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The literature review in modeling and fuzzy control of flexible manipulator link with moving end effector

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Abstract

This investigation provides a review of the literature on the control of robot arms using the fuzzy logic control and the traditional control with a focus on the first one. With the flexible link classification of single link and multi-link manipulators. In addition to showing common methods for deriving the mathematical modeling of the flexible link manipulator and its comparison based on criteria in the flexible link used. Therefore the main distinguishing feature of the review literature here is that it takes a holistic view of the control process in the various systems, rather than focusing on one side in it, which leads to an insufficient understanding of the control systems used.

Keywords: Flexible Manipulator; Finite Element; Vibration Control; Fuzzy

1 Introduction

Studies of the flexible manipulator arms in the controlling areas is begun from the space research robots sides, such as the manipulator must be light space as much as possible in order to minimize the cost of launching into space, the Book [1, 2]. Tzou [3]. For risky, monotonous and boring work, robotic manipulators are commonly used. In order to minimize the vibration end effect to achieve good position accuracy, most modern robotic processors are designed and constructed in a way that reduces rigidity. The use of hard materials and bulky construction ensures this high rigidity. Therefore, in terms of power consumption or speed, current heavy solid processors were shown to be inefficient in terms of operating load. The weight of the arms must be decreased in order to increase efficiency in the industry then, the speed of work is improved. For these purposes, it is very desirable to build flexible manipulator robotics. Conventional robots are usually heavy and bulky, but flexible joint processors have the potential advantage of lower cost, larger workload, and higher operating speed, greater load to weight of the manipulator ratio, smaller actuators, lower energy consumption, better maneuverability, and better and safer transmission operation due to reduced inertia Dwivedy [4].

Since the main problem is controlling the vibration of the payload in the tip of manipulators and the vibration of the flexible arms, many researchers have tried to solve this problem by improving the dynamic models and integrating different control strategies. In the following sections there is a literature review on modeling and controlling flexible links. Although one might find more available references in this area, a total of 33 publications were reviewed here.

The review was divided into 5 parts. Part 1 deals with a brief introduction to applications Flexible manipulators, part 2 describes the different modeling techniques for flexible manipulators. Part 3 dealing with on single-link manipulators. Part 4 dealing with on Two &Multi-link manipulators. Finally the conclusion which was summarized in the last part.

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2 Mathematical Modelling of Flexible Manipulator Links

Driving the mathematical model of the system to be controlled is a major important thing to selection of appropriate control method for achieving the required results, which is also considered the language of dealing between the physical system and the simulated system on the program used.

The dynamic kinematic equations for elastic structures can be derived using classic analytical techniques. These equations are complex, a method for estimating a finite-dimensional system of ordinary differential equations is generally used. In this context, two sets of normal patterns are considered, that are, unrestricted and restricted patterns of vibration, [5, 6]. The Book [7] provides an educational lesson on elastic manipulators, examining the mathematical representations commonly used in modeling elastic connections and joints and discussing design considerations arising directly from the flexible nature of the arms.

Martins. J. M et al.[8] built a mathematical model of a flexible robot arm in two ways Assumed Mode Method (AMM) & Finite Element Method (FEM) to reach the possibility of using the best mathematical analysis method depending on the application and the different mechanical structures and operating mechanisms. Simulations and experimental results are shown to respond to flexible manipulators in the time and frequency domains. Moreover, the model was validated by comparing the results to evaluate the performance of the modeling approaches. They concluded that the AMM method with the square offset gives better results at the axis angle, and the FE method produces better results with the axis speed and the endpoint acceleration.

M. Tajdari et al. [9] presented a new approach to modeling specific nonlinear elements on a flexible robotic arm using Hamilton mechanics and simulating their dynamic behavior by using the Matlab program to control the effect of the end of the flexible arm. And when applying the square torque to the joints Flexible manipulators to simulate their dynamic behavior. For two degrees of freedom, fluctuation does not appear at the angle of the first arm, nevertheless, the difference in the second arm angle is observance.

The versatile manipulator therefore does not execute its mission correctly. The second member's variability is more than the first. The error is therefore important in determining the exact end-effector position. The explanation for the higher vibration is its relation with the end of the first and also it’s overlaid vibration in the second connection.

M.A. Ahmad et al. [10] studied the effect of the flexible arm length on the mathematical model using the finite element method and simulated its effect by the matlab program, and the results were presented based on time and frequency ranges. Various lengths of the flexible arm were taken to measure the efficiency of the system through the effect of dynamic behavior from the levels of vibrational frequencies and response time. They concluded that the resonance state would occur at lower frequencies and the system’s response would be slow as the arm length increased.

3 Single-Link Flexible Manipulators

Much of the academic researches on control of all kinds is focused on the single-flexible manipulator link. It represent the simplified model for the application of the robot arms, because it is easy to handle and gives good results to understand the dynamic behavior of the system as well as deriving the mathematical modeling has an uncomplicated. Nagarajan and Turcic [11] derived elementary and systemic equations for systems with elastic and sold arms. Pricott et al. [12] use FEM to study flexible manipulators. Nguyen H M & and Pham A T [13] presented the method of flexible robotic arms control using a fuzzy logic control combined with the traditional PID control. The mathematical model was built using the dynamic LSM algorithm method to represent the rubber effect on the arm. It turns out that the use of a fuzzy logic control combined with PID The using FPID to design nonlinear compensator is an advance step to make out the simple controller, which has enough force to do in real time control. The compare FPID with PID to focus special function describe elastic. That is an important problem because it is a cause of nonlinear properties, which is an insecure problem of PID and linear controllers.

Tokhi et al [14, 15, 16–17] used the finite element method to develop dynamic models of a single-link flexible manipulator and compared experimentally existing frequencies to validate FEM modeling in some cases. They also used a bang-bang type of torque to study the dynamic response. Nura M T and Kamal A A [18] studied Single link versatile manipulator hybrid intelligent control. Output based filter (OBF) have been designed for the suppression of tip deflections with the signal performance of the system; they have been combined with both a linear quadratic controller and a fuzzy system logic controller for the control of fixed point monitoring. Based on the results of the simulation, effective monitoring and significant deflections of the tip were observed. The time response analysis was used to test the system. Based on the OBF of the simulation, it was found that the two cases achieved very good monitoring and elimination of tip deflections, but thus better results were achieved with LQR-OBF.

Ekhlas H. Karam1 et al. [19] applied the PID with nonlinear signum function to a flexible robotic arm, and to construct a dynamic model the finite element method was used. Bacteria Foraging Optimization (BFO) algorithm used to calibrate traditional control. Using the Matlab program, they achieved a reduction in vibrations at the end of the flexible arm to zero, even with a change in the load. Mohammad Khairudin et al. [20] applied a linear quadratic regulator (LQR) control to a flexible manipulator arm, and the system performance was evaluated in terms of the ability to track inputs for angular center response, endpoint displacement, endpoint residue and axis speed Then, the results were compared with traditional PID control. They concluded that the traditional control needs in each case to be re-calibrated to obtain the gain whereas the LQR control, the gain that has been found can be used in all cases, meaning that it does not need calibration every time. Moreover, it has been proven that the LQR controller Better performance compared to PID controller. The LQR controller also presented faster settling time and smaller overshoot responses and tracking performances of the proposed controller compared with PID controllers. Waladin K. Sa'id et al.[21] studied the dynamic model to control the vibration of a flexible manipulator arm. Lagrange-assumed modes approach was applied to obtain a dynamic model of the robot arm. A linear model of the single-link arm was simulated using the Matlab "Simulink tool". Hybrid control was suggested to overcome the problem of vibration at the tip of the arm during movement. A modified version of the PD controller is designed to track the path of the joint while the sliding pattern control is used to damped vibrations. A second controller (fuzzy logic control with PID) was also developed as a way to control both damping vibrations and tracking the joint path.

Al-khafaji A. A, and Darus [22] developed a mathematical model for a flexible underwater robotic arm and were designed in the form of a flexible beam from Euler-Bernoulli using the finite element method based on the Lagrange approach analysis and by the Matlab program simulated the system performance and evaluate it based on accuracy in Describe the behavior of the manipulator. When studying the performance and accuracy of the algorithm on the basis of changing the element number from 1 to 25, it has been proven that by increasing the number of elements, better accuracy is achieved in characterizing the system but at the expense of more implementation times. It is also noted that the damping did not affect the resonance frequencies in the system, but it did lead to a large attenuation in the system's response capacity.

S. Mahto and U.S. Dixit [23] performed a parametric study of a flexible arm manipulator through a linear modeling technique using the finite element method, and compared the dynamic response of the mechanical system under different types of excitations. They concluded that the dynamic response depends on several influencing factors, like the loads at the tip of the arm, the length of the arms, the amount of torque and the inertia of the hub. P. Sooraska and G. Chen [24] used A newly developed stability analysis system, using the "straight lines" standard, has been applied by Timoshenko's theory to constructing the mathematical model for a flexible "shoulder elbow" arm with its dampers. Results from the computer simulation show that the built control unit can suppress vibration and tip control in order to monitor a specific point successfully with satisfactory precision and energy. The analytical stability of the Fuzzy Control System (PI + D) 2 demonstrates, moreover, that the analytic version supports graphical stability analysis not just of the Fuzzy PI + D subsystem by micro acquiring.

4 Multi-Link Flexible Manipulators

There may be no significant difference between single-link flexible manipulator control systems and the multi-link flexible manipulator control systems, only the complexity of driving the mathematical modelling with difficulty control over the flexible links vibration, so requires more experience and wide understanding of the system to be controlled.

Sherif K H and Mahmoud H S [25] studied the possibility of applying fuzzy logic control dynamically with a multivariate nonlinear coupling system on a flexible two-arm manipulator to control the position and speed of the robot axes for the movement of the final responders. The main objective of the fuzzy logic control scheme is to represent the human experience by the rules of fuzzy logic system and also because it is fast and more accurate controlling. Simulation results showed that control performance can be obtained, and we can also conclude that analysis of operational characteristics led to major results that enable deriving control algorithms and assessing the fuzzy logic controller under dynamic operating conditions. Low and Vidyasagar [26] used a two-link system (rigid-flexible) and considered the second link as elastic and used the Lagrange method to study its dynamic behavior. Mohamed M et al. [27] studied the effect of fuzzy logic control technology to improve performance and increase response to a multi-link robot arm and compare it with a traditional control unit. Since the dynamic equations of motion in a nonlinear robotic arm are very complex, it is difficult to control by using the traditional proportional integral control unit (PI), the fuzzy logic control has the advantage of controlling nonlinear systems. Therefore it is more susceptible and has a good response compared to PI control. The results showed that the proposed controller is better compared to the traditional PI control as it has a smooth motion, fast response and less error than the PI controller. Xinxin Yang et al. [28] studied the dynamic modeling and adaptive robust space robot tracking control with flexible two-link manipulators in unknown disturbances. With the assumed mode approach and Lagrangian method, the dynamic system model is represented. A new Linear Quadratic Regulator method (LQR) is proposed to minimize the vibrations of flexible manipulators in the fast subsystem. The efficiency of the closed-loop space robot system is demonstrated by numerical simulation results. With the proposed control, the closed-loop stability under unknown disturbances has been proven. Numerical simulations have been provided to illustrate the effectiveness of the proposed control. Fukuda and Arakawa [29] The modeling and dynamic properties of flexible two-link robotic arms operating on vertical baleen were investigated, influenced by load gravity as well as the vibration coupling between first and second arms. The links only take account of the bending vibration. The governing equations were also derived from a homogeneous processing matrix, Euler bundle equations with appropriate limits and modular analysis procedures. Shuai Zhang et al. [30] studied the effect of using active control in vibrations of two-link flexible piezoelectric materials manipulator and motion equation was derived using the absolute nodal coordinate equation and constructing the MFBD model with electro-mechanical coupling relations of piezoelectric actuators and sensors are analyzed with The possibility of controlling gains via the Internet. The simulation results were that fuzzy logic control performed better than traditional PID control. In addition, the described control methods can be expanded to control the vibration of the other manipulator system. Wenwei et al. [31] studied the modeling method for a two-link flexible manipulator that includes experimental data to improve model accuracy using Euler-Lagrange's equations of motion, after building the shape and determining factors depending on the mass matrix that must be specific positive and that the expected natural frequencies of the linear model it should correspond to the experimental results. Milford and Ashokanathan [32] derived partial differential equations, by matching boundary conditions on the elbow, control system positions for general two-link flexible transformers and show that the subjective frequencies can vary by up to 30 percent as the transformer passes its range of motion. They also conducted experiments to confirm the models.

Ehsan Badfar & Rohollah Abdollahi [33] studied the effect of using a path tracker for rigid-flexible arm manipulators using the Linear Matrices Inequality (LMI) concept to simplify the process of finding a stabilizing gains. The system's equations were also achieved and transformed into a state space form. The linear quadratic control strategy is selected to successfully track the pre-defined trajectory precisely. The main advantage of this method is simple practical implementation and also this method ensures the stability of closed loop system, it is also possible to consider different control approaches such as adaptive control and also fuzzy control.

5 Conclusion

This review of the literature on the latest flexible manipulators reveals that dynamic analysis and control of flexible manipulators is a wide area of research ranging from simple capture and location operations of an industrial robot to microsurgery, maintenance of nuclear plants, and space robots.

In this paper the focus was on the varied single and two or multi-link flexible manipulator systems using different control methods. It turns out that all the previous research did not touch on a rigid-flexible manipulator systems, and this is the void on which this research focuses.

Compliance with ethical standards

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