Scientific Report

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Period of the fellowship	01/April/2013 to 30/June/2014

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

During my ERCIM period, I conducted the research and project in the Automation Research Group/Automatic Control Laboratory in the Interdisciplinary Centre for Security, Reliability and Trust (SnT) of the University of Luxembourg. My scientific coordinator within the SnT is Prof. Dr.-Ing. Holger Voos. Our research works were focused on the “Control and Synchronization of Complex Dynamical Networks (CDNs)”.

In general, the project has been finished successfully and in accordance with the initial planning. Firstly, we explored the group synchronization and control of a new class of adaptive complex networks with Brownian motion and time-varying delay. This work is useful because large-scale networks of high order are very complex and usually only partial information regarding the states of key nodes is available in network outputs. Therefore, estimation of the key states of a CDN becomes necessary. We investigated the group mean square synchronization (GMSS) for a new class of CDNs with stochastic perturbation and interval time-varying delays (TVD). The CDNs with TVD coupling and non-identical nodes are more unified and general. The weight configuration matrices are also including TVD and non-time-varying delays (NTVD), some restricting conditions have been exceed, such as being symmetric or irreducible or coupling diffusive conditions etc. By controlling these nodes in the *i*-th group or community which have links with the nodes in different groups or communities, some sufficient criteria are proposed to ensure the achievement of group synchronization (GS) in dynamic nodes of this class of CDNs with limited stochastic perturbation (LSP) and interval TVD.

Secondly, we successfully developed the uncertainty quantification (UQ) of group mean square synchronization (GMSS) for a new class of complex dynamical networks with interval time-varying delays and limited stochastic perturbations (LSP). Based on the control theory and the stochastic collocation (SC) method, we have studied the robustness of the control algorithm with respect to the value of the final time. To that end, we assumed a normal distribution for time and used the SC method with different values of nodes n collocation points T_i to quantify the sensitivity. These results show that the synchronization errors are close to zero with a high probability and are also valid for different numbers of nodes. In addition, some examples with different structure chaotic systems and their numerical simulation results have been presented to demonstrate the theoretical analysis. The conclusion of this study is that the accuracy of the synchronization and control algorithm is robust against variations of time.

Finally, we proposed the exponential synchronization (ES) problem for a new class of complex dynamical networks (CDN) with hybrid time-varying delay (TVD) and non-time-varying delay (NTVD) nodes by using coupling periodically intermittent pinning control (PIPC). Based on the Lyapunov stability theory, Kronecker product rules and PIPC method, sufficient conditions for ES and PIPC criteria of such CDNs have been derived. The obtained results are effective and less conservative than existing results. Furthermore, to verify the effectiveness of the proposed theoretical results, Barabási-Albert Networks (BAN) and Nearest-Neighbor Networks (NNN) consisting of coupled non-delayed and delay Lee oscillators are finally applied as examples.

The results of the work during the ERCIM period have been published in international journals as well as in proceedings of international leading conferences with high impact and peer review. I have published two SCI indexed International Journal papers, two submitted papers are already accepted for publication at international conferences (European Control Conference 2014 (*ECC2014)* and the *IEEE* Chinese Control Conference *CCC2014*), one paper is submitted to the IEEE Multi-Conference on Systems and Control (*IEEE-MSC 2014*), and one paper is under final preparation and will be submitted to a special issue of the *Journal of the Franklin Institute* in one month.

During the ERCIM period, I also attended seminars and have given talks about my research work at the SnT Automation Research Group. I have given two seminar presentations of my work after in SnT, one was at the beginning of the project in April 2013 and another one was in this April 2014. In addition I attended the ERCIM seminar held in Athens, Greece on Oct. 30-Nov. 02, 2013.

In addition, two REP programs have been conducted in The Netherlands and Italy. One was a one-week visit of the cluster of Prof. Kees Oosterlee at the Center for Mathematics and Computer Science (CWI), The Netherlands, in collaboration with Dr. Jeroen Witteveen, between November 18 and November 22, 2013. The other one was a one-week visit of the group of Prof. Francesco Carravetta at the Istituto di Analisi dei Sistemi ed Informatica "Antonio Ruberti" (IASI), Italy, in collaboration with Prof. Francesco Carravetta between January 19 and January 25, 2014. During these visits, I could establish closer links to some of the researchers in the respective institutes who have similar academic interests. Furthermore, I used these opportunities to present the results of our work on pinning control and synchronization of complex dynamical networks (CDN) in the visited institutes.

One very important result of the work was also the successful submission of a proposal for a two-year PostDoc project to the Fond National de Recherche (FNR) in Luxembourg, which will start directly after the ERCIM period in July 2014. In this national research project, we will use the obtained results in order to investigate the distributed and coordinated networked control of wind farms. The goal is to control an overall wind farm using distributed but interacting local controllers in order to achieve a maximum power generation in spite of aerodynamic disturbances between the single wind turbines, which is a very important research with high practical relevance.

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

[1]. L. Pan, Z. Guan and L. Zhou, ``Chaos Multiscale-synchronization between Two Different Fractional-order Hyper-chaotic Systems Based on Feedback Control," *International Journal of Bifurcation and Chaos*, Vol. 23, No. 8, 2013, pp. 1350146.

Abstract: In this paper, the chaos multiscale-synchronization between two different Fractional-order Hyperchaotic System (FOHCS)s have been investigated. The Lü-like and its FOHCS are also studied. The Lü-like FOHCS is controlled to be multiscale-synchronization with Liu FOHCS and new Lorenz FOHCS, respectively. The analytical conditions for the multiscale-synchronization of these pairs of different FOHCSs are derived by utilizing Laplace transform. Furthermore, multiscale-synchronization between two different FOHCSs is achieved by utilizing the different linear and nonlinear feedback control method in a short period and both remain in chaotic states. Numerical simulations are used to verify the theoretical analysis using different values of the fractional-order parameter and the different linear and nonlinear control functions.

[2]. L. Pan, L. Zhou and D. Li, ``Synchronization of Three-Scroll Unified Chaotic System (TSUCS) and its hyper-chaotic system using active pinning control," *Nonlinear Dynamics*, vol. 73, no. 3, 2013, pp. 2059-2071.

Abstract: This paper studies the synchronization and anti-synchronization problem of the Three-Scroll Unified Chaotic System (TSUCS), which has nonlinear terms in each subsystem. By virtue of active control, a novel active pinning control strategy is presented, which only needs one or two states of the TSUCS. Under the proposed controller, the synchronization of two TSUCS with parametric uncertainty is achieved and therefore the robust stability of TSUCS synchronization is ensured. Some stability theories about synchronization and anti-synchronization have been given and proved the use of this class of a novel TSUCS and its hyper-unified chaotic system with the active pinning control strategy. Numerical simulations are given to verify the theoretical analysis, which clearly shows that the control strategy can really make the chaotic systems achieve synchronization and anti-synchronization in a quite short time.

[3]. L. Pan, H. Voos, I. N'Doye and M. Darouach, ``Group Synchronization and Control of a New Class of Adaptive Complex Network with Brownian Motion and Time-varying Delay," *The 13th European Control Conference (IEEE ECC 2014),* June 24-27, 2014, Strasbourg, France. (Accepted, will publish in 2014).

Abstract: In this paper, the Group Mean Square Synchronization (GMSS) of a new class of adaptive Complex Dynamical Network (CDN) with Limited Stochastic Perturbation (LSP) and interval Time-Varying Delays (TVD) is investigated. The zero-mean real scalar Brownian Motion (BM) with LSP is also discussed. In this CDN, the weight configuration matrices are considered in two cases: TVD and Non-Time-Varying Delay (NTVD). The outer-coupling matrices are also assumed to be two cases: symmetric and dissymmetric. Based on the control theory and stochastic analysis such as: adaptive control method, Itô formula, Lyapunov Stability Theory (LST) and Kronecker product rules, the controllers and adaptive schemes are constructed which let all nodes reach the GMSS asymptotically in the CDN. Finally, some examples of several complex chaotic systems are presented to demonstrate the proposed theoretical analysis.

[4]. L. Pan, H. Voos, I. N'Doye and M. Darouach, ``Uncertainty Quantification of Group Synchronization and Control of a New Class of Adaptive Complex Dynamical Network with Brownian Motion and Time-varying Delay," *The 33rd Chinese Control Conference (IEEE CCC 2014),* July 28-30, 2014, Nanjing, China. (Accepted, will publish in 2014).

Abstract: This paper investigates the Uncertainty Quantification (UQ) of Group Mean Square Synchronization (GMSS) for a new class of Complex Dynamical Network (CDN) with interval Time-varying Delays (TVD) and Limited Stochastic Perturbation (LSP). Based on the control theory and Stochastic Collocation (SC) method, we have studied the robustness of the control algorithm with respect to the value of the final time. To that end, we assumed a normal distribution for time and used the SC method with different values of nodes n collocation points T_i to quantify the sensitivity. These results show that the

synchronization errors are close to zero with a high probability and confirm for different number of nodes. Finally, some examples with different structure chaotic systems and their numerical simulation results are presented to demonstrate the theoretical analysis. Therefore, the conclusion of this study is that the accuracy of the synchronization and control algorithm is robust to variations of time.

[5]. L. Pan, H. Voos, I. N'Doye and M. Darouach, ``Exponential Synchronization for a New Class of Complex Dynamical Network with Periodically Intermittent Pinning Control and Hybrid Time-varying Delay," *The 2014 IEEE Multi-Conference on Systems and Control (IEEE MSC 2014)*, 8-10 October, 2014, Antibes/Nice, France. (Submitted, under review).

Abstract: In this paper, the Exponential Synchronization (ES) problem for a new class of Complex Dynamical Networks (CDN) with hybrid Time-Varying Delay (TVD) and Non-Time-Varying Delay (NTVD) nodes is investigated by using coupling Periodically Intermittent Pinning Control (PIPC). Based on the Lyapunov Stability Theory (LST), Kronecker product rules and PIPC method, sufficient conditions for ES and PIPC criteria of such CDN are derived. The obtained results are effective and less conservative. Furthermore, to verify the effectiveness of the proposed theoretical results, Barab\'{a}si-Albert Network (BAN) and Nearest-Neighbor Network (NNN) consisting of coupled non-delayed and delay Lee oscillators are finally given as the examples.

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

[1]. ERCIM Seminar, Athens, Greece on Oct. 30-Nov. 02, 2013.

[2]. *The 13th European Control Conference (IEEE ECC 2014)*, June 24-27, 2014, Strasbourg, France.

IV – RESEARCH EXCHANGE PROGRAMME (REP)

[1]. My first exchange comprised a one-week visit to the cluster of Prof. Kees Oosterlee at the Center for Mathematics and Computer Science (CWI), The Netherlands, in collaboration with Dr. Jeroen Witteveen between November 18 and November 22, 2013.

I have given a presentation during my visit and did some cooperation with Prof. Kees Oosterlee and his colleagues on uncertainty quantification of synchronization and control of a complex network. We have studied the robustness of the control algorithm with respect to the value of the final time T. To that end, we assumed a normal distribution for T and we used the stochastic collocation method with n=3 and n=4 collocation points T_i to quantify the sensitivity in terms of the cumulative distribution function (CDF). The results show the synchronization error e_1 for the different collocation points T_i for n=3 and n=4, respectively, for all 21 nodes in the system. In the following, we focus on node number 1 at the final time t=T. The result also shows the dependence of the synchronization error e_1 of node 1 at t=T on the value of T by interpolation of the values obtained at the collocation points T_i. The Figures in our paper shows the resulting distribution of $e_1(1, T)$. This result shows that the error $e_1(1, T)$ is close to zero with a high probability. This result is confirmed for both n = 3 and n = 4. Therefore, the conclusion of this study is that the accuracy of the synchronization and control algorithm is robust against variations of T.

[2]. My second visit also comprised a one-week stay in the group of Prof. Francesco Carravetta at the Istituto di Analisi dei Sistemi ed Informatica\Antonio Ruberti" (IASI), Italy, in collaboration with Prof. Francesco Carravetta between January 19 and January 25, 2014.

We have investigated the linear feedback controlling of a novel chaotic system. The chaotic system is a new attractor which is similar to the Lorenz chaotic attractor, but it is not topological equivalent with the Lorenz chaotic system. This report proposes a novel approach for controlling this new attractor by linear feedback functions. The results obtained in this report show that the trajectories of a new chaotic attractor can be controlled to any periodic target orbits or points. Furthermore, some numerical simulations show that the developed controller design method is effective and feasible. Therefore, the linear feedback controlling of new chaotic system may have good application prospects. Finally, some examples with these chaotic systems and their numerical simulation results are presented to demonstrate the theoretical analysis.