ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

DEVELOPMENT IN VIBRATION CONTROL OF ROBOT

Sunil Kumar*

*Department of Mechanical Engineering, Sant Longowal Institute of Engineering and Technology, Sangrur, Punjab-148106, India

DOI: 10.5281/zenodo.1241398

ABSTRACT

In robot's vibration is one of the unwanted phenomena and hurdle to achieve high accuracy in performing tasks. The use of heavy rigid robots in industry is not solution of vibration control. In this direction number of researchers have attemptedthrough experimentation and modeling and simulation to reduce or omit effect of vibration. Depending on the type of robots different control strategies like PID, PD, optimal control, active vibration control etc. are applied. In this regard a comprehensive assessment of strategies developed and implemented for vibration control are presented. This article will benefit researchers in understanding the control of vibration in robots.

I. INTRODUCTION

Robots are widely used in industry for replacement of human in hazardous, repetitious and tedious jobs. To have high accuracy and precision by reducing unwanted vibration in robots is one of the important filed among the researchers. Robots are designed to have high stiffness so that vibration in the end-effector can be reduce. Weight robots with high payload to arm weight ratio response better to vibration in low speed but at higher speed inertia force leads to link deformation and unwanted vibration. To have high accuracy in end-effector motion under vibration condition is challenging task. Passive vibration control is generally implemented to reduce vibration by attaching mass spring and damper in the system. In case of robot's addition attachment restricts the motion and source of vibration is required to control it. Active vibration has edge over passive vibration control of robots. Active vibration counters the vibration instantaneously by responding low as well as high frequency disturbances. Mostly design strategies for vibration control are done along with the track control [1, 2]. In experimental studies smart materials like piezoelectric materials, shape memory alloys, electro-strictive etc. are used for promising solution to reduce vibration [3, 4, 5] in active vibration control (AVC). In some of the case along with smart materials controllers like PD, PID, artificial intelligence algorithms for control are applied for better control of vibration.

Many researchers have experimentally and through modeling and simulation have given different strategies for the control of vibration in different robots. In view of this in present study articles related to vibration control of robots are presented in two sections. First section presents the articles related to vibration control by experimentation and modeling. Second section presents articles related to vibration control through modeling and simulation.

II.VIBRATION CONTROL THROUGH EXPERIMENTATION AND MODELING

Application of smart materials in robotics have attracted many researchers in control of vibration. Piezoelectric transducers have been used in most cases for vibration control of robot. Shan et al.[6] investigated experimentallysingle-link flexible robothaving two PZTactuators. By using PPF and velocity feedback control reduced vibration of end-effector for single-link flexible robot. Wang [7]studied AV of3-PRR parallel manipulator which has one flexible link bonded with two PZT actuators.The investigation has been performed by experimental and as well as theoretical investigation to show the effectiveness of AV. Vliet[8] has introduced a scheme of damping vibration in big and flexible macro-robot. In this schemeexperiment has been done by frequency matching on planar macro-robot.To regulate end-effector of flexible link optical sensor has been applied by Tsoa et al. [9].Optical sensor contains a laser diode and a position measuringsensorto measure real-time dynamic deflection of flexible link. Model has been purposed which have non-linear and measuring dynamic system model along with feedback based Lyapunov controller. Sun et al. [10] have investigated a

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Lyapunov approach combined with PD feedback and command controller. Controller controlled the patch of PZT actuators, fixed with surface of single flexible arm. Wang and Mills [11] have showed that piezoelectric actuators effectively damp the vibration of the flexible linkages by using the Lagrange finite element formulation. It has been further applied to have dynamic model for flexible planar linkage. The linkage has two prismatic and one rotational DOF. An effort has been made by Bandopadhya and Bhattacharya [12] to effectivelydecrease vibration of a single link planar flexible robot. Propositional controller has been applied on model along with active material for reduction of vibration of passive layers and further Kalman filter has been used to estimate state. Active damping control complications of robot for oscillating base have been taken care by Lin et.al. [13]. The study of two-time scale fuzzy logic controller for vibration stabilizer has been proposed for multiple link robot to controloscillation in various dimension. Further, PD and fast-subsystem controller has been used for reducing vibration of oscillating base. Hassan et al. [14] have used model-based predictive controller (MPC) tooverwhelm unwanted vibration producedin flexible one-link robot by using MIMOsystem along with piezoceramic actuators. Chu [15]purposed a novel approach for actively reducing vibration of two-arm flexible robot two sets of piezoelectric actuator/stain gauge sensor.Hillsley and Yurkovich [16] has analysed through experimentation vibration of the end effector of two-link flexible robot used for point-to-point movements. Strategy for vibration of high-speed linear robots has been purposed by Chang [17], which used auxiliary piezoelectric actuator.

III. VIBRATION CONTROL THOUGH MODELING AND SIMULATION

Onsay and Akay [18] have implemented time-optimal open-loop controller to damp out unwanted vibration of flexible linkused for point-to-point movement by using modal state-space approach. Srivastava and Kundra[19] presented algorithm to enhance dynamic behavior of a structure by modifying local damped structure and by modifying stiffness matrix for added structure. The equations of motion have been formulated using the Lagrange-Euler of the first type for planar parallel manipulator including structural flexibility of several linkages by Mills [20]. In another study, Khulief [21] has developed an algorithm of FEM of system dynamics in combination with modal reduction schemes and further applied on a double span beam. Further, an approach for active damping using a piezoelectric actuator has been described to attenuate structural vibration of the linkage**.**Stability and robustness has been achievedwith the help ofcollocated actuator-sensor-pairs.This pairs have ability of active execution of passive control. The soft computing for modeling and control of dynamic systems depend on nature of the application. Accordingly, Darus and Tokhi [22] have investigated the same technique with SISO and SIMOvfor autonomous vehicles control structures. They have further employed it into modelling and control for damping out vibration of 2D flexible structures. Xing et al. [23] have used interlinked passive and active vibration isolation system. This system allowstuning of the stiffness and damping with use ofposition and velocity feedback.

Zuo and Slotine[24] have proposed robust controller for multi-DOF AV isolation, which take care of plant uncertainty and payload vibration by the use of frequency-shaped sliding control. Modal decomposition has been applied to rewrite MIMO vibration control problem asgrouping of SISO control problems in modal coordinates and further a skyhook model has been recasted as frequency-shaped sliding surface. Jnifene[25] has used position control system scheme to enhance performance of less damped dynamic systems and delayed position feedback signal for of flexible structure. Detailed analysis of stability of single-link flexible robot has been performed with time delay control and by choosing appropriate values of time delay for controller gains. Gorabal et al. [26] have studied the vibration control using friction damper pads. In this work, damping behaviour of a pneumatic friction damper suspension system has been analysed using lab view through implementation of finite element analysis modeling. Gonzalez and Madrigal [27] have carried out a steady state response of passive and active suspension, represented through bond graphs with preferred derivative causality assignment.Chin and Lau [28] have accentuated the organized modeling of hydrodynamic damping by use of CFD software ANSYS-CFXTM on complex-shaped remote operated vehicle. Kumar et al. [29] have attempted active vibration control with PID controller of a beam. Beam has been modeled as Euler-Bernoulli beam elements on which two Piezoelectric Ceramic Lead ZirconateTitanate patches. Best results have been achieved by them when patches bonded at the ends. Sharma and Pandey [30] have attempted to optimize the vibration for residual stresses in ultrasonic supported turning. In this research, interactions between parameters have been studied thermo-mechanical mechanism, which has beenaccountable in inducing residual stress.

Six axis articulated industrial robots have limited usage for different machining processes due to its low accuracy. Yun and Li [31], addressed the low frequency vibration (10Hz) by using AVC with MIMO system and LOR algorithm for hybrid and parallel robots. Vibration in flexible link modeled as Euler-Bernoulli beam

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

with PD controller of robot has been taken care by piezoelectric patches as actuators within AVC [32]. Kumar et al. [33] has controlled vibration of base and end-effector using AVC for single flexible link underwater welding robot. AVC has also been used by Chu and Cui [34] through Lagrange's equation for axially translating robot link which has rotating-prismatic joint. Vibration has been damped by the use of self-sensing actuator along with AVC. A new closed-loop control schema for cancelling undue vibration in the 2- DOF antenna used in robot with the algorithms which estimated 3D beam position [35].Kapsalaset al. [36]addressedand designed VC of flexible metallic arm by using Matlab/Simulink synthetic environment.The closed-loop controller having feedforward Proportional-Integral (PI) controller has been simulated. Shape Memory Alloys (SMA)has been used for flexible robot of two rigid and one flexible links by Lima et al. [37]. To control its vibration State Dependent Ricatti Equations (SDRE) technique has been simulated for its feasible test. The vibrations in heavily loaded joints of robot arms where focused by Tsetserukou et al. [38] while the end-effector is in interaction.Pouyaet al. [39] took concern of optimal path planning with reduction in residual vibrationof two–flexible manipulator. Genetic algorithm and BFGS (Broyden–Fletcher–Goldfarb–Shanno) algorithmshas been used for optimizing the variable to reduce vibration. Transient vibration of a waist axis of an articulated robot has been reduced by model-based control system through increasing cut-off frequency and damping ratio at driven machine part [40]. Abdullahi [41] used fuzzy logic control scheme for damping out unwanted vibration flexible manipulators with payload using error and its derivative.

IV.CONCLUSIONS

Research from around the world has been involved for vibration control of robot's. In different types of robot's vibration have been controlled, by applying different control strategies and using smart material, accordingly the review has been done. Piezoelectric has been used by most of the researchers as sensors to detect vibration frequency and accordingly signal are given to actuator to control vibration. Many researchers have modeled and control vibration using different control strategies like AVC, model-based controllers, PD, PID, Sliding mode, etc. In case of robots roll of passive vibration control is limited as it has limitation of addition mass, spring and damper attachments and further its poor response in fast movement leading to use of AVC in most of work. Focus of researcher is to control the vibration in end-effector so that error in its motion is minimized. The main prominence is to provide information about the strategies developed by researchers for the control of vibration in robot's

V. REFERENCES

[1] Mahmood, I.A., B. Bhikkaji, and S.O.R. Moheimani. Vibration and Position Control of a Flexible Manipulator. in Information, Decision and Control, 2007. IDC '07.
[2] Ahmad, M.A., et al. Vibration control of flexible joint manipulator using input shaping with PD-type Fuzzy Logic Control. in Industrial Electronics, 2009. ISIE 2009. IEEE International Symposium on.
[3] Preumont, A., Vibration Control of Active Structures: An Introduction, Kluwer Academic Publishers, 2002.
[4] Clark, R. L., and Saunders, W. R., Adaptive Struture: Dynamics and Control, John Wiley & Sons, 1998.
[5] Fuller, C. R., Elliott, S. J., and Nelson, P. A., Active Control of Vibration, Academic Press, 1996.
[6] Shan, J., Liu, H., and Sun, D., "Slewing and vibration control of a single-link flexible manipulator by positive position feedback (PPF)," Mechatronics, 2005, Vol 15, 487-503.
[7] Wang Z and Keogh P "Active Vibration Control for Robotic Machining", , ASME 2017 International Mechanical Engineering Congress and Exposition, Advanced Manufacturing, Vol 2.
[8] Vliet JV. A frequency matching algorithm for active damping of macro-micro manipulator vibrations. Intell Robot Syst, 1998. 782-787.
[9] Tsoa SK, Yangb TW, Xuc WL, Sun ZQ. Vibration control for a flexible-link robot arm with deflection feedback. International Journal of Non-Linear Mechanics. 2003, Vol 38, 51–62.
[10] Sun D, Mills JK, Shan J, Tso SK. A PZT actuator control of a single-link flexible manipulator based on linear velocity feedback and actuator placement. Mechatronics. 2004, Vol 14(4), 381-401.
[11] Wang X, Mills JK. FEM dynamic model for active vibration control of flexible linkages and its application to a planar parallel manipulator. ApplAcoust. 2005, Vol. 66, 1151-1161.
[12] Bandopadhya D, Bhattacharya B. A dynamic performance evaluation of flexible manipulator with active proportional damping and estimation algorithm. 2006 IEEE Conf Robot Autom Mechatronics, 2006, 193-198.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

[13] Lin J, Huang ZZ, Huang PH. An active damping control of robot manipulators with oscillatory bases by singular perturbation approach. J Sound Vib., 2007, Vol 304(1-2), 345-360.

[14] Hassan M, Dubay R, Li C, Wang R. Active vibration control of a flexible one-link manipulator using a multivariable predictive controller. Mechatronics. 2007, Vol 17(6), 311-323.

[15] Zhong Yi Chu1 and Jing Cui, Experiment on vibration control of a two-link flexible manipulator using an input shaper and adaptive positive position feedback. Advances in Mechanical Engineering. 2015, Vol. 7(10) 1–13.

[16] Hillsley K L and Yurkovich S, Vibration Control of a Two-Link Flexible Robot Arm. Dynamics and Control. 1993, Vol 3, 261-280.

[17] Chang T N, Kwadzogah R and Caudill R J, Vibration Control of Linear Robots Using a Piezoelectric Actuator. IEEE/ASME Transactions on Mechatronics. 2003, Vol. 8(4).

[18] Önsay T, Akay A. Vibration reduction of a flexible arm by time-optimal open-loop control. J Sound Vib. 1991, Vol 147(2), 283-300.

[19] Srivastava RK, Kundra TK. Structural dynamic modification with damped beam elements, Computers & Structures.1993, Vol, 48(5), 943-950.

[20] Mills JK. Dynamic modeling and vibration control of high speed planar parallel manipulator. Proc 2001 IEEE/RSJ IntConfIntell Robot Syst Expand Soc Role Robot Next Millenn (Cat No01CH37180). 2001, Vol. 3, 1287-1292.

[21] Khulief Y, Active modal control of vibrations in elastic structures in the presence of material damping. Comput Methods Appl Mech Eng. 2001, Vol. 190, 6947-6961.

[22] Darus IZM, Tokhi MO. Soft computing-based active vibration control of a flexible structure. EngApplArtifIntell. 2005, Vol. 18(1), 93-114.

[23] Xing JT, Xiong YP, Price WG. Passive-active vibration isolation systems to produce zero or infinite dynamic modulus: Theoretical and conceptual design strategies. J Sound Vib. 2005, Vol. 286(3), 615-636.

[24] Zuo L, Slotine J-JE. Robust vibration isolation via frequency-shaped sliding control and modal decomposition. J Sound Vib. 2005, Vol. 285(4-5), 1123-1149.

[25] Jnifene A. Active vibration control of flexible structures using delayed position feedback. Syst Control Lett. 2007, Vol. 56(3), 215-222.

[26] Gorabal S V, Kurbet S N, and Appukuttan K K. Investigation of penumatic friction damper suspension system by using FEA. National conference on advances in mechanical engineerging (NAME-2010).2010, 34-44.

[27] Gonzalez AG, Madrigal J. Steady State of Passive and Active Suspensions in the Physical Domain. 2010, 124-129.

[28] Chin C, Lau M. Modeling and Testing of Hydrodynamic Damping Model for a Complex-shaped Remotely-operated Vehicle for Control. 2012, 150-163.

[29] Kumar S, Srivastava R, Srivastava RK. Active Vibration Control of Smart Piezo Cantilever Beam Using PID Controller.IJRET: International Journal of Research in Engineering and Technology.2014, Vol. 3(1),392-399.

[30] Sharma V, Pandey P M. Optimization of machining and vibration parameters for residual stresses minimization in ultrasonic assisted turning of 4340 hardened steel. Ultrasonics. 2016, Vol. 70, 172-182.

[31] Yun Y and Li Y, Active Vibration Control Based on a 3-DOF Dual Compliant Parallel Robot Using LQR Algorithm The 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems, October 11-15, 2009 St. Louis, USA.

[32] Williams D, Khodoparast H H, Yang C, Active vibration control of a flexible link robot with the use of piezoelectric actuator, MATEC Web of Conferences 148, 11005 2018.

[33] Sunil Kumar, Vikas Rastogi, Pardeep Gupta, Active vibration control modelling in bond graph for underwater flexible single arm robotic manipulator, International Conference on Bond Graph Modeling and Simulation (ICBGM 2016), Proceedings of a meeting held 24-27 July 2016, Montreal, Quebec, Canada, 2016 Summer Simulation Multi-Conference (SummerSim'16). Simulation Series Vol 48 #10, 87-91.

[34] Chu Z Y and Cui J, Experiment on vibration control of a two-link flexible manipulator using an input shaper and adaptive positive position feedback, Advances in Mechanical Engineering. 2015, Vol. 7(10) 1–13.

[35] Batlle V F, Talegon D F and Berrio C F C, Improved Object Detection Using a Robotic Sensing Antenna with Vibration Damping Control, Sensors. 2017, Vol 17, 1-28.

[36] Kapsalas C N, Sakellariou J S, Koustoumpardis P N, Aspragathos N A, On the vibration control of a flexible metallic beam handled by an industrial robot within an ARX-based synthetic environment IFTOMM / IEEE / Eurobotics 25th International Conference on Robotics - Raad, Belgrade 2016.
[37] Lima J J, Tusset A M, Janzen F C, Piccirillo V, Nascimento C B, SDRE Applied to Position and Vibration Control of a Robot Manipulator with a Flexible Link, Journal of Theoretical and Applied Mechanics. 2016, Vol 54(4), 1067-107.
[38] Tsetserukou D, Kawakami N, Tachi S, Vibration Damping Control of Robot Arm Intended for Service Application in Human Environment 8th IEEE-RAS International Conference on Humanoid Robots. 2008, 441-446.
[39] Pouya M, Rasht, Iran, Pashaki P V, Vibration Optimization of a Two–Link Flexible Manipulator with Optimal Input Torques Mechanics and Mechanical Engineering. 2017, Vol. 21 (2) 253–265.
[40] Itoh M and Yoshikawa H, Vibration Suppression Control for an Articulated Robot: Effects of Model-Based Control Applied to a Waist Axis International Journal of Control, Automation, and Systems. 2003, Vol. 1(3), 263-270.
[41] Abdullahi A M, Mohamed Z, Muhammad M, Bature A, Vibration Control Comparison of a Single Link Flexible Manipulator Between Fuzzy Logic Control and Pole Placement Control, International Journal of Scientific & Technology Research. 2013, Vol 2(12), 236-241.

CITE AN ARTICLE

Kumar, S. (2018). DEVELOPMENT IN VIBRATION CONTROL OF ROBOT. *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY*, *7*(5), 80-84.