International Journal of Control, Automation and Systems 16(X) (2018) 1-11
http://dx.doi.org/10.1007/s12555-017-0089-z

ISSN:1598-6446 eISSN:2005-4092
http://www.springer.com/12555

Decentralized Event-triggered Stability Analysis of Neutral-type BAM Neural Networks with Markovian Jump Parameters and Mixed Time Varying Delays

M. Syed Ali, R. Vadivel, and O. M. Kwon*

Abstract: This paper investigates decentralized event-triggered stability analysis of neutral-type BAM neural networks with Markovian jump parameters and mixed time varying delays. We apply the decentralized event triggered approach to the bidirectional associative memory (BAM) neural networks to reduce the network traffic and the resource of computation. A bidirectional associative memory neural networks is constructed with the mixed time varying delays and Markov process parameters. The criteria for the asymptotically stability are proposed by using with the Lyapunov-Krasovskii functional method, reciprocal convex property and Jensen's inequality. Stability condition of neutral-type BAM neural networks with Markovian jump parameters and mixed delays is established in terms of linear matrix inequalities. Finally three numerical examples are given to demonstrate the effectiveness of the proposed results

Keywords: BAM Neural networks, event-triggered communication scheme, linear matrix inequality, Lyapunov-Krasovskii functional, Markovian jumping parameters, time varying delay.

1. INTRODUCTION

Neural networks have found a large number of successful applications in various fields of science and engineering. The bidirectional associative memory (BAM) neural networks was proposed and researched by Kosko [1, 2], consist of neurons in two layers, the X-layer and the Y-layer. The first layer in the neurons are fully interconnected to the neurons arranged in the second layer, while there are no interconnect among neurons in the same layer [3–5]. Moreover, it is well known that time delays are very important in hardware implementations, because of the finite switching speed of amplifiers or of information processing, and the existence of time delays can lead to oscillation, divergence, and even instability [6–8]. In past years, some quite significant results on parameter uncertainties and neutral-type neural network with time varying delays have been reported [9–12].

When the neural network also incorporates sudden changes in its structure, the Markovian jump linear system is very appropriate to describe its dynamics [13]. This class of systems is the special class of hybrid systems, which is specified by two components in the particular state. The first one denotes to the mode, which was described by a continuous-time finite-state Markovian process, and the second one denotes to the state which was represented by a system of differential equations . Recently, there has been a growing interest in the study of BAM neural networks with Markovian jump parameters [14–16].

With the high speed development of digital technologies, various number of control methods have been used for find out the stability and controlling the consider neural network [17–19]. In the past few years event-triggered control has been proved to be an efficient way to reduce the transmitted data in the networks, which can relieve the burden of network bandwidth [20, 21]. Nowadays, decentralized event-triggered communication scheme(DETC) attracts renewed consideration due to the presence of reliable wireless network transmission and low cost microprocessors [22–25]. For instance the problem of network-based event-triggered filtering for Markovian jump sys-

Manuscript received February 19, 2017; revised July 18, 2017 and August 18, 2017; accepted September 28, 2017. Recommended by Associate Editor Xiaojie Su under the direction of Editor Duk-Sun Shim. This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (NRF-2016R1D1A1A09917886) and by the Brain Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT & Future Planning (NRF-2017M3C7A1044815). This work was also supported by "Human Resources Program in Energy Technology" of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea (No. 20164030201330).

M. Syed Ali and R. Vadivel are with the Department of Mathematics, Thiruvalluvar University, Vellore - 632 115, Tamilnadu, India (e-mails: syedgru@gmail.com, vadivelsr@yahoo.com). O. M. Kwon is with the School of Electrical Engineering, Chungbuk National University, Chungdae-ro 1, Cheongju 28644, Korea (e-mail: madwind@chungbuk.ac.kr).
* Corresponding author.

VICE CHANCELLOR

International Journal of Control, Automation and Systems 16(1) (2018) 225-233
http://dx.doi.org/10.1007/s12555-017-9263-6

ISSN:1598-6446 eISSN:2005-4092
http://www.springer.com/12555

Robust H_∞ State-feedback Control for Nonlinear Uncertain Systems with Mixed Time-varying Delays

R. Saravanakumar, M. Syed Ali, He Huang, Jinde Cao, and Young Hoon Joo*

Abstract: This paper presents a new less conservative stability and H_∞ state-feedback controller design of nonlinear uncertain systems with discrete interval and distributed time-varying delays. The main objective of this work is to attain robust asymptotic stability of concerned nonlinear system with H_∞ performance index. By constructing suitable Lyapunov-Krasovskii functional (LKF) with quadruple integral terms, sufficient conditions are obtained for delay-dependent robust H_∞ state-feedback control in the form of linear matrix inequalities (LMIs). Finally, numerical examples are added to show the advantage and usefulness of this work.

Keywords: Distributed delay, interval time-varying delay, Linear matrix inequalities, nonlinear disturbance, robust H_∞ state-feedback control.

1. INTRODUCTION

Over the past twenty years, great research interest has been accumulated to time delay systems because they have been successfully applied in various fields, such as aircraft stabilization, nuclear reactors, ship stabilization, models of lasers and neural networks. Thus the problems of time delay systems have undergone much stability analysis in recent decades [1, 2]. Recently, a new type of time delays, that is, interval time-varying delays, has been frequently confronted from various practical and theoretical systems and has been gathered much attention in the area of time-delay systems [1, 3]. Systems with distributed delays are arisen when the number of summands in a system equation is increased and the differences between neighboring argument values are decreased [4, 5]. It is often applied to the modeling of feeding system and combustion chambers in a liquid mono propellant rocket motor with pressure feeding [1]. The existence of distributed delays in a time-varying delay system may cause the filter design more complicated and difficult to be solved by traditional method.

The control design for uncertain systems with mixed time-varying delays is one of the difficult issue in control theory [6, 7]. Theoretically, this issue possibly solved by Lyapunov method approach. H_∞ performance is generally used to synthesize controllers to ensure stability with guaranteed performance in control theory. Stability is a major problem while synthesizing the controller design. Thus, the stability problem and H_∞ control for delayed systems have received significant research interest in the control community [8, 9].

In practice, real systems usually present some uncertainties due to environmental noise and slowly varying parameters, etc. Accordingly, the stability problem of uncertain nonlinear time-varying delay systems has been received considerable attention [10, 11]. To the best of the author's knowledge, H_∞ control of nonlinear uncertain systems with discrete interval and distributed time-varying delays has not yet been fully investigated, which motivates the current study.

From the above statements, we have studied the H_∞ state-feedback control problem for nonlinear uncertain systems with mixed time-varying delays. By using the LKF technique and convexity of some matrix functions, a new method is proposed. Then, the less conservative criteria for the existence of robust H_∞ controller are derived in terms of LMI. At last, numerical examples are given to show the usefulness and superiority of our approach.

2. PROBLEM DESCRIPTION AND PRELIMINARIES

Consider a nonlinear uncertain system:

Manuscript received May 5, 2017; accepted June 18, 2017. Recommended by Associate Editor Do Wan Kim under the direction of Editor Duk-Sun Shim. This work was partially supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2016R1A6A1A03013567), the Korea government (MEST) (NRF-2015R1A2A2A05001610) and by the National Natural Science Foundation of China under Grant no 61273122.

R. Saravanakumar and Young Hoon Joo are with the Department of Control and Robotics Engineering, Kunsan National University, Kunsan, Chonbuk 573-701, Korea (e-mails: saravanamaths30@gmail.com, yhjoo@kunsan.ac.kr). M. Syed Ali is with Department of Mathematics, Thiruvalluvar University, Vellore 632115, Tamil Nadu, India (e-mails: syedgru@gmail.com). He Huang is with the School of Electronics and Information Engineering, Soochow University, Suzhou 215006, China (e-mail: hehuang@suda.edu.cn). Jinde Cao is with the Department of Mathematics, Southeast University, Nanjing 210018, China (e-mail: jdcao@seu.edu.cn).
* Corresponding author.

VICE-CHANCELLOR

IF : 2.8

Environ Sci Pollut Res
DOI 10.1007/s11356-017-8501-z

RESEARCH ARTICLE

Airborne bacteria associated with corrosion of mild steel 1010 and aluminum alloy 1100

Aruliah Rajasekar [1,2] · Wang Xiao [1] · Manivannan Sethuraman [1,3] · Punniyakotti Parthipan [2] · Punniyakotti Elumalai [2]

Received: 20 September 2016 / Accepted: 23 January 2017

Abstract A novel approach to measure the contribution of airborne bacteria on corrosion effects of mild steel (MS) and aluminum alloy (AA) as a function of their exposure period, and the atmospheric chemical composition was investigated at an urban industrial coastal site, Singapore. The 16S rRNA and phylogenetic analyses showed that *Firmicutes* are the predominant bacteria detected in AA and MS samples. The dominant bacterial groups identified were *Bacillaceae*, *Staphylococcaceae*, and *Paenibacillaceae*. The growth and proliferation of these bacteria could be due to the presence of humidity and chemical pollutants in the atmosphere, leading to corrosion. Weight loss showed stronger corrosion resistance of AA (1.37 mg/cm^2) than MS (26.13 mg/cm^2) over the exposure period of 150 days. The higher corrosion rate could be a result of simultaneous action of pollutants and bacterial exopolysaccharides on the metal surfaces. This study demonstrates the significant involvement of airborne bacteria on atmospheric corrosion of engineering materials.

Keywords Mild steel · Aluminum alloy · Atmospheric corrosion · Biofilm · Microbial community · 16S rRNA analysis

Responsible editor: Diane Purchase

Electronic supplementary material The online version of this article (doi:10.1007/s11356-017-8501-z) contains supplementary material, which is available to authorized users.

✉ Aruliah Rajasekar
rajasekargood@gmail.com

[1] Department of Civil and Environmental Engineering & Minerals, Metals and Materials Technology Centre (M3TC), Faculty of Engineering, National University of Singapore, Block EA, 9 Engineering Drive 1, Singapore 117576, Singapore

[2] Present address: Environmental Molecular Microbiology Research Laboratory, Department of Biotechnology, Thiruvalluvar University, Serkkadu, Vellore, Tamil Nadu 632 115, India

[3] Present address: Biofouling and Biofilm Processing Section, Water and Steam Chemistry Division, BARC Facilities, Kalpakkam, Tamil Nadu 603 102, India

Introduction

Microbiologically influenced corrosion (MIC) is an electrochemical progression in which microorganisms initiate, facilitate, or accelerate the corrosion reaction (Beech 2004; Rajasekar et al. 2010, 2011). From previous studies, it is known that microorganisms tend to append themselves to surfaces exposed to the ambient environment to colonize, proliferate, and form a biofilm (Flemming 1996). The biofilm, consisting of microbial cells and their metabolites as well as extracellular polymeric substance (EPS), creates gradients of pH, dissolved oxygen, nutrient contents, temperature and pressure, leading to MIC of metals and alloys (Sarro et al. 2006; Sherar et al. 2011; Narenkumar et al. 2016). The overall economic burden of corrosion amounts to at least 4%–5% of the GNP (Gross National Product), and 20%–25% of this cost has been estimated to be due to the action of microorganisms (Flemming 1996; Koch et al. 2002).

Steel and its alloys are the most commonly employed metallic materials for construction of a wide range of equipment and metallic structures deployed in open-air environments due to their low cost and excellent mechanical strength (Brown and Masters 1982; De la Fuente et al. 2011). Most types of steel are exposed to open-air conditions, habitually in exceedingly polluted atmospheres, where corrosion is much more severe than in clean rural environments. Atmospheric corrosion leads to degradation of structures, devices, and products

Published online: 31 January 2017

Neural Comput & Applic
DOI 10.1007/s00521-017-3224-0

ORIGINAL ARTICLE

Exponential dissipativity criteria for generalized BAM neural networks with variable delays

R. Saravanakumar[1,4] · Grienggrai Rajchakit[2] · M. Syed Ali[3] · Young Hoon Joo[4]

Received: 23 March 2017 / Accepted: 4 October 2017

Abstract This article evaluates the exponential dissipativity and passivity criterions for generalized bidirectional associative memory neural networks (BAMGNNs) including interval time-varying delayed signals. Exponential dissipativity and passivity criterions are proposed by making suitable Lyapunov–Krasovskii functional and proposing a novel approach. The improved reciprocally convex combination and weighted integral inequality techniques are utilized to obtain new exponential dissipativity and passivity conditions of such delayed BAMGNNs. The feasibility of the obtained results is clearly demonstrated by numerical examples.

Keywords Generalized BAM neural network · Exponential stability · Passivity and dissipativity analysis · Time-varying delay · Weighted integral inequality

1 Introduction

Artificial neural networks (NNs) have been successfully studied in the past 2 decades, since they have been applied and extended to numerous engineering systems, such as image processing, communication, fault diagnosis, parallel computations, fixed-point computations, and industrial automation [1]. During the implementation and application of NNs, time-delayed signals are unavoidable because of the inherent finite signal transfer time between the neurons. The existence of time-delayed signals in systems may cause divergence, instability, and the gradual degradation of the system performance. Thus, time-delayed NNs have received a great deal of research attention [2–10]. In previous years, static NNs and local field NNs have been studied separately. To avoid such doubly work, Zhang et al. [11] proposed a new combined NN model named as generalized neural network (GNN), which brings both static and local field NNs together. Recently, a number of stability problems for such GNNs have been investigated in [12–15].

Recently, the dissipativity problem has gained extensive research attention, since it is an important subject for physical systems, such as the design of group coordination, hybrid systems, nonlinear time-delay systems, and Internet-based control [16, 17]. Passivity, and its generalization dissipativity, characterizes the energy consumption of a system and is used in a variety of applications (e.g., electrical, mechanical, chemical, and communication systems). In most cases, passivity can be used to demonstrate that passive systems will be stable under specific criteria [18, 19]. The dissipativity criteria are a more general case of passivity and stability analyses. Thus, it is essential to consider dissipativity problems for NNs.

✉ Young Hoon Joo
yhjoo@kunsan.ac.kr

1 Department of Mathematics, Faculty of Science, Mahidol University, Rama 6 Road, Bangkok 10400, Thailand

2 Department of Mathematics, Faculty of Science, Maejo University, Sansai, Chiang Mai 50290, Thailand

3 Department of Mathematics, Thiruvalluvar University, Vellore, Tamil Nadu 632115, India

4 Department of Control and Robotics Engineering, Kunsan National University, Kunsan, Chonbuk 573-701, Republic of Korea

Published online: 11 November 2017

香港浸會大學　嘉漢林業珠三角環境應用研究中心
Hong Kong Baptist University
Sino-Forest Applied Research Centre for Pearl River Delta Environment

Mr PUNNIYAKOTTI Elumalai
Department of Biotechnology
Thiruvalluvar University
Serkadu, Vellore-632112
Tamil Nadu
India

1 December 2016

Dear Mr. Punniyakotti,

Agreement about the Monthly Financial Allowance

During your study period from 15 December 2016 to 14 June 2017, as a special full time PhD research student in the Sino-Forest Applied Research Centre for Pearl River Delta Environment, Hong Kong Baptist University, you will receive monthly financial allowance HK$6500 per month.

You will work on various research projects and you need to do both laboratory work and instrumental analysis.

If you agreement with the offer, please sign both copies of the agreement and return one copy to me.

Welcome to our Research Centre!

Prof. Jonathan WONG, Director
Date:

Mr. PUNNIYAKOTTI Elumalai
Date:

David C. Lam Building DLB 517, Hong Kong Baptist University, Kowloon Tong, Hong Kong
香港九龍塘香港浸會大學思齊樓517室
Tel.: (852) 3411 2537 Fax: (852) 3411 2095 Email: arcpe@hkbu.edu.hk

VICE-CHANCELLOR

香港浸會大學
HONG KONG BAPTIST UNIVERSITY

研究院
GRADUATE SCHOOL

November 4, 2016

Mr PUNNIYAKOTTI Elumalai
Dept. of Biotechnology
Thiruvalluvar University
Serkadu, Vellore-632112
Tamil Nadu
India

Dear Mr PUNNIYAKOTTI,

Application for Admission as
A Special Full-time Research Student
[Programme Code: VS (PH.D.) RCPE]

I am pleased to inform you that you have been accepted as a special full time PhD research student in the **Sino-Forest Applied Research Centre for Pearl River Delta Environment**. You will be expected to arrive in Hong Kong on or before **January 1, 2017** and report to the Graduate School for registration.

Upon your arrival, please discuss with your Co-supervisor (Prof. Wong Jonathan W C) on an agreed date to commence your studies. The duration of the study period is 6 months, i.e., from January 1, 2017 to June 30, 2017.

Please contact Mr. Lo Kam Fai of the Graduate School for further enquiries [tel: (852) 3411 2214; email: kamfailo@hkbu.edu.hk). We welcome you to our University and wish you all the best in this intellectual pursuit.

Yours sincerely,

Dr. Vicky Wong
Senior Assistant Academic Registrar

Enclosures

VW/CT/FL/pc

cc Prof. Wong Jonathan W C, Director and Co-supervisor, Sino-Forest Applied Research Centre for Pearl River Delta Environment
Student File (Student No. 16554752)

香港 九龍塘 Kowloon Tong, Hong Kong 電話 Tel : (852) 3411 5127 傳真 Fax : (852) 3411 5133
電郵 E-mail : gs@hkbu.edu.hk 網址 Website : www.hkbu.edu.hk/~gs

香港浸會大學
HONG KONG BAPTIST UNIVERSITY

研究院
GRADUATE SCHOOL

June 6, 2017

Dept. of Biotechnology
Thiruvalluvar University
Serkadu, Vellore-632112
Tamil Nadu
India
PUNNIYAKOTTI Elumalai

To Whom It May Concern

Dear Sir/Madam,

This is to certify that Mr PUNNIYAKOTTI Elumalai (16554752) was enrolled as a visiting PhD student in our Sino-Forest Applied Research Centre for Pearl River Delta Environment from December 16, 2016. His last day of studies is scheduled for June 15, 2017. His performance during the exchange study period has been good.

Thank you.

Yours sincerely,

Dr. Vicky Wong
Senior Assistant Academic Registrar

VW/FL/pc

香港 九龍 Kowloon Tong, Hong Kong 電話 Tel: (852) 3411 5127 傳真 Fax: (852) 3411 5533

P129

Neurocomputing 171 (2016) 1533–1547

Contents lists available at ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

New passivity criteria for memristor-based neutral-type stochastic BAM neural networks with mixed time-varying delays☆

M. Syed Ali [a], R. Saravanakumar [a], Jinde Cao [b,c,*]

[a] Department of Mathematics, Thiruvalluvar University, Vellore 632115, Tamil Nadu, India
[b] Department of Mathematics, Southeast University, Nanjing 210096, China
[c] Department of Mathematics, Faculty of Science, King Abdulaziz University, Jeddah 21589, Saudi Arabia

ARTICLE INFO

Article history:
Received 15 April 2015
Received in revised form
7 June 2015
Accepted 30 July 2015
Communicated by Y. Liu
Available online 8 August 2015

Keywords:
Passivity analysis
Memristor
Neutral-type stochastic BAM neural networks
Quadruple integral
Time-varying delay

ABSTRACT

This paper deals with the problem of passivity analysis issue for a class of memristor-based neutral-type stochastic bidirectional associative memory neural networks (MNSBAMNNs) with discrete interval and distributed time-varying delays. By constructing new Lyapunov–Krasovskii functional (LKF) with quadruple integral terms and suitable activation function conditions, some delay-dependent passivity criteria are obtained in the linear matrix inequality (LMI) format. A numerical example is given to demonstrate the effectiveness and superiority of the new scheme.

1. Introduction

In recent years, the stability analysis of memristor-based neural networks (MNNs) has been greatly focused and has become an emerging area of research due to the fact that it has most successful applications such as image processing, optimization, pattern recognition and other areas [1–3]. Moreover, MNNs are made of hybrid complementary metal oxide semiconductors that have a very wide range of applications in bioinspired engineering [4–6]. MNNs are well suited to characterize the nonvolatile feature of the memory cell because of hysteresis effects. The studies of MNNs would benefit a number of important applications in neural learning circuits [5], associative memories [6], new classes of artificial neural systems [7,8]. The MNNs are a class of state-dependent nonlinear systems from a systems-theoretic point of view [9,10]. With the development and application of memristors, the studies of such state-dependent nonlinear system with its various generalizations have become an active area of research, to allow the memristors to be readily used in emerging technologies.

In real nervous networks, synaptic transmission is a noisy process brought on by random fluctuations from the release of neurotransmitters and further probabilistic causes. Therefore, noise cannot be avoided in real applications of artificial neural networks. Practically there are two main resources that degrade the performance of neural networks that is parameter uncertainties and stochastic perturbation [11,12]. In [13], pth moment exponential stochastic synchronization of coupled MNNs with mixed delays has been studied via delayed impulsive control. Synchronization control of stochastic MNNs with mixed delays has been presented in [14].

Bidirectional associative memory neural networks (BAMNNs) are composed of neurons ordered in two layers; x-layer and y-layer. The neurons in one layer are fully interconnected to the neurons in the other layer [15]. In practical applications, the BAMNNs have been successfully applied to automatic control, pattern recognition, associative memory, image processing, optimization and parallel computation. Thus, many researchers have studied stability properties of the BAMNNs and presented various sufficient conditions for the asymptotic stability results [16,17]. More recently, the functional differential inclusions and dynamic behaviors for memristor-based BAMNNs with time-varying delays were investigated in [18].

☆ The work was supported by National Board of Higher Mathematics (NBHM), New Delhi under research project no. 2/48/10/2011-R & D-II/865, National Natural Science Foundation of China under Grant nos. 61573096 and 61272530, the Specialized Research Fund for the Doctoral Program of Higher Education under Grant nos. 20110092110017 and 20130092110017, and the Natural Science Foundation of Jiangsu Province of China under Grant no. BK2012741.

* Corresponding address at: Department of Mathematics, Southeast University, Nanjing 210096, China.
E-mail addresses: syedgru@gmail.com (M. Syed Ali), saravanamaths30@gmail.com (R. Saravanakumar), jdcao@seu.edu.cn (J. Cao).

http://dx.doi.org/10.1016/j.neucom.2015.07.101
0925-2312/

P 133

Neurocomputing 155 (2015) 167–173

Contents lists available at ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

Delay-dependent stability criteria of uncertain Markovian jump neural networks with discrete interval and distributed time-varying delays ☆

M. Syed Ali [a,*], Sabri Arik [b], R. Saravanakumar [a]

[a] Department of Mathematics, Thiruvalluvar University, Vellore 632115, Tamil Nadu, India
[b] Department of Computer Engineering, Istanbul University, 34320 Avcilar, Istanbul, Turkey

ARTICLE INFO

Article history:
Received 29 September 2014
Received in revised form
25 January 2015
Accepted 26 January 2015
Communicated by Yang Tang
Available online 11 February 2015

Keywords:
Distributed time-varying delay
Interval time-varying delay
Linear matrix inequality (LMI)
Markovian jumping parameters
Neural networks

ABSTRACT

In this paper, a class of uncertain neural networks with discrete interval and distributed time-varyin delays and Markovian jumping parameters (MJPs) are carried out. The Markovian jumping parameters are modeled as a continuous-time, finite-state Markov chain. By using the Lyapunov–Krasovski functionals (LKFs) and linear matrix inequality technique, some new delay-dependent criteria is derivec to guarantee the mean-square asymptotic stability of the equilibrium point. Numerical simulations ar given to demonstrate the effectiveness of the proposed method. The results are also compared with th existing results to show the less conservativeness.

1. Introduction

It is well known that, many kinds of neural networks such as cellular neural networks, Hopfield neural networks, Cohen–Grossberg neural networks, recurrent neural networks (RNNs), complex dynamical networks (CDNs), bidirectional associative memory (BAM) neural networks, chaotic neural networks (CNNs) and static neural networks (SNNs) have been studied, since their extensive applications in different fields such as fault diagnosis, pattern recognition, signal processing and parallel computation [1–6]. Some of these applications require the equilibrium points of the designed network to be stable. Since axonal signal transmission time delays often occur in various neural networks, and may also cause undesirable dynamic network behaviors such as oscillation and instability. Thus it is important to study the stability of neural networks [7–9].

On the other hand Markovian jump neural networks (MJNNs) can be regarded as a special class of hybrid systems, which can model dynamic systems whose structures are subject to random abrupt parameter changes resulting from component or interconnection failures, sudden environment changes, changing subsystem interconnections, and so forth [10,11]. A neural network may have finite modes, which may jump from one to another at vario time. It is shown that such jumping can be determined by Markovian chain [12]. Much work on MJNNs has been reported the literature [13–16]. A great number of results on the stabilit and estimation problems related to such neural networks (NNs have appeared in the recent years [17]. Applications of this kind c neural networks can be found in modeling production systems economic systems, and other practical systems.

The phenomena of time-delays are very often encountered various physical systems, like communication systems, nucle reactors, aircraft stabilization, ship stabilization, models of lase manual control and systems with lossless transmission lines. I example see [18–21]. Stability is always required for the real-wor applications of neural networks, since their potential applicatio to solve some previously unsolvable problems and improve syste performance in many fields such as pattern recognition, fau diagnosis, signal processing and parallel computation. Some these applications require the equilibrium points of the designe network to be stable. Thus, stability analysis is one of th fundamental research issues in the study of neural networks. the past decade, lots of research efforts have been devoted to th stability analysis of neural networks with time delays. This because time delays are unavoidable in neural networks and, mor importantly, the existence of time delays often makes a neur network unstable.

In practice, interval time delays exist in biological and artific neural networks due to the finite switching speed of neurons a amplifiers. That is, the range of delay varies in an interval for whi

☆ The work was supported by National Board of Higher Mathematics (NBHM), New Delhi under research Project no. 2/48/10/2011-R&D-II/865.

* Corresponding author.
E-mail addresses: syedgru@gmail.com (M. Syed Ali), arik@istanbul.edu.tr (S. Arik), saravanamaths@gmail.com (R. Saravanakumar).

http://dx.doi.org/10.1016/j.neucom.2015.01.056
0925-2312/

P132

Neurocomputing 166 (2015) 83–95

Contents lists available at ScienceDirect

Neurocomputing

journal homepage: www.elsevier.com/locate/neucom

Less conservative delay-dependent H_∞ control of uncertain neural networks with discrete interval and distributed time-varying delays ☆

M. Syed Ali [a], R. Saravanakumar [a], Quanxin Zhu [b,*]

[a] Department of Mathematics, Thiruvalluvar University, Vellore 632115, Tamil Nadu, India
[b] School of Mathematical Sciences and Institute of Finance and Statistics, Nanjing Normal University, Nanjing 210023, China

ARTICLE INFO

Article history:
Received 12 October 2014
Received in revised form
9 April 2015
Accepted 11 April 2015
Communicated by S. Arik
Available online 21 April 2015

Keywords:
Distributed delay
Interval time-varying delay
Linear matrix inequality (LMI)
Lyapunov method
Neural network
H_∞ control

ABSTRACT

This paper deals with the robust H_∞ control problem for a class of uncertain neural networks with discrete interval and distributed time-varying delays. The main purpose of this paper is to estimate robust asymptotic stability of the given neural network with H_∞ performance analysis γ. By constructing novel Lyapunov–Krasovskii functionals with triple integral terms, several new less conservative delay-dependent stability conditions for H_∞ control are obtained in terms of linear matrix inequalities. Numerical examples are given to illustrate the effectiveness of the proposed theoretical results. The method given in this paper shows less conservative results when comparing with some existing methods.

1. Introduction

In recent years extensive research goes on delayed neural networks since their potential applications to solve some previously unsolvable problems and improve system performance in many fields such as pattern recognition, fault diagnosis, signal processing and parallel computation. Some of these applications require the equilibrium points of the designed network to be stable. Thus, the problems of time delay systems have undergone much stability analysis in recent decades [1–12].

Time delay is an interesting feature of signal transmission between neurons, and becomes one of the main sources for causing instability and poor performances of neural networks, see [2–4,12]. According to the way it occurs, time delay can be classified as two-types: discrete and distributed delays. Discrete time-delay is relatively easier to be identified in practice and hence the stability analysis for neural networks with discrete delays has been an attractive subject of research in the past few years. Neural network usually has a spatial nature due to the presence of various parallel pathways with a variety of axon sizes and lengths, so it is desirable to model them by introducing unbounded delays. Thus, there will be a distribution of conduction velocities along these pathways and a distribution of propagation delays. In these circumstances the signal propagation is not instantaneous and cannot be modelled with discrete delays and a more appropriate way is to incorporate continuously distributed delays in neural network models. For some systems, delay phenomena may not be simply considered as delays in the velocity terms and/or discrete delays in the states. Therefore, it is desirable to extend the system model to include distributed delays. In recent years there has been a growing research interest in study of neural networks with distributed delays [13]. In fact, both discrete and distributed delays should be taken into account when modelling a realistic networks [14–16]. Recently, a new type of time delays, that is, interval time-varying delays, has been frequently confronted from various practical and theoretical systems and has gathered much attention in the area of time-delay systems [17–20].

The control design for uncertain neural networks with discrete interval and distributed time-varying delays has been a hard problem of control theory. Stability is one of the most important problem in the synthesis of control systems. H_∞ performance is usually analyzed in control theory to synthesize controllers achieving stabilization with guaranteed performance. Therefore, the problem of delay-dependent stability analysis and H_∞ control for delayed systems has received substantial observation among control community for the last few years [19–21].

The work was jointly supported by the National Board of Higher Mathematics (NBHM), New Delhi under research project no. 2/48/10/2011-R&D-II/865, the National Natural Science Foundation of China (61374080), the Natural Science Foundation of Zhejiang Province (LY12F03010), the Natural Science Foundation of Ningbo (2012A610032), and a Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions.

* Corresponding author.
E-mail addresses: syedgrus@gmail.com (M. Syed Ali), saravanamaths30@gmail.com (R. Saravanakumar), zqx22@126.com (Q. Zhu).

http://dx.doi.org/10.1016/j.neucom.2015.04.023
0925-2312/

VICE-CHANCELLOR
THIRUVALLUVAR UNIVERSITY
SERKADU, VELLORE - 632 115.

P136

RESEARCH ARTICLE

Stability Criteria for Stochastic Takagi-Sugeno Fuzzy Cohen-Grossberg BAM Neural Networks with Mixed Time-Varying Delays

MUHAMMED SYED ALI,[1] PAGAVATHIGOUNDER BALASUBRAMANIAM,[2] FATHALLA A. RIHAN,[3,4] AND SHANMUGAM LAKSHMANAN[3]

[1]*Department of Mathematics, Thiruvalluvar University, Vellore 632115, Tamil Nadu, India;* [2]*Department of Mathematics, Gandhigram Rural University, Tamil Nadu, India;* [3]*Department of Mathematical Science, College of Science, UAE University, Al-Ain 15551, UAE; and* [4]*Department of Mathematics, Faculty of Science, Helwan University, Cairo 11795, Egypt*

Received 25 June 2014; revised 23 November 2014; accepted 10 December 2014

This article is concerned with the asymptotic stability analysis of Takagi–Sugeno stochastic fuzzy Cohen–Grossberg neural networks with discrete and distributed time-varying delays. Based on the Lyapunov functional and linear matrix inequality (LMI) technique, sufficient conditions are derived to ensure the global convergence of the equilibrium point. The proposed conditions can be checked easily by LMI Control Toolbox in Matlab. It has been shown that the results are less restrictive than previously known criteria. They are obtained under mild conditions, assuming neither differentiability nor strict monotonicity for activation function. Numerical examples are given to demonstrate the effectiveness of our results. © *2014 Wiley Periodicals, Inc. Complexity 21: 143–154, 2016*

Key Words: Cohen–Grossberg bidirectional associative memory neural network; global asymptotic stability; linear matrix inequality; Lyapunov functional; stochastic analysis; time-varying delays; T–S fuzzy model

1. INTRODUCTION

During the last decades, artificial neural networks have received considerable attention due to their applications in signal processing, image processing, pattern recognition, control, and optimization. In 1983, Cohen and Grossberg [1] proposed a class of neural networks, which are called now Cohen–Grossberg neural networks. This model has received increasing interest due to its promising potential for applications in classification, parallel computation, associative memory, especially in solving some optimization problems. Such applications rely on the qualitative properties of stability. Therefore, the qualitative analysis is prior condition to develop the application of these dynamical networks. Conversely, the time delay is inevitable in electronic implementation of neural networks due to their finite speed of switching and transmission of signals. Such time delay may cause influence

Correspondence to: *Syed Ali, E-mail: syedgru@gmail.com*

 Vol. 21 No. 5
DOI 10.1002/cplx.21642
Published online 30 December 2014 in Wiley Online Library (wileyonlinelibrary.com)

பயிலரங்கம்

அமர்வு I : "தமிழ்நாட்டில் பட்டுத்தொழில் தொடங்குவதற்கான வாய்ப்பும் வழிமுறைகளும்"
முனைவர் S. இராஜாகுமார்
விஞ்ஞானி-D மற்றும் தலைவர்
மண்டல பட்டு வளர்ப்பு ஆராய்ச்சி நிலையம்
மத்திய பட்டு வாரியம்
சேலம்.

அமர்வு II : "மல்பெரி சாகுபடி மற்றும் பட்டுப்புழு வளர்ப்பு தொழில்நுட்பம்"
முனைவர் ச. பாலசரஸ்வதி
விஞ்ஞானி-D
மண்டல பட்டு வளர்ப்பு ஆராய்ச்சி நிலையம்
மத்திய பட்டு வாரியம்
சேலம்.

அமர்வு III : "பட்டு வளர்ப்பில் அரசு நலத்திட்டங்கள்"
திரு. து. அலெக்ஸாண்டர்
உதவி இயக்குநர்
பட்டு வளர்ச்சித் துறை
தமிழ்நாடு அரசு
விழுப்புரம்.

அமர்வு IV : "பட்டு விவசாயிகளின் வெற்றிக்கதைகள் மற்றும் முன்னோடி விவசாயிகளின் அனுபவ பகிர்வு"
திரு. ஸ்ரீ. விஜயகுமார்
ஆய்வாளர் (ஓய்வு)
பட்டு விவசாயிகள் பயிற்சி மையம்
தமிழ்நாடு அரசு
வாணியம்பாடி.

தொடர்புக்கு:

மண்டல பட்டு வளர்ப்பு ஆராய்ச்சி நிலையம்
மத்திய பட்டு வாரியம்
இந்திய அரசு
சேலம்
அலைபேசி எண் :

செயலாக்க ஒருங்கிணைப்பாளர் மற்றும் செயலர்
முனைவர் க. சிங்காரவேலு
இணைப்பேராசிரியர், விலங்கியல் துறை
திருவள்ளுவர் பல்கலைக்கழகம்
வேலூர்-632 115.
அலைபேசி எண் : 9952395363

திருவள்ளுவர் பல்கலைக்கழகம் - விலங்கியல் துறை
மண்டல பட்டு வளர்ப்பு ஆராய்ச்சி நிலையம் - மத்திய பட்டு வாரியம்
தமிழ்நாடு அரசு பட்டு வளர்ச்சித் துறை
இணைந்து நடத்தும்
பட்டுத் தொழில் பற்றிய விழிப்புணர்வு நிகழ்ச்சி மற்றும்
தொழில்நுட்பப் பயிரலங்கம்

அறிவிப்பும் அழைப்பும்

நாள் : 27-08-2018, திங்கட்கிழமை
நேரம் : காலை 10.00 மணி

நிகழ்விடம்
திருவள்ளுவர் பல்கலைக்கழக அரங்கம்
சேர்க்காடு, வேலூர் - 632 115.

VICE-CHANCELLOR
THIRUVALLUVAR UNIVERSITY
SERKADU, VELLORE - 632 115.

Journal of Cluster Science
https://doi.org/10.1007/s10876-018-1332-3

ORIGINAL PAPER

Bismuth Oxyiodide Nanoflakes Showed Toxicity Against the Malaria Vector *Anopheles stephensi* and In Vivo Antiplasmodial Activity

Kadarkarai Murugan[1,2] · Jagannathan Madhavan[3] · Christina Mary Samidoss[1] · Chellasamy Panneerselvam[4] · Al Thabiani Aziz[4] · Arumugam Malathi[3] · Aruliah Rajasekar[5] · Amuthavalli Pandiyan[1] · Suresh Kumar[6] · Abdullah A. Alarfaj[7] · Akon Higuchi[8] · Giovanni Benelli[9,10]

Received: 16 December 2017

Abstract
Anopheles stephensi is a mosquito vector of malaria, which is still considered a relevant public health problem due to increasing outdoor transmission, growing resistance to insecticides used to target vectors, and antiplasmodial drugs as well. Thus, there is a vital need to explore novel sources of effective compounds. In this study, the hydrothermal method was used for the synthesis of bismuth oxyiodide (BiOI) nanoflakes. Furthermore, the toxicity of BiOI nanoflakes was evaluated for the first time on *A. stephensi,* as well as in vivo against the malaria parasite *Plasmodium berghei*. The synthesis of BiOI nanoflakes was confirmed by various characterization techniques, including X-ray diffraction, Fourier transform-infrared spectroscopy, field emission scanning electron microscopy and transmission electron microscopy (HR-TEM). LC_{50} of BiOI nanoflakes on *A. stephensi* were 2.263 ppm (larva I), 3.414 ppm (II), 4.956 ppm (III), 6.983 ppm (IV) and 8.605 ppm (pupae). In vivo antiplasmodial experiments conducted on *P. berghei* infecting albino mice showed 27.2% of chemo-suppression after 4 days of treatment with 300 mg/kg/day of BiOI, a lower performance if compared to chloroquine. Overall, our results suggested that hydrothermal synthesis of BiOI nanoflakes may be considered to develop newer and safer tools for malaria vector control.

Keywords Culicidae · Integrated vector management · Mosquito · Nanotechnology · *Plasmodium berghei*

Introduction

Despite a recent decline, the epidemiological burden of malaria persists in sub-Saharan Africa due to several factors, including increasing outdoor transmission as well as growing resistance to antiplasmodial drugs and insecticides used to target malaria mosquitoes [11, 48, 53, 61]. This is reflected by residual transmission to the vulnerable groups that accounted for 92% of global deaths reported from African region in 2016 [71]. Residual transmission, which is

✉ Kadarkarai Murugan
kmvvkg@gmail.com

✉ Giovanni Benelli
benelli.giovanni@gmail.com

1 Department of Zoology, Bharathiar University, Coimbatore 641 046, India

2 Thiruvalluvar University, Vellore 632 115, India

3 Solar Energy Lab, Department of Chemistry, Thiruvalluvar University, Vellore 632 115, India

4 Department of Biology, Faculty of Science, University of Tabuk, Tabuk 71491, Saudi Arabia

5 Department of Biotechnology, Thiruvalluvar University, Vellore 632 115, India

6 Department of Medical Microbiology and Parasitology, Universiti Putra Malaysia (UPM), Serdang, Selangor 43400, Malaysia

7 Department of Botany and Microbiology, College of Science, King Saud University, Riyadh 11451, Saudi Arabia

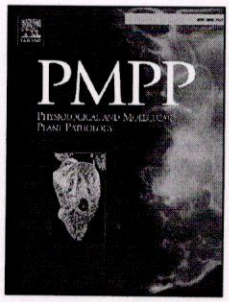
8 Department of Chemical and Materials Engineering, National Central University, Taoyuan 32001, Taiwan

9 Department of Agriculture, Food and Environment, University of Pisa, Via del Borghetto 80, 56124 Pisa, Italy

10 The BioRobotics Institute, Scuola Superiore Sant'Anna, Viale Rinaldo Piaggio 34, 56025 Pontedera, Pisa, Italy

Published online: 17 January 2018

Accepted Manuscript



Sargassum wightii-synthesized ZnO nanoparticles reduce the fitness and reproduction of the malaria vector *Anopheles stephensi* and cotton bollworm *Helicoverpa armigera*

Kadarkarai Murugan, Mathath Roni, Chellasamy Panneerselvam, Al Thabiani Aziz, Udaiyan Suresh, Rajapandian Rajaganesh, Rajasekar Aruliah, Jazem A. Mahyoub, Subrata Trivedi, Hasibur Rehman, Hatem Ahmed Naji Al-Aoh, Suresh Kumar, Akon Higuchi, Baskaralingam Vaseeharan, Hui Wei, Sengottayan Senthil-Nathan, Angelo Canale, Giovanni Benelli

PII: S0885-5765(17)30020-6

DOI: 10.1016/j.pmpp.2017.02.004

Reference: YPMPP 1239

To appear in: *Physiological and Molecular Plant Pathology*

Received Date: 17 January 2017

Accepted Date: 25 February 2017

Please cite this article as: Murugan K, Roni M, Panneerselvam C, Aziz AT, Suresh U, Rajaganesh R, Aruliah R, Mahyoub JA, Trivedi S, Rehman H, Naji Al-Aoh HA, Kumar S, Higuchi A, Vaseeharan B, Wei H, Senthil-Nathan S, Canale A, Benelli G, *Sargassum wightii*-synthesized ZnO nanoparticles reduce the fitness and reproduction of the malaria vector *Anopheles stephensi* and cotton bollworm *Helicoverpa armigera*, *Physiological and Molecular Plant Pathology* (2017), doi: 10.1016/j.pmpp.2017.02.004.

VICE-CHANCELLOR
THIRUVALLUVAR UNIVERSITY
SERKADU, VELLORE - 632 115.

J Clust Sci
DOI 10.1007/s10876-017-1228-7

ORIGINAL PAPER

Solution Combustion Synthesis of Hierarchically Structured V_2O_5 Nanoflakes: Efficacy Against *Plasmodium falciparum*, *Plasmodium berghei* and the Malaria Vector *Anopheles stephensi*

Kadarkarai Murugan[1,2] · Christina Mary Samidoss[1] · Jayaraman Theerthagiri[3] · Chellasamy Panneerselvam[4] · Jagannathan Madhavan[3] · Aruliah Rajasekar[5] · Angelo Canale[6] · Giovanni Benelli[6]

Received: 10 April 2017

Abstract The effective prevention and treatment of malaria still represent a major public health challenge. Here, the solution combustion method was used for the synthesis of hierarchically structured V_2O_5 nanoflakes. The toxicity of V_2O_5 nanoflakes was evaluated on the malaria vector *Anopheles stephensi* and on the malaria parasites *Plasmodium falciparum* and *P. berghei*, relying to in vitro and in vivo assays. V_2O_5 nanoflakes were examined by various techniques, including powder X-ray diffraction, field emission scanning electron microscopy (FESEM), energy dispersive X-ray spectroscopy (XRD), and high resolution transmission electron microscopy (HR-TEM). LC_{50} of V_2O_5 nanoflakes against *A. stephensi* larvae and pupae were 1.936 ppm (larva I), 3.606 ppm (II), 4.750 ppm (III), 6.636 ppm (IV), and 8.876 ppm (pupae). Furthermore, the antiplasmodial activity of V_2O_5 nanoflakes was evaluated against chloroquine-resistant (CQ-r) and CQ-sensitive (CQ-s) strains of *P. falciparum*. IC_{50} of V_2O_5 nanoflakes were 84.54 μg/ml (CQ-s) and 88.17 μg/ml (CQ-r). In vivo antiplasmodial experiments conducted on *P. berghei* infecting albino mice showed moderate activity of V_2O_5 nanoflakes, if compared to chloroquine. Overall, our results highlighted the promising potential of

✉ Giovanni Benelli
benelli.giovanni@gmail.com

[1] Department of Zoology, Bharathiar University, Coimbatore 641 046, India

[2] Thiruvalluvar University, Vellore 632 115, India

[3] Solar Energy Lab, Department of Chemistry, Thiruvalluvar University, Vellore 632 115, India

[4] Faculty of Science, Department of Biology, University of Tabuk, Tabuk 71491, Saudi Arabia

[5] Department of Biotechnology, Thiruvalluvar University, Vellore 632 115, India

[6] Department of Agriculture, Food and Environment, University of Pisa, Via del Borghetto 80, 56124 Pisa, Italy

Published online: 11 May 2017

Arab J Sci Eng (2015) 40:1825–1836
DOI 10.1007/s13369-015-1590-4

RESEARCH ARTICLE - BIOLOGICAL SCIENCES

Role of *Bacillus subtilis* and *Pseudomonas aeruginosa* on Corrosion Behaviour of Stainless Steel

Hafiz Zeshan Wadood · Aruliah Rajasekar · Yen-Peng Ting · Anjum Nasim Sabari

Received: 7 October 2014 / Accepted: 19 January 2015 / Published online: 4 February 2015

Abstract Corrosion behavior of SS304 in minimal salt medium with 1.5 % NaCl as a corrosive agent in presence of *Bacillus subtilis* strain S1X and *Pseudomonas aeruginosa* strain ZK has been investigated. Electrochemical techniques such as Tafel polarization and electrochemical impedance spectroscopy with surface analytical techniques like atomic force microscopy, scanning electron microscopy–energy dispersive spectrum analysis and Fourier transform infrared spectroscopy showed that both bacteria inhibit corrosion of SS304 due to the development of a protective biofilm on metal surface. The pH values of bacterial-inoculated systems decreased with increasing incubation time showing the production of some acidic metabolites by bacterial isolates.

Keywords Microbiologically influenced corrosion · Stainless steel 304 · Biofilm · Electrochemical impedance spectroscopy · Tafel polarization

1 Introduction

Corrosion of a material, particularly a metal, is an electrochemical process which shifts an electron from zero-valent metal to an environmental electron acceptor that results in the decline of metal surface [1–3]. Microorganisms are considered to play an important role in this process, and the phenomenon is termed as microbiologically influenced corrosion (MIC) or biocorrosion. MIC or biocorrosion is a long-lasting problem that affects a diverse range of industries including dentistry, pulp and paper, shipping, gas and petroleum industries, sugar industries [1,4–7]. Stainless steel 304 (SS 304) is an important alloy because of its mechanical properties and resistance to corrosion. SS304 is widely used in different industries such as in the manufacture of implantable medical devices, power generation plants, food production industry, cooling water systems in industries, nuclear power plants, oil drilling platforms, pulp and paper industries and has some marine applications [8–10]. Stainless steel exhibits resistance to corrosion due to the presence of nickel (Ni), manganese (Mn), chromium (Cr) and perhaps molybdenum (Mo), which are the main alloying metals in its metallurgical formulation. The resistance of stainless steel to corrosion is due to the passivation of its surface which results from the reaction of the alloying elements mentioned above, with oxygen to form a stable oxide film [11,12]. Despite that passivation, slow corrosion rate and a reduced amount of corrosion products on the surface of SS 304 render this metal vulnerable to biofouling [13,14]. This passivated surface of stainless steel provides an ideal location for the attachment of microbes and therefore is vulnerable to localized corrosion in the form of pits, under stress or in chloride-containing solutions/medium [15,16]. All types of stainless steel do not have the same behavior, but generally, stainless steel tends to be deteriorated in the presence of microbial biofilms. For the formation of a mature biofilm, bacterial gene expression is changed which concurrently changes metabolic activities of bacterial cells in their biofilm mode of development. This change in metabolic activities causes corrosion of stainless steel. The process of biocorrosion starts with the develop-

H. Z. Wadood (✉) · A. N. Sabari
Department of Microbiology and Molecular Genetics, University of the Punjab, Lahore 54590, Pakistan
e-mail: shan_wadood@yahoo.com; zeshan.wadood@gmail.com

A. Rajasekar
Department of Biotechnology, Thiruvalluvar University, Serkkadu, Vellore 632 115, India

A. Rajasekar · Y.-P. Ting
Department of Chemical and Biomolecular Engineering, National University of Singapore, Singapore 117576, Singapore

Hindawi Publishing Corporation
ISRN Corrosion
Volume 2014, Article ID 803219, 11 pages
http://dx.doi.org/10.1155/2014/803219

Research Article

Characterization of Corrosive Bacterial Consortia Isolated from Water in a Cooling Tower

Rajasekar Aruliah[1,2] and Yen-Peng Ting[1]

[1] *Department of Chemical & Biomolecular Engineering, National University of Singapore, Singapore 117576*
[2] *Environmental Molecular Microbiology Lab, Department of Biotechnology, Thiruvalluvar University, Serkkadu, Vellore 632 115, India*

Correspondence should be addressed to Rajasekar Aruliah; rajasekar.aruliah@gmail.com and Yen-Peng Ting; chetyp@nus.edu.sg

Received 16 October 2013; Accepted 13 November 2013; Published 4 March 2014

Academic Editors: M. Criado, W. Fürbeth, S. J. Lee, and Q. Qu

An analysis of a culturable corrosive bacterial community in water samples from a cooling tower was performed using traditional cultivation techniques and its identification based on 16S rRNA gene sequence. Seven aerobic bacterial species were identified: *Pseudomonas putida* ARTYP1, *Pseudomonas aeruginosa* ARTYP2, *Massilia timonae* ARTYP3, *Massilia albidiflava* ARTYP4, *Pseudomonas mosselii* ARTYP5, *Massilia* sp. ARTYP6, and *Pseudomonas* sp. ARTYP7. Although some of these species have commonly been observed and reported in biocorrosion studies, the genus *Massilia* is identified for the first time in water from a cooling tower. The biocorrosion behaviour of copper metal by the new species *Massilia timonae* ARTYP3 was selected for further investigation using a weight loss method, as well as electrochemical and surface analysis techniques (SEM, AFM, and FTIR). In contrast with an uninoculated system, thin bacterial biofilms and pitting corrosion were observed on the copper metal surface in the presence of *M. timonae*. The use of a biocide, bronopol, inhibited the formation of biofilm and pitting corrosion on the copper metal surface.

1. Introduction

In order to implement efficient monitoring and control strategies for the inhibition of biocorrosion, it is important to have knowledge of the microbial population responsible for this phenomenon, as well as interactions of different microorganisms with metallic surfaces [1–8]. In many industries, cooling towers are commonly used for heat transfer from recirculated water to the atmosphere, typically by means of trickling or spraying the water over a material with high surface area [9]. These towers generally have sizable water reservoirs, with temperature typically maintained between 25°C and 35°C. These conditions provide an ideal environment for microbial growth and propagation [10–13]. Both microbes and the substrates for microbial growth can either be present in the incoming water or be introduced from the atmosphere. Copper and copper alloys, which are used in many cooling tower systems, are known to be susceptible to microbiologically influenced corrosion (MIC) [10, 14]. Corrosion and its products have a negative impact on heat transfer and can cause a decrease in cooling efficiency of the cooling tower. Organisms responsible for MIC, including bacteria, microalgae and fungi readily attach themselves to the copper surface by excreting extracellular polymeric substances (EPS) to form a slime layer [15–18] and thereby initiate corrosion. A multilayer structure of microorganisms and their EPS have been reported to be entrapped between layers of different inorganic corrosion products on copper-based surfaces after exposure to natural seawater environment [19–24].

Interestingly, many traditional chemicals used water treatment, for example, antiscalants and zinc-based corrosion inhibitors, which are a source of nutrients that accelerate the growth of microbes in cooling towers [25]. Nonetheless, the control of corrosive bacterial fouling can be achieved through the application of effective biocides [26], or nitrate, or nitrite [27–30]. Environmental regulations and the development of water reservoirs in environmentally sensitive areas have spurred the development of easily degradable "green"

香港浸會大學
HONG KONG BAPTIST UNIVERSITY

研究院
GRADUATE SCHOOL

November 4, 2016

Mr PUNNIYAKOTTI Elumalai
Dept. of Biotechnology
Thiruvalluvar University
Serkadu, Vellore-632112
Tamil Nadu
India

Dear Mr PUNNIYAKOTTI,

Application for Admission as
A Special Full-time Research Student
[Programme Code: VS (PH.D.) RCPE]

I am pleased to inform you that you have been accepted as a special full time PhD research student in the **Sino-Forest Applied Research Centre for Pearl River Delta Environment**. You will be expected to arrive in Hong Kong on or before January 1, 2017 and report to the Graduate School for registration.

Upon your arrival, please discuss with your Co-supervisor (Prof. Wong Jonathan W C) on an agreed date to commence your studies. The duration of the study period is 6 months, i.e., from January 1, 2017 to June 30, 2017.

Please contact Mr. Lo Kam Fai of the Graduate School for further enquiries [tel: (852) 3411 2214; email: kamfailo@hkbu.edu.hk). We welcome you to our University and wish you all the best in this intellectual pursuit.

Yours sincerely,

Dr. Vicky Wong
Senior Assistant Academic Registrar

Enclosures

VW/CT/FL/pc

cc Prof. Wong Jonathan W C, Director and Co-supervisor, Sino-Forest Applied Research Centre for Pearl River Delta Environment
Student File (Student No. 16554752)

S:\RPGSADM\RPG Admission\Visiting Research Students\adm_vs_template.doc

Fax : (852) 3411 5133

香港浸會大學
HONG KONG BAPTIST UNIVERSITY

研究院
GRADUATE SCHOOL

November 4, 2016

Mr PUNNIYAKOTTI Elumalai
Dept. of Biotechnology
Thiruvalluvar University
Serkadu, Vellore-632112
Tamil Nadu
India

Dear Mr PUNNIYAKOTTI,

Application for Admission as
A Special Full-time Research Student
[Programme Code: VS (PH.D.) RCPE]

I am pleased to inform you that you have been accepted as a special full time PhD research student in the **Sino-Forest Applied Research Centre for Pearl River Delta Environment**. You will be expected to arrive in Hong Kong on or before **January 1, 2017** and report to the Graduate School for registration.

Upon your arrival, please discuss with your Co-supervisor (Prof. Wong Jonathan W C) on an agreed date to commence your studies. The duration of the study period is 6 months, i.e., from January 1, 2017 to June 30, 2017.

Please contact Mr. Lo Kam Fai of the Graduate School for further enquiries [tel: (852) 3411 2214; email: kamfailo@hkbu.edu.hk). We welcome you to our University and wish you all the best in this intellectual pursuit.

Yours sincerely,

Dr Vicky Wong
Senior Assistant Academic Registrar

Enclosures

VW/CT/FL/pc

cc Prof. Wong Jonathan W C, Director and Co-supervisor, Sino-Forest Applied Research Centre for Pearl River Delta Environment
Student File (Student No. 16554752)

傳真 Fax : (852) 3411 5133

CERTIFICATE of AWARD

Sino-Forest Applied Research Centre for Pearl River Delta Environment

This is to certify that

Dr. Rajasekar Aruliah

has participated in the ASIA-PACIFIC Conference on Biotechnology for Waste Conversion 2016

Prof Jonathan W C Wong
Director of ARCPE
7th December 2016

香港浸會大學
HONG KONG BAPTIST UNIVERSITY

ASIA-PACIFIC Conference on Biotechnology for Waste Conversion Hong Kong China 2016

3.3.3

VICE-CHANCELLOR
THIRUVALLUVAR UNIVERSITY
VELLORE - 632 115