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Unwanted noise and vibration control using finite element analysis and artificial intelligence

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ABSTRACT

A mechatronic approach integrating both passive and active controllers is presented in this study to deal with unwanted noise and vibration produced in an automobile wiper system operation. Wiper system is a flexible structure with high order, nonlinear model that is considered as a multi objective control problem since there is a conflict between its functionality quality in wiping and generated unwanted noise and vibration. A passive control technique using multi body system (MBS) model and finite element analysis (FEA) is introduced to identify the potential of the effectiveness of the physical parameters of wiper blade to give appropriate range to reduce the unwanted noise and vibration in the system. While, the significant contribution of active controller is to deal with uncertainties exerted to system within wiper operation. In passive control stage, natural frequencies of a uni-blade automobile wiper are determined using modal testing. Later, a 3-dimensional model of a wiper blade assembly is developed in multi body system design to investigate the good validation test and agreement of the physical behavior of the system in experiment with finite element analysis. Parametric modification via complex eigenvalue is adopted to predict instability of the wiper blade. In active control level, experimental data collected from the wiper system during its operation. A system identification model named nonlinear auto regressive exogenous Elman neural network (NARXENN) is developed for implying the active controller. A bi-level adaptive-fuzzy controller is brought in whose parameters are tuned simultaneously by a multi objective genetic algorithm (MOGA) to deal with the conflict interests in wiper control problem.

1. Introduction

Wiper system is considered in this study as an in hand and practical paradigm of flexible manipulators that have broad application in high technology industry, nonlinearly elastic shuttle antenna and space shuttle missions. An important issue in application of such these mechanisms is to deal with the unwanted vibration and noise created within their operation. It is even becoming more important factor to provide a leading edge in the market. The researches in wiper system attempt on identifying the techniques to reduce the level of unwanted vibration and noise either by analytical, numerical and experimental approaches [1–3].

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These three approaches can be used either as stand alone or combination of them. Due to inherent characteristics of flexible structures analytical approach has been approved to be inadequate to provide a complete understanding of the physical behaviors [4]. One way to resolve deformability in the model is numerical method using finite element method to conduct the research. Experimental approach is the essential to endorse the results made by analytical or numerical approaches. Investigation about geometrical configuration of a wiper system suffered where environmental disturbances as wind lift, variation of frictional coefficient between wiper blade and windscreen stem from rain and snow loading intervene [5,6]. Several methods were applied for controlling the chaotic motion of wiper blade [7–9].

From the number of papers published in open literature and some aforementioned, it can be deduced that wiper system is still regarded as one potential problem in unwanted noise and vibration during the operation. So, a combination of an active in addition the passive control designs is desired to suppress low frequency beep sound with the range of 100 Hz or less.

A narrative approach with fusion of passive and active controllers is introduced in this survey to control unwanted vibration and suppress annoying chatter noise generated from wiper operation (Fig. 1). In the passive phase the parametric optimization of a wiper system has been made under various conditions to make it more stable based on the noise created by the rubber. Active vibration control phase of this research is to preface the controller to control the system to be more robust during the operation where the flutter instabilities are based on the coupling between the rubber blade and the windshield.

In the passive control phase of this study, it was decided to imply numerical approach using multi body system (MBS) and finite element analysis (FEA) in order to come out with a solution to investigate the noise and vibration. Using this approach required to investigate the good validation test and agreement of the physical behavior of the system in experiment with finite element model (FEM). In active control phase, an experimental method carried out for identifying dynamic characteristics of a windscreen wiper system of a conventional passenger car. The experimental data verified with a FEA was adopted for past processing system identification and control of wiper system. The main goal of this part is to suppress chatter noise of wiper system while improving oscillatory behavior of wiper blade in optimum rise time of system even in present of uncertainty and external disturbances like wind lift and variation of frictional coefficient between wiper blade and windscreen due to rain and snow loading intervene. To fulfil this task, a multi-objective, bi-level adaptive-fuzzy controller incorporating with a multi objective genetic algorithm (MOGA) is presented.

Nonlinear characteristic of a wiper model requires a reliable nonlinear system identification method to estimate transfer function of wiper system so that helps for designing a more accurate controller. In order to control vibration and noise of wiper system which is considered as a flexible manipulator with several modes of frequencies it was proved that nonparametric approaches and specifically NN performed better at higher resonant modes than conventional RLS even in problems associated with non-minimum phase characteristics of the system [10–12].

NARX is one the well-known system identification models which proved to be greatly efficient and accurate for nonlinear system identification [13,14]. In Elman neural network (ENN) there is a set of carefully chosen feedback connections that allows the network remember cues from the recent past unlike Multi layer perceptron (MLP) which posses a non-dynamic static of structure of only feedforward connections. Besides, the distinct self-connections of the context nodes in the Elman network make it sensitive to the history of input data, which is essentially useful in dynamical system modeling with white noise input [11,12,15]. Hence, A nonlinear auto regressive exogenous (NARX) in cascade with Elman neural network (ENN) named NARXENN is utilized for the purpose of system identification of nonlinear wiper system with Bang–Bang input and end-point acceleration as we as hub displacement as output.

In an effective IL algorithm, the algorithm is able to estimate next input value in which, the system performance becomes better and better on successive trials needless to reconfigure the algorithm when the system is operating [16]. Some applications of ILC for flexible manipulators were investigated as well [12,17].

Fuzzy logic controller (FLC) has advantage of control a system by means of expert knowledge and regardless of actual dynamics of plant which considered as main shortfall of traditional controllers [18]. Also, there have been some investigations on FLC incorporating with evolutionary and swarm approaches [19,20].

Broadly speaking, there has not been yet an exact analytical approach for handling a complex multi-objective problem. So, MOGA using fitness sharing technique is employed in this study to find the best Pareto optimal set of objectives in conflict [21]. The main advantage of MOGA is its versatility for including a variety of objectives and constraints while designing the controller [22–24].

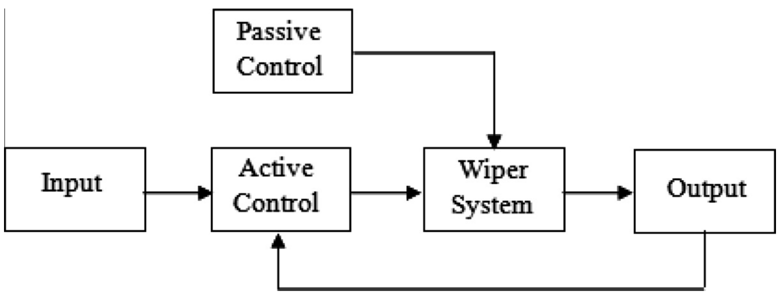

Fig. 1. Schematic representation of bi-level Active–Passive controller.