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Full Length Article

Intelligent tuning of vibration mitigation process for single link manipulator using fuzzy logic

Ahmed A. Ali [a,*], Rana Abdul Rahman Lateef [b], Mahmood Wael Saeed [a]

[a] Baghdad University, College of Engineering, Mechanical Engineering Department, Iraq
[b] Baghdad College for Economic Sciences University, Iraq

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ABSTRACT

In this work, active vibration mitigation for smart single link manipulator is presented. Two piezoelectric transducers were utilized to act as actuator and sensor respectively. Classical Proportional (P) controller was tested numerically and experimentally. The comparison between measured results showed good agreement. The proposed work includes the introducing of fuzzy logic for tuning controller's gain within finite element method. Classical Proportional-Integral (PI), Fuzzy-P and Fuzzy-PI controllers were totally integrated as a series of [IF-Then] states and solved numerically by using Finite Element (FE) solver (ANSYS). Proposed method will pave the way on solving the tuning process totally within single FE solver with high efficiency. Proposed method satisfied mitigation in the overall free response with about 52% and 74% of the manipulator settling time when Fuzzy-P and Fuzzy-PI controllers were activated respectively. This contribution can be utilized for many other applications related to fuzzy topics.

1. Introduction

Manipulators are utilized in a large number of applications in numerous fields. Robotic manipulators are designed to increased stiffness in order to reduce the vibration of the tip to achieve required position accuracy. This high stiffness is obtained by using heavy material. Hence, in certain applications their use is unavoidable. Their use means increase of power consumption and decrease the speed at the end effectors with respect to the operating payload [1]. In addition, the operation of flexible manipulator- robots is limited by their dynamic behavior due to low stiffness, which still oscillates after a move is completed for an interval. So that the time required for this vibration to reach the steady state doesn't meet with the demand of increasing productivity. These opposed between high speed and high positional accuracy made the single flexible robotic implement task to be a challenging research problem [2]. To get better industrial productivity, the weight of the links must be reduced and increase their speed of rotation. Due to lightweight requirements and high-speed operations, a flexible link model is highly needed. Flexibility is a consequence of the lightweight material used in manipulator robotic arms that are implemented to work at high speeds with low inertia. In order to overcome this problem, a smart manipulator with a distributed sensors and actuators into the structure beside a control system (that can process the response from the sensor and use control technique to send commands to the actuator) can be used. Many works studied and analyzed the vibration of manipulator by considering it as a cantilever beam by using numerous analyzing methods besides testing numerous controlling techniques experimentally and numerically. Authors of reference [1] proposed a new method merges between passive and active vibration control for a single link manipulator. Results showed the validation of proposed method for light damping system. In reference [2], a numerically rigid/ flexible two links arm was tested to control the repeated tasks cases with various environments. Authors worked on using proportional- derivative terms besides iterative variable to satisfied an adaptive iterative learning algorithm for boundary control. MATLAB was utilized to test this method.

A review on two links manipulators was presented by reference [3]. Methods of controlling and corresponding problems were presented for a wide range or previously published articles in which numerical and/or experimental tests were carried out. Experimental and numerical model of single link manipulator was presented by reference [4]. In mentioned work residual vibration was controlled for selected stopping positions and moving period. Based on velocity profile many tests were carried out with high degree of agreement between them, where the authors noticed that the

* Corresponding author.
E-mail addresses: Dr.Ahmed.ali@coeng.uobaghdad.edu.iq, Ahmedrobot65@yahoo.com (A.A. Ali), taught.rana.abdalrahman@baghdadcollege.edu.iq, ranacsbaghdad@gmail.com (R.A.R. Lateef), mahmoodwael@rocketmail.com (M.W. Saeed).

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right selection of deceleration time acts on decreasing the amplitude of residual vibrations. In reference [5] depending on passive vibration control, two smart coupled beams were subjected to pulse excitation and about 50% of structural vibration was dissipated. Mentioned work can be utilized for vibration mitigation for enhancing the stability of existed structures. Active vibration control for two connected piezoelectric plate was presented in reference [6] in which fuzzy fast – sliding mode controller for vibration suppression was proposed with non-contact sensor. Good enhancement in system stability was satisfied specially for small excitations. Authors in reference [7] tested three controlling algorithms based on model predictive controlling method. Two-link manipulator was tested in vertical situation by using the mentioned methods experimentally and numerically for the purpose of comparison.

Authors of reference [8] proposed local linearization of multi degree of freedom manipulators and a new H∞ method. The proposed method was considered as an effective and new controlling technique, where robotic model was prepared based on local linearization as mentioned previously. Results of mentioned work were confirmed by simulation of experiments.

In reference [9] single link-flexible manipulator was equipped with piezoelectric actuators and tested for vibration suppression by a novel distributed observer controller. The new controlling technique presented by mentioned wok was proven exponentially stable. High enhancement in tracking position of tested manipulator was satisfied and proven numerically and analytically. Authors of reference [10] prepared a closed loop simulation for actively vibration suppression of a single- link flexible manipulator. Mathematical model of tested arm was presented as a four degree of freedom spring-mass system. Proportional – Integral – Derivative (PID) controller was integrated to be solved within Newmark method. Good stability enhancing was satisfied and numerical results were proven analytically with high degree of agreement. Single link flexible manipulator made from composite material was tested in reference [11] for active vibration control of its end point vibration. Many angles of lay-up fibers were tested numerically and experimentally with a high degree of agreement between them. Bending mode was targeted to be suppressed depending on numerous profiles of motions and different time intervals. Results of mentioned work showed that the vibration at the end is governed by controlling the first vibrational mode of tested manipulator (bending mode). In reference [12] flexible manipulator was modeled as a beam equipped with piezoelectric actuator and proportionally pneumatic valve. Dynamic model of tested system was driven from experimental model by identification approaches. Proportional – Derivative (PD), self-organizing map and pole placement controller were utilized to conduct the functions of many controllers. Experimental results showed high enhancement in manipulator vibrational performance.

Authors in reference [13] worked on suppressing of vibration for flexible manipulator by utilizing two controlling strategies, one of them for trajectory tracking. Variable-speed control moment gyros were acted as actuators. Results showed that high enhancing in vibrational controlling performance of tested manipulator was noticed. In reference [14], disturbances observing besides designing of boundary control were proposed by authors for flexible manipulator arm. Stability of vibration suppression controller and disturbances observers were validated theoretically besides numerical presentation of proposed closed loop system. Authors of reference [15] worked on developing and modifying input shaping method for vibration mitigation for many vibrational modes. Proposed method was utilized for actively vibration suppression of a single link flexible manipulator where the authors introduced the modification in the input shaping method to satisfy much better performance enhancement than the traditional input shaping method. While researchers of reference [16] prepared single beam fixed from one end, free from another, and tested two vibration mitigation methods for the purpose of reducing the residual vibration of its end point. They noticed that simultaneous controlling of both position and time can be effectively controlled and carried out by the second proposed method. Researchers of reference [17] carried out controlling of four links mechanical manipulator by utilizing a system of piezoelectric actuators and sensors for testing classical and H∞ controlling method besides the testing of reduced modal modeling method numerically.

In reference [18] model predictive controlling technique was used for actively vibration attenuation of single link manipulator. Researchers in reference [19] worked on the vibration suppression for a smart single cantilevered beam by utilizing piezo-patches served as actuators and sensors. Closed loop controlling system was presented depending on single-input- single-output feedback for satisfying control strategy. Authors of reference [20] studied actively vibration attenuation of beam with embedded piezoelectric patches. Proportional – Integral – Derivative (PID) controller was proposed for structure modeled by state space method based on its physical model. In reference [21] Proportional – Integral – Derivative (PID) controller was proposed for active vibration suppression based on the feedback of sensed output signal. The dynamic model of the manipulator can be presented as a lumped multi degree of freedom system as stated in references [22,23]. Developing of position controlling algorithm was introduced by reference [22] utilizing mechanical waves. Researchers of reference [23] proposed closed loop stage for structural damping enhancement and open loop for positioning high-speed movement. Wide range of applications in which active vibration control can be utilized such as automotive [24–26] and construction [27,28]. Also modern controlling strategies can be utilized for vibration suppression of nonlinear system as in references [29–32]. Active vibration control for aircraft wing using PID, velocity feedback and acceleration feedback was presented by references [33–36].

From literature, it was noticed that the using of fuzzy logic in active vibration control includes a series of complex processing and requires many software to be achieved. In this work, integration of fuzzy logic for intelligent tuning of both P & PI controller within ANSYS program was performed. This tuning process utilized the fuzzy logic to achieve active vibration controlling process for single link manipulator. The contribution of this work will eliminate many steps and reduces the controlling process complexity.

Numerically and experimentally testing for classical P controller will be presented, besides the numerically testing of classical PI, fuzzy-P and fuzzy-PI respectively.

2. Finite element model

In active vibration control technique it is necessary to use coupled-field analysis for coupling the interaction between electric field and applied stress therefore, coupled field elements that consider electrical and structural coupling are required to perform the finite element analysis of smart structure. Linear presentation for piezoelectricity is considered where in which the piezoelectric, dielectric and elastic coefficients are represent as constants. Constitutive equations that mechanical APDL (ANSYS15) used to model piezoelectric transducer material are arranged in matrix form and integrated within ANSYS by using direct programming language. The model (the aluminum beam) which is tested should be discretized to small elements for satisfying FE analysis. SOLID45 was selected to mesh the tested manipulator while SOLID5 was utilized to mesh the piezoelectric actuator, these elements were selected based on the information presented in [37,38] respectively.