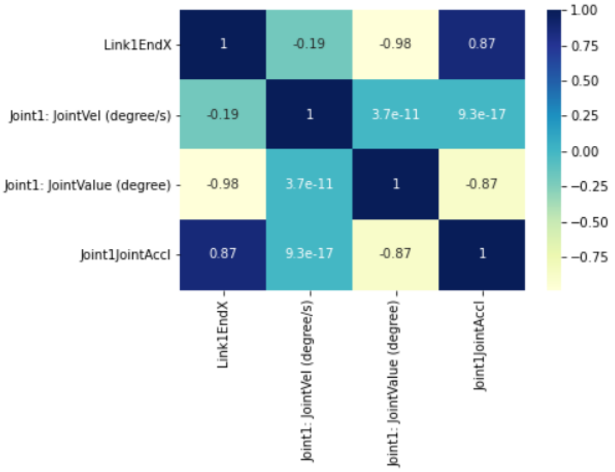

Figure 5: Heatmap for the data set

```
reg = linear_model.LinearRegression()
reg.fit(new_df,Joint1JointAccl)

LinearRegression()

reg.predict([[-0.08,0,180]])

array([-507.5200452])
```

Figure 6: Code Snippet of the Linear Regression work

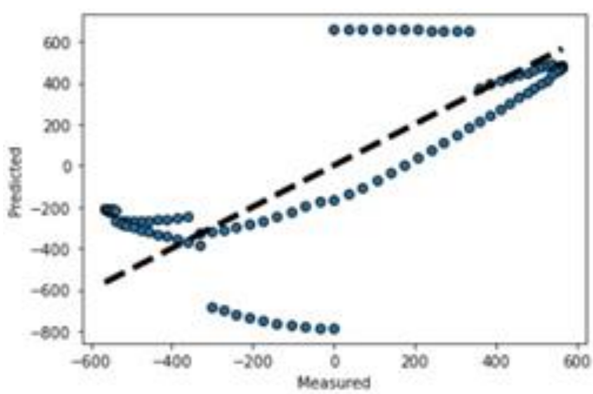

Figure7: Predicted vs. Measured graph

Moreover, based on this principle and the sole purpose of applying Linear Regression the dataset currently under examination is divided into training and testing dataset randomly which would help to train the model in a more uniform manner and give the output. Hence the equation got helps us to represent the dataset in a mathematical form which helps to sum up the experimentation.

V. CONCLUSION

Apart from the Kinematics study of the robots with the help of RoboAnalyzer very little work had been done in this field to study the data generated after the kinematical solutions havebeen achieved. The primary focus of this researchpaper was to focus on how to increase the reusability of the data from the RoboAnalyzer that is being generated as well as implementing Machine Learning Principle to attain favorable outputs which are matching with theexperimental data present in hand. Hence in this paper a Linear regression-based Machine Learning model has been constructed and tested to find out whether the result achieved from the model matches the Experimental data or not. Moreover, the selection of the Linear regression model was based on the fact that the codependency was found within the various parameters with the help of various data analytical methods which would help to suffice inreasoning as to why this model was selected. One of the biggest challenges in this proposed works seems to be based on the fact that the model selected was based on the tested method of linear relation between the link length and Joint Acceleration, Meanwhile the Machine Learning can be used for prediction in higher dof model hence in those cases the textual principle on the basis of which this model was based on in hope that this might satisfy the problem equations of higher DOF model might not be true hence this principle might be jeopardized.

Moreover, the main purpose of the linear regression in real life is to forecast future output on the basis of the present data but in this case as we take the data that is in the form of time series data we don’t seem to predict any value that is not already present in the current dataset. The data is then used to cross validate the experimental findings of the two link robot, One of the biggest drawbacks as can be guessed fromfig.7 of this algorithm was in the form of the limited data being present for this configuration of the robot which caused the model to not be tested on diverse data and hence the model has limited functionality in terms of use beyond this research model and as previously has been discussed and can be inferred from the graph that the model is based on an artificial dataset which shows that it cannot be used to find relation in real world robot kinematics solution. Moreover, basedon the theory of robot kinematics the principle ofserial chain robots has been studied in detail throughout research in the history of robotics but the codependency in higher degree of freedom Robot models can be taken for research in futurestudies with the help of various Machine Learning and Deep Learning techniques to show the versatility and multi-faceted use of Machine Learning in the study of robotics.

REFERENCES

1. Gupta, V., R.G. Chittawadigi, and S.K. Saha, RoboAnalyzer: robot visualization software for robot technicians, in Proceedings of the Advances in Robotics. 2017. p. 1-5. https://doi.org/10.1145/3132446.3134890
2. Liu, G., et al. A base force/torque sensor approach to robot manipulator inertial parameter estimation. in Proceedings. 1998 IEEE International Conference on Robotics and Automation (Cat. No. 98CH36146). 1998. IEEE. https://doi.org/10.1109/ROBOT.1998.680950
3. Poignet, P. and M. Gautier. Nonlinear model predictive control of a robot manipulator. in 6th International workshop on advanced motion control. Proceedings (Cat. No. 00TH8494). 2000. IEEE. https://doi.org/10.1109/AMC.2000.862901
4. Slotine, J.-J.E. and W.J.A. Li, Composite adaptive control of robot manipulators. 1989. 25(4): p. 509-519. https://doi.org/10.1016/0005-1098(89)90094-0
5. Erkaya, S.J.S.V.J.o.M.E., Effects of Joint Clearance on the Motion Accuracy of Robotic Manipulators. 2018. 64(2). https://doi.org/10.5545/sv-jme.2017.4534
6. Faroni, M., et al., Predictive joint trajectory scaling for manipulators with kinodynamic constraints. 2020. 95: p. 104264. https://doi.org/10.1016/j.conengprac.2019.104264
7. Tang, S.H., et al., Predicting the motion of a robot manipulator with unknown trajectories based on an artificial neural network. 2014. 11(10): p. 176. https://doi.org/10.5772/59278
8. Swere, E. and D.J.J.E.E. Mulvaney, Robot navigation using decision trees. 2003: p. 15-17. https://neuro.bstu.by/ai/To-dom/My_research/Papers-0/For-research/R-navigation/Navigate-by-memory/swere.pdf
9. Karsak, E.E.J.I.J.o.P.R., Robot selection using an integrated approach based on quality function deployment and fuzzy regression. 2008. 46(3): p. 723-738. https://doi.org/10.1080/00207540600919571