DESIGN OF A ROBUST ACTIVE FUZZY PDC ANTI-VIBRATION CONTROLLER FOR THE GLOVED-HAND SYSTEM

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”To my compassionate husband and my dearest parents for their continuous support”

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ABSTRACT

The prolonged use of the vibrating hand-held tools can cause discomfort, muscle fatigue and ergonomic injuries to the users which are known as hand-arm vibration syndrome (HAVS). The undesired vibration decreases the tool performance and the user productivity. Therefore it is very important to design a vibration suppression tool that can isolate or suppress the vibration transmission to the worker's hand to protect them from HAVS. This work is carried out to design a vibration control approach that can be applied to the anti-vibration gloves to reduce the vibration transmission from the vibrating tool to the users so that it can keep the vibration level within the healthy caution zone which is less than $2.5\ m/s^2$ for 8 hours exposure time. While the anti-vibration glove which includes viscoelastic materials is used as the passive vibration control approach, for the active vibration control we need to produce an actuation signal to cancel the vibration by using active elements along with the sensors and controller. Therefore, in this work first, an active model of the glove-hand system is considered and then by obtaining the mathematical model of the system, a fuzzy parallel distributed compensation (PDC) controller is designed in a way that it can perform well for different users with different hand masses. The capability and reliability of the proposed controller are evaluated through simulations and then the results are compared with the other active vibration control techniques including proportional integral derivative (PID) controller and active force controller (AFC). The simulation results show the excellent performance of the designed controller over the other types of controllers and its significant capability in reducing the transmitted vibration to the user's hand.

ABSTRAK

Penggunaan peralatan mudah alih secara berpanjangan boleh memudaratkan badan, melemahkan otot-otot dan menghasilkan kecederaan ergonomik kepada penggunanya. Kesan ini dikenali sebagai ”hard-arm vibration syndrome (HAVS). Vibrasi yang tidak dikehendaki boleh mengurangkan prestasi alat dan juga produktiviti pengguna. Oleh itu, adalah amat penting untuk mereka-cipta satu alat penghalang atau pengurang getaran yang dapat mengasingkan serta menghalang trasmisi getaran alat tersebut kepada penggunanya. Kerja ini telah dijalankan dengan untuk mereka satu cara untuk mengawal getaran yang dapat digunakan pada sarung tangan anti-getaran agar dapat mengawal kadar getaran pada tahap yang selamat terhadap penggunanya, iaitu kurang daripada $2.5\ m/s^2$ dalam masa 8 jam sepanjang tempoh penggunaan. Walaupun sarung tangan anti-getaran dihasil dengan menggunakan material viscoelastic yang dapat bantu mengawal getaran secara pasif, namun begitu satu cara aktif juga diperlukan untuk bantu membatalkan getaran dengan menghasilkan isyarat actuation menggunakan elemen-elemen aktif serta pelbagai sensor dan alat pengawal. Oleh itu, dalam kerja ini kita terlebih dahulu perlu mempertimbangkan satu model aktif system sarung tangan, dan diikuti dengan memperolehi satu sistem model matematik sistem yang dikehendaki, sebuah ”Fuzzy paralled distributed compensation (PDC) controller” akan direka-cipta agar ia sesuai diguna oleh pengguna yang mempunyai pelbagai jisim tangan yang berbeza. Tahap keupayaan dan tahap kebolehpercayaan kontroller yang dicadangkan akan diuji menggunakan program simulasi dan hasilnya akan dibandingkan dengan cara kawalan getaran yang lain seperti ”Proportional integral derivative (PID) controller” dan juga ” Active force controller (AFC). Hasil simulasi menunjukkan prestasi alat pengawal yang direka adalah amat menakjubkan berbanding dengan alat pengawal yang lain serta tahap kemampuannya yang bagus dalam mengurangkan transmisi getaran kepada tangan pengguna.

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LIST OF ABBREVIATIONS

AFC	–	Active Force Control
AV	–	Anti-Vibration
AVC	–	Active Vibration Control
DOF	–	Degree of Freedom
HAVS	–	Hand-Arm Vibration Syndrome
ISO	–	International Organization for Standardization
LMI	–	Linear Matrix Inequality
PID	–	Proportional Integral Derivative
PDC	–	Parallel Distributed Compensation
	–	

LIST OF SYMBOLS

Hz	–	Hertz
$\mathbf{A}$	–	system matrix
$\mathbf{B}$	–	controlled input matrix
$\mathbf{E}$	–	disturbance input matrix
$\mathbf{C}$	–	output matrix
$\mathbf{F}$	–	state feedback matrix gain
$\mathbf{x}$	–	vector of state variables
$\mathbf{u}$	–	controlled input
$\mathbf{w}$	–	disturbance input
$\mathbf{y}$	–	output
k_p	–	proportional gain of PID controller
k_i	–	integral gain of PID controller
k_d	–	derivative gain of PID controller
M'	–	estimation of the mass in AFC
Q'	–	disturbance force in AFC
k_1	–	stiffness coefficient of the hand
k_2	–	stiffness coefficient of the soft tissue of the hand
k_3	–	stiffness coefficient of the glove
F_a	–	actuator force or control input
F_p	–	push force
F_w	–	vibration input or disturbance
c_1	–	damping coefficient of the hand
c_2	–	damping coefficient of the soft tissue of the hand
c_3	–	damping coefficient of the glove
m_1	–	mass of the palm and back of the hand
m_2	–	mass of the hand soft tissue
m_3	–	mass of the glove
z_i	–	displacement of mass i

$\dot{z}_i$	–	velocity of of mass i
$\ddot{z}_i$	–	acceleration of mass i
r	–	number of rules
M_{ij}	–	fuzzy set
$s_i(t)$	–	known premise variables
$M_{ij}\big(s_j(t)\big)$	–	membership grade of $s_j(t)$ in M_i
$V\big(\mathbf{x}(t)\big)$	–	Lyapunov function
$\mathbf{P}$	–	Positive definite matrix
	–	

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CHAPTER 1

INTRODUCTION

The health risks caused by the vibration of the hand-held tools has been focus of many researches during the past decades. The effects of anti-vibration (AV) gloves on reducing the health risks of the vibrating tools have been investigated in many studies and various types of anti-vibration gloves have been introduced to the market such as the gel-filled, air-filled or leather AV gloves. It is shown that the efficacy of the designed AV gloves depends not only on the glove material, but also on tool operating conditions, the frequency and direction of vibration, the amount of various force applied, operators, etc [3]. So it has been tried to improve the efficacy of the AV gloves by adding an active elements to them and make an active system. In active vibration control (AVC) an actuator is utilized to apply an external force or displacement based on the measurement of the system response through feedback control. The levels of acceleration, displacement or velocity measured by sensors is entered to the control system which provides the control signals for actuators based on the chosen control strategy.

1.1 Problem Statement

Many types of control schemes have been employed to generate the control signal needed for the active AV mechanism. Design of the control scheme could be quite challenging in this area since there are many parameters effecting the performance of the controller. Beside that, the vibration of different body parts occurs at different frequencies. For example, the hand-arm system vibration occurs at $30-100$ Hz and the vibration above 100 Hz will affect the hand in particular [4].

In designing of a robust AVC system, modelling of structural dynamics and considering the uncertainties of the system parameters such as changes of the vibration frequency and range for different tools, the type of AV glove used, the amount of force applied, and the characteristics of different users in the model play an important role. So in this work, we have considered a simple but precise model for the gloved-hand system based on the changes of the system characteristics for different users and then the controller is designed to be robust to these changes in the system.

In the available robust control schemes applied to AV systems, the robust performance of the controller with respect to the variation of the hand masses i.e. different operators that work with the tool is not considered. In this study, based on the uncertainty of the mass of hand considered in the glove-hand model, a robust controller is designed that can attenuate the vibration for different users.

The designed controller later is applied to control the vibration of a two-stroke engine which has a wide range of applications including grass trimmer machine, chain saws, lawnmowers, motorcycles, scooters and palm-oil fruit harvester but its vibration hasn't been studied well in previous works.

1.2 Objective

The objectives of this study are:

i) To derive the mathematical modelling of the considered passive and active gloved-hand system
ii) To design a proper type of controller for suppressing the vibration in active system
iii) To investigate the vibration isolation effectiveness of the designed controller to be employed in AV glove
iv) To validate the robust performance of the designed controller with respect to changes of the hand masses

1.3 Research Scope

i) The model considered in this work is based on the hand system only

ii) The type of controller used in this work is the model-based control

iii) The case study under consideration in this research is a two-stroke engine

1.4 Contributions

i) Applying the control techniques used for the AV systems such as proportional Integral derivative (PID) and active force control (AFC) controllers on the gloved-hand model

ii) Design and development of a disturbance rejection fuzzy parallel distritbuted compensation (PDC) controller which:

- Has the ability to reject the vibration with the designed control input that is enforced to be bellow a maximum value according to the effective range of the implemented actuator.
- It is robust to the changes of the hand masses.

1.5 Dissertation Organization

This dissertation is organized as follows.

i) Chapter 1: Introduction

ii) Chapter 2: Literature review

iii) Chapter 3: Research methodology

iv) Chapter 4: Results and discussion

v) Chapter 5: Conclusions and future work

In Chapter 1 the problem statements, the objectives to be achieved and the scopes of work and the contribution of the research are presented. Chapter 2 contains the models for demonstrating the hand and glove system and the limitations in designing the anti-vibration gloves. In Chapter 3 the proposed methods used in this research in order to achieve the final results are described. The results obtained in this work are analyzed in Chapter 4. Finally, in Chapter 5 the conclusions and suggested future works are given.

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