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SENSORLESS ANTI-SWING CONTROL STRATEGY FOR AUTOMATIC GANTRY CRANE

BY

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Master of Science in Mechatronics Engineering

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ABSTRACT

Gantry crane is a machine used to transfer payload from one position to another position. The payload suspended from trolley by flexible cable is subject to swing caused by trolley acceleration. Anti-swing control of gantry crane system is hence required to transfer the payload to desired position without causing excessive swing at the final position. Most of the anti-swing controls proposed are feedback controls that require sensors to measure the trolley position and swing angle. However, installing swing angle sensor on a real gantry crane is troublesome, since there is a hoisting mechanism on parallel flexible cable and it is sometimes costly when vision-based sensor is used. To overcome this problem, sensorless anti-swing control of automatic gantry crane system is proposed in this study. The control scheme is expected to be simple and easy to implement in the absence of swing angle sensor. Firstly, model-based sensorless anti-swing control is proposed based on two difference approaches. The experimental results show that the proposed sensorless anti-swing control methods work effectively as the performance is close to that of sensor-based feedback anti-swing control method for swing suppression. In addition, a series of experiment shows that the proposed methods are also robust to small variations of cable length. Secondly, to overcome time consuming process in mathematical modeling, sensorless anti-swing control using neural network state estimator as soft sensor is proposed. The swing angle is estimated from input voltage and acceleration by using dynamic recurrent neural network. The performance is evaluated experimentally using lab-scale gantry crane. The result shows that the proposed method works also effectively for swing suppression. In term of swing, it has instead better performance than model-based sensorless anti-swing controls.

ملخص البحث

يستعمل المرفاع القنطري المتحرك، لنقل الحمل من موقع لآخر. يكون الحمل المعلق بالحامل بواسطة كابل مرن عرضة للاهتزاز بسبب تسارع الحامل. لذا يتطلب استعمال نظام مضاد للاهتزاز لمنع الاهتزاز الزائد بعد وصوله إلى الموقع المطلوب أثناء انتقاله من موقع إلى آخر. يعتبر أغلب أنظمة منع الاهتزاز أنظمة تحكم بالتغذية المرتدة التي تتطلب اسنعمال مجسات أو حساسات لتحسس موقع الحامل، وزاوية الاهتزاز. مع ذلك، يعتبر تركيب حساسة زاوية الاهتزاز على المرفاع شيئا صعبا، و ذلك لوجود ميكانيكية الرفع على الكبل المرن المتوازي، ولارتفاع التكاليف عند استعمال حساسات الرؤية. لحل هذه المشكلة يُقترح في هذه الدراسة استعمال نظام منع الاهتزاز بدون حساسات لنظام الرفع القنطري المتحرك الأتوماتيكي. يُتوقع أن تكون خطة التحكم سهلة وبسيطة بغياب حساسة زاوية الاهتزاز.

أولا، يُقترح استعمال نموذج لنظام التحكم المانع للاهتزاز اعتمادا على طريقتين مختلفتين. أظهرت التجارب فعالية نظام التحكم المقترح، كما أظهرت التجارب أن الأداء مقارب لأداء أنظمة التحكم بالتغذية المرتدة التي تستعمل حساسات لمنع الاهتزاز. بالإضافة إلى ذلك، أظهرت سلسلة من التجارب قوة الآلية المقترحة مع أطوال مختلفة من الكابل. ثانيا، لحل مشكلة عملية استهلاك الوقت في التمثيل الرياضي، يُقترح استعمال نظام التحكم المانع للاهتزاز المعتمد على مقدر حالة الشبكة العصبية كمحسس خفيف. تُقدر زاوية الاهتزاز عن طريق فرق الجهد، والتسارع المدخلة باستعمال ديناميكية الشبكة العصبية المتكررة يُقيم الأداء تجريبيا باستعمال مقياس مختبري للرافعة القنطرية المتحركة. كما أظهرت النتائج أن الآلية المقترحة تعمل بفعالية لمنع الاهتزاز. بالنسبة للاهتزاز، تشير النتائج إلي أن الأداء أفضل من نموذج نظام التحكم المانع الاهتزاز بدون المحسسات.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Mechatronics Engineering.

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Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Mechatronics Engineering.

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Mahmud Iwan Solihin

Signature:……………………… Date: ……………………

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……………………..	…………………….
Signature	Date

To:

My beloved parents

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LIST OF SYMBOLS

a_2	Denominator parameter
a_1	Denominator parameter
A	Matrix of linear system
b	Friction coefficient
B	Input matrix of linear system
c	Center of RBFN
C	Output matrix of linear system
D	Matrix of linear system
e	Error of signals
e_b	Back emf
f	Matrix of nonlinear system
f	Neuron activation function
F	Total external
g	Gravitational acceleration
g	Input matrix of nonlinear system
h	Output matrix of nonlinear system
H	Performance index
i	Current
I	Input vector of DRNN
j	Index of actual unit, j=1,….,n_m
J	Total moment of inertia
k_0	Numerator parameter
k_1	Artificial response constant
k_2	Artificial response constant
K	Feedback gain
K_d	Derivative gain
K_e	Motor back emf constant

K_i	Integral gain
K_p	Proportional gain
K_t	Motor torque constant
λ	Length of the cable
L	Inductance
L	Lagrange function
L	Observer gain
m_1	Mass of the load
m_2	Mass of the trolley
M	Index of actual layer, m=1,….,M
M	Number of layer (excluding input layer)
n_m	Number of unit (neurons) in layer m
P	Number of training pattern/set
q	Input matrix of DRNN
r	Radii of gyration
R	Resistance
T	Total external torques
u	Input voltage
$u_i^{(m-1)\mu}$	Output of unit i in layer m-1 for pattern μ
v	Trolley speed
v_1	Artificial response
v_2	Artificial response
s	Laplace domain function
t	Time
w_{ji}^{m}	Weight between unit j in layer m and unit i in layer m-1
W	Matrix of DRNN
x	Trolley displacement
x_m	Horizontal payload displacement
x_{ref}	Position reference
x_{ref}^{mod}	Modified position reference
y	Linear system output vector
y_m	Vertical payload displacement

y_j^{μ}	Actual network output value for unit j for pattern μ
$y_j^{z\mu}$	Desired network output value for unit j for pattern μ
α	Momentum constant
β	Passive decay matrix of DRNN
δ_j^{u}	Learning error for unit j for pattern μ
$\Delta^{\mu} w_{ji}^{m}$	Change of given weight for pattern μ
κ	Kinetic energy
λ	DRNN state
μ	Index of actual training pattern, μ=1,2,….,P
η	Coefficient of learning rate
$\phi(.)$	Function of a basis function
φ_j^{μ}	Weighted sum of input values for unit j in layer μ
σ	Width of RBFN
$\sigma(.)$	Neuron function of DRNN
θ	Swing angle
θ_m	Motor rotational angle
ω	Motor angular velocity
ω_n	Damping ratio
ψ	Potential energy
ζ	Natural frequency

LIST OF ABBREVIATIONS

C.C.D.	Charge-coupled Device
D.C.	Direct Current
D.A.Q.	Data Acquisition Card
D.R.N.N.	Dynamic Recurrent Neural Network
G.U.I.	Graphical User Interface
M.F.N.	Multilayer Feedforward Neural Network
M.S.E.	Mean Squared Error
N.C.T.F.	Nominal Characteristic Trajectory Following
P.C.	Personal Computer
P.I.D.	Proportional Integral Derivative
P.D.	Proportional Derivative
R.B.F.N.	Radial Basis Function Neural Network
S.S.E.	Sum Squared Error

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Crane is a machine used for gripping loads, lifting, moving it and lowering it. Cranes are widely used for transporting heavy loads and hazardous materials in shipyards, factories, nuclear installations and high building constructions (Omar, 2003). In general, there are two types of crane namely rotary cranes and gantry cranes. Rotary cranes are commonly used in shipyards and construction site. This type of crane involves rotational and translational movement during operation. An example of rotary crane is shown in Figure 1.1.

Figure 1.1 Rotary tower crane in a construction.

Other famous cranes used in factories and shipyards are gantry cranes as shown in Figure 1.2. This type of crane incorporates a trolley which moves along the jib and translates in a horizontal plane. In bridge type of gantry cranes, the jib is mounted on another set of orthogonal railings so that the trolley can move in a two-dimensional horizontal plane. The payload is suspended by a cable from the trolley, whose length can be varied by a hoisting mechanism. The trolley should move the payload as fast as possible without causing any excessive sway at the final position so that it can achieve higher productivity.

Figure 1.2 Gantry crane in a shipyard.

However, the load suspended on the trolley of the crane is subject to swing caused by improper control of trolley motion and/or disturbance on the load such as wind and collision with other objects. Thus, automatic control of gantry crane should