行政院國家科學委員會專題研究計畫 成果報告

一個架構在有效基本虹吸計算的簡單僵局防止策略
研究成果報告(精簡版)

計 畫 類 別 ：個別型
計 畫 編 號 ：NSC 96-2221-E-004-007-
執 行 期 間 ：96 年 08 月 01 日至 97 年 10 月 31 日
執 行 單 位 ：國立政治大學資訊管理學系

計 畫 主 持 人 ：趙玉

計畫參與人員： 博士班研究生-兼任助理人員：楊筱芳

報 告 附 件 ：出席國際會議研究心得報告及發表論文

處 理 方 式 ：本計畫可公開查詢

中 華 民 國 97 年 12 月 19 日

行政院國家科學委員會補助專題研究計畫成果報告

一個架構在有效基本虹吸計算的簡單僵局防止策略

計畫類別：**x** 個別型計畫　　□整合型計畫

計畫編號：**NSC**　2221－　E　－　004　－　007

執行期間：**96** 年 **08** 月 **01** 日起至民國 **97** 年 **07** 月 **31** 日

計畫主持人：趙玉

共同主持人：

計畫參與人員：

執行單位：政治大學資管系

中　華　民　國　**97**　年　**9**　月　**30**　日

行政院國家科學委員會專題研究計畫成果報告

一個架構在有效基本虹吸計算的簡單僵局防止策略

A Simple Deadlock Prevention Policy Based on Efficient Computation of Elementary Siphons

計畫編號：NSC 2221－　E　－　004　－　007
執 行 期 限：96 年 08 月 01 日起至民國 99 年 07 月 31 日
主　持　人：趙玉 政治大學資管系

一、中文摘要

基本虹吸的計算對僵局控制是必要昂貴的，這是因爲需要完全列舉Petri網內虹吸和SMS(嚴格最小虹吸管)的數量 迅速而成指數隨著網的大小增長。我們透過提供一個反例，發現周et al的一種多項式技術找到基本虹吸的宣稱是錯誤的，並且能根據強連結的資源子網(附屬SCRC) ，爲一S3PR子類別計算基本虹吸管而不需知SMS的數量。　我們提議把它擴充到任意的S3PR 和S3PCR(用同步資源的簡單的順序過程的系統) , S3PNR(有非釋放資源的簡單的順序過程的系統) , S3PWR(有加權的資源的簡單的順序過程的系統) , S3PGR2(簡單的順序過程的系統用 一般的資源要求) 或者S4PR(一種一般化的Petri網的種類) ,並且(協調選擇的系統與一般的資源一起處理)的S2CPGR . 我們接著將研究基本虹吸管尋找的最佳化.被提議的技術將能以多項式時間和空間計算基本虹吸管； 不過使用周等的傳統的僵局預防，需要列舉呈指數成長的依賴虹吸管。我們因此提出一個簡單的僵局預防政策而無需列舉依賴虹吸管。

關鍵詞：Petri網, 虹吸管, 僵局

Abstract

Computation of elementary siphons is essential for deadlock control and expensive since complete siphon enumeration of the Petri net is needed and the number of *SMS* (*Strict Minimal Siphons*) grows quickly and exponentially with the size of the net. We discover that the claim of a polynomial technique to find elementary siphons by Zhou et al is incorrect by providing a counter example and were able to compute elementary siphons from strongly connected resource subnets (sub-SCRC) without the knowledge of SMS for a restrictive subclass of S^3PR. We propose to extend it to arbitrary S^3PR and S^3PCR (systems of simple sequential processes with concurrent resources), S^3PNR (systems of simple sequential processes with nonreleasing resources), S^3PWR (systems of simple sequential processes with weighted resources), S^3PGR^2 (systems of simple sequential processes with general resources requirement) or S^4PR (a class of generalized Petri nets), and S^2CPGR (*System* of *Synchronized Choice Processes with General Resources*). We will then investigate the issue of optimization of searching elementary siphons. The proposed technique will compute elementary siphons in polynomial time and space; however, it requires enumeration of dependent siphons which could be exponential using traditional deadlock prevention approach by Zhou et al. We hence propose a simple deadlock prevention policy without enumeration of dependent siphons.

Keywords: **Flexible manufacturing systems, Deadlock prevention, Petri nets, Siphons, S3PR.**

二、緣由與目的

Effective handling of deadlocks in various FMSs has turned out to be a major concern in the operation of these systems. Deadlock in a PN occurs when a set of places (called siphon S) become empty of tokens. To prevent emptiable siphons, we often add a control place V_S and some control arcs. By controlling the initial number of tokens (denoted by $M_0(V_S)$) in V_S, we can limit the maximal of tokens leaking from S. We say that S is invariant-controlled. The control arcs are chosen to disturb the original uncontrolled model as little as possible so as to reach as many states as possible. However, this policy may generate new emptiable siphons and hence require adding too many control places and arcs to the original Petri net model.

Ezpeleta *et al.* proposed a class of PN called systems of simple sequential processes with resources (S^3PR) [1]. They add a control place V_S —and associated arcs—for each emptiable siphon S (hence also called *all-siphon* approach) to make S invariant-controlled without generating new emptiable siphons. The initial marking of V_S; i.e., $M_0(V_S)$ is assigned so that S remains marked under all reachable markings. To prevent new SMS from being generated, Ezpeleta *et al.* moved all output arcs of each V_S to the output of the entry (called *idle place*) of input raw materials to limit their rate into the system —called *all-sided* approach. This may overly constrain the system so that many reachable states are no longer attainable.

The same problem occurs for the *elementary-siphon* approach proposed by Li *et al.* [2-3] which simplifies the control. S can be divided into two groups: elementary and dependent. They add a control place for each elementary siphon S_e, while controlling all dependent S too so that there is no need to add a control place for S. This leads to much fewer control places so that the method is suitable for large-scale Petri nets. However, all control arcs remain to be Type-2 and suffer the same problem with fewer reachable states compared with the optimal one in [4-5].

We discover that the claim of a polynomial technique to find elementary siphons by Zhou et al is incorrect by providing a counter example and were able to compute elementary siphons from strongly connected resource subnets (sub-SCRC) without the knowledge of SMS for a restrictive subclass of S^3PR. We propose to extend it to arbitrary S^3PR and S^3PCR (systems of simple sequential processes with concurrent resources), S^3PNR (systems of simple sequential processes with nonreleasing resources), S^3PWR (systems of simple sequential processes with weighted resources), S^3PGR^2 (systems of simple sequential processes with general resources requirement) or S^4PR (a class of generalized Petri nets), and S^2CPGR (*System* of *Synchronized Choice Processes with General Resources*). We then investigate the issue of optimization of searching elementary siphons. The proposed technique will compute elementary siphons in polynomial time and space; however, it requires enumeration of dependent siphons which could be exponential using traditional deadlock prevention approach by Zhou et al. We hence propose a simple deadlock prevention policy without enumeration of dependent siphons.

三、Results

We were able to compute elementary siphons from elementary resource circuits without the knowledge of SMS for a restrictive subclass of S^3PR (called BS^3PR) where $c_{b1} \cap c_{b2}$ is at most $\{r\}$, i.e., the intersection between any two elementary resource circuits is at most a

single resource place. We extended BS^{3}PR so that the elementary resource circuits (called basic circuits) do not connect in a circular fashion in any BS^{3}PR. Each elementary siphon remains to correspond to a basic circuit. However, $c_{b1} \cap c_{b2}$ may be a resource directed path — more than a single resource place. Basic circuits cannot span more than two working processes (WP) and hence there are only two kinds of basic circuits: one that extends between adjacent WPs and the other occurs within a single WP. Both can be located in time linear with respect to the number of resource places. We have proposed algorithms to compute both. We study non-BS^{3}PR where a set of basic circuits may connect in a circular fashion to create new basic circuits. We discover that the characteristic T-vector η of any connected component (CC) of a resource subnet is a linear combination of those of the segments in the CC. If there is only one new basic circuit, then the corresponding siphon must be a dependent one. In case of more than one new basic circuit, a linear sum of the characteristic T-vectors η of these basic circuits must be a linear sum of those of old basic circuits. This implies that one new siphon may be dependent or redundant.

We further extend the above approach to RAS more complicated than S^{3}PR nets. They are more complicated by allowing an operation place to use more than one resource and when entering the next operation place, it may not release the resource. Some resource (called similar) places have the same sets of input and output transitions; i.e., they have the same holder places *H(r)*. Again, we may synthesize elementary siphons from strongly connected subnets. How they may contain operation places; Further they may contain TT-handles and hence are not state machines. We may reduce them to resource subnets by eliminating all operation places. Further we may remove TT-handles.

Siphons are similar if their places are either identical or similar. Similar siphons have the same characteristic T-vectors. Hence only one of them is elementary, while the rest are dependent. This implies that we may keep only one but delete the rest among a set of similar places. We should keep the similar place with the minimal initial marking since the maximum amount of each type of resource that can be used in a job stage depends on the similar place with the minimal marking. The above deletion reduces the size of the net and simplifies the computations of elementary siphons. Further, when the holder place of one resource place r_1 is a subset of another r_2, i.e., $H(r_1) \supseteq H(r_2)$, and initially the amount of resources in r_2 is no less than that in r_1, i.e., $M_0(r_1) \leq M_0(r_2)$, then if S_1 is invariant-controlled, then so is S_2, where S_1 (S_2) is an SMS built from a set of resource places R_1 plus r_1 (r_2). Thus, S_2 is dependent and we may delete r_2 and reduces the size of the net. Note that η_2 may not be a linear combination of those of elementary siphons and S_2 represents a new kind of dependent siphons.

Li&Zhou indicated that it is not limited to S^{3}PR and may be extended to arbitrary nets. We [7] demonstrate a counter example where we cannot synthesize a dependent siphon from a compound circuit as we have done earlier for an S^{3}PR. We show that the dependent condition may be relaxed so that an elementary siphon, while requiring a monitor previously, may be controlled after some elementary siphons get controlled. We showed that a compound siphon is a dependent one using the revised definition and is controlled if the Marking Linear Inequality (MLI) in Theorem 1 of [5] is

satisfied.

Thus, for S^2CPGR, we can follow the algorithm for arbitrary S^3PR to synthesize elementary siphons.

The results reported in the literature show that the control of weakly dependent siphons (WDS) is quite conservative. Li *et al.* present two open problems. First, for what kinds of Petri nets, we can definitely find a set of elementary siphons such that no WDS can be derived? Second, could we develop an algorithm to find a set of elementary siphons that can minimize the number of WDS in a net? We [8] try to answer the first problem for an S^3PR (systems of simple sequential processes with resources) by investigating its structural conditions under which there are no WDS in it. We address such an issue by using our incremental approach for the synthesis of subnets (to compute an SMS) of a strongly connected resource component. At each step, we add a PP-handle H_i with at least one interior resource place. We derive the structural condition for no WDS and show that the maximal class of S^3PR is a $2c^+$-system.

An optimal set of elementary siphons should have the minimal number of elementary siphons and be maximally permissive for its control model. (Minimal number of elementary siphons allows to minimize the number of monitors and control arcs required. To this objective, we should select as many basic circuits as possible to synthesize elementary siphons. In [9], we report that after all elementary and compound or dependent siphons have been controlled; the FMS are live and maximally permissive. The rest monitors with weighted control arcs are redundant and can be removed.

In [10], we propose an intermediate, called one-sided, approach, which does not generate new SMS, based on our siphon-synthesis theory, by appropriately choosing the locations of Type-1 arcs and it can reach more states than the all-sided approach. The same results can be extended to the elementary-siphon approach by Li *et al.* except no need to fine tuning the locations of Type-1 arcs. Comparison with other approaches has been made.

四、參考文獻

1 J. Ezpeleta, J. M. Colom, and J. Martinez, "A Petri net based deadlock prevention policy for flexible manufacturing systems," *IEEE Trans. Robot. Automat.*, vol. 11, pp. 173–184, Apr. 1995.

2 Z. Li and M. Zhou, "Elementary siphons of Petri nets and their application to deadlock prevention in flexible manufacturing systems," *IEEE Trans. Syst.*, *Man*, *Cybern. A.*, vol. 34, no. 1, pp. 38-51, Jan. 2004.

3 Z. Li and M. Zhou, "Clarifications on the definitions of elementary siphons in Petri nets," *IEEE Trans. Syst., Man, Cybern., A.*, vol. 36, pp.1227- 1229, Nov. 2006.

4 Uzam M and Zhou, MengChu, "An improved iterative synthesis approach for liveness enforcing supervisors of flexible manufacturing systems," *Int J Prod Res* 44(10), pp.1987–2030, 2006.

5 Z. W. Li, M. C. Zhou, and M. D. Jeng, "A Maximally Permissive Deadlock Prevention Policy for FMS based on Petri Net Siphon Control and the Theory of Regions," *IEEE Transactions on Automation Science and Engineering*, vol.5, no.1, pp.182-188, Jan 2008.

6 Chao, D. Y.: 'Incremental approach to computation of elementary siphons for arbitrary S^3PR', *Control Theory & Applications, IET* 2(2), pp.168-179, 2008, doi: 10.1049/iet-cta:20070130.

7 Chao, D. Y., "Revised Dependent Siphons,"

to appear in Int J Adv Manuf Technol ., 2008, doi: 10.1007/s00170-008-1684-1.

8 D. Y. Chao, ”Conditions of S^3PR With No Weakly Dependent Siphons,” 1st revision, *Control Theory & Applications, IET*, 2008.

9 D. Y. Chao, ”Elimination of Weighted Arcs of A Deadlock Prevention Policy for Flexible Manufacturing Systems,” submitted to *Control Theory & Applications, IET*, 2008.

10 D. Y. Chao,”A Simple Modification of Deadlock Prevention Policy of S3PR Based on Elementary Siphons,” to appear in Trans. Mea. & Instru., 2008.

國立政治大學補助學術活動執行成果報告書

填表日期：　　年　　月　　日

<table>
<tr><td>活動類別</td><td colspan="5">□研究團隊　□學術研討會　x 出席國際會議發表論文
□讀書會　□鼓勵教師及研究人員申請國科會專題研究計畫
□其他_____</td></tr>
<tr><td>申請人姓名</td><td>趙玉</td><td>服務單位</td><td>資訊管理學系</td><td>職稱</td><td>x 教師/研究人員
□博士生　□碩士生</td></tr>
<tr><td>電話</td><td>81247</td><td>e-mail</td><td colspan="3">yaw@nccu.edu.tw</td></tr>
<tr><td colspan="2">實際活動起迄日期</td><td colspan="2">June 23-27</td><td>活動地點</td><td>陝西西安</td></tr>
<tr><td>活動名稱</td><td colspan="5">（中文）
（英文）Workshop on Petri Nets and Agile Manufacturing a satellite event of the Petri Nets 2008</td></tr>
<tr><td colspan="6">成 果 摘 要</td></tr>
</table>

一、內容摘要

1. 參與人數　８０＋
2. 主協辦單位：Petri Nets Steering Committee
3. 論文題目、各計畫名稱、讀書會名稱或研討會議程（中、英文）

論文題目：Daniel Yuh Chao, A Simple Modification of Deadlock Prevention Policy of S^3PR Based on Elementary Siphons

研討會議程：**Workshop on Petri Nets and Agile Manufacturing**

Tutorial: Deadlock Control Methods and Applications **:** MengChu Zhou, Maria Pia Fanti**,** ZhiWu Li**,** and NaiQi Wu

Contents

I. Synthesis of process-oriented Petri net models
I. Synthesis of resource-oriented Petri net models
I. Elementary siphon-based deadlock control methods
V. Benchmark studies and comparisons
V. Application to flexible manufacturing systems
I. Deadlock control methods using Resource-oriented Petri nets
I. Application to flexible assembly systems
I. Application to automatic guided vehicle systems
X. Application to semiconductor manufacturing systems
X. Synthesis of colored Petri net models
I. Application to automatic warehouses

June 23:

09.00-10.30 Parts I-II (Prof Mengchu Zhou)

10.30-11.00 Break

11.00-12.30 Part III-V (Prof ZhiWu Li)

12.30-14.00 Lunch

14.00-15.30 PartVI-IX 3 (Prof Naiqi Wu and Prof. Mengchu Zhou)

15.30-16.00 Break

16.00-17.30 Part X-XI (Prof Maria Fianti)

June 24, 2008 Morning

9:00-9:40 **Keynote Speech I.**

Session Chair: Prof. MengChu Zhou, New Jersey Institute of Technology, USA

Speaker: Prof. F.L. Lewis, University of Texas at Arlington, USA

P. Ballal and **F.L. Lewis**, Matrix Formulation for Dempster-Shafer Evidence Computations: Application in Free-Choice Petri Nets for Intelligent Diagnostics

9:45-12:15 **Technical Session: Petri Nets and Manufacturing Systems**

Session Chair: Prof. Zhiwu Li, Xidian University, China

Session Co-Chair: Prof. Yi-Sheng Huang, National Defense University

9:45-10:10 Wu and Zhou, Intelligent Token Petri Nets for Modeling and Control of Reconfigurable Automated Manufacturing Systems with Dynamical Changes

10:10-10:35 Daniel Yuh Chao, A Simple Modification of Deadlock Prevention Policy of S^3PR Based on Elementary Siphons

10:35-11:00 He and Wu, Deadlock-free Assignment of Wafer Processing in Photolithography Equipment -by Using a CPN Model

11:00-11:25 Li, Qin, and Zhu, Identification of Controllable Transitions for an Optimal Liveness-enforcing Supervisor for a Class of Petri Nets

11:25-11:50 Barkaoui and Ayed, Parameterized Verification of Workflow Soundness

11:50-12:15 Wang, Li and Jia, On Computation of the Strict Minimal Siphons in a Subclass of Petri Nets Using Resource Digraphs

12:15-13:30 **Lunch**

June 24, 2008 Afternoon

1:30-14:10 **Keynote Speech II**.

Session Chair: Prof. MengChu Zhou, New Jersey Institute of Technology, USA

Speaker: Prof. M. P. Fanti, Politecnico di Bari, Italy

Dotoli, Fanti, and Mangini, Fault Monitoring of Discrete Event Systems by First Order Hybrid Petri Nets

14:15-16:45 **Technical Session: Petri Nets and Discrete Event Systems**

Session Chair: Prof. Zhiwu Li, Xidian University

Session Co-Chair: Prof. K. Barkaoui, CEDRIC - Consevatoire National des Arts et Metiers, France

14:15-14:40 Huang, Modeling and Analysis of Air Traffic Control Systems Using Hierarchical Timed Colored Petri Nets

14:40-15:05 Yuan, Zhao, Huang, and Zhang, A Study on Fairness of Place/Transition Systems -To Make Fairness Fairer

15:05-15:30 Zeng, Wu, Mao, Su and Chu, A Hybrid Approach to Design Deadlock-Free Petri Net Controller for Discrete Event Systems

15:30-15:55 Sun, Jiang, and Zhou, Interactive Web Service Composition based on Petri nets

15:55-16:20 Wang, Zhou and Ding, Software architectural modeling and verification: a Petri net and temporal logic approach

16:20-16:45 Dang, Lu, Zhao, and Jafari, Wholesale Power Trading through Concurrent Multiple-Issue Negotiation

二、重要結論或研究成果（中英文論文、期刊、光碟、出版或獲校外研究經費補助）

All but one gave their talks on schedule. I listened to all of them and learned much of it. It helps me to get new ideas to prepare for next year's

NSC proposal. Also I realize that 西安电子科技大学 is a big university with students over 40000. They have their own hotel ——— the first time that I have seen as well as car drivers. I am impressed by the quality of their phd students. Their service to the conference speakers is the best in the world. No universities in Taiwan can compete with it. Their academic programs are astounding and impressive. The whole Xian city contains so many new high-rises that looks much better than Taipei——— The most beautiful city I have ever seen.

Among all talks, some fall into my specialty, some do not. For the first category, I am able to grasp their ideas. Unfortunately, some has already done what I thought would be a new idea to explore. For instance, Wang, Li and Jia, in their paper titled "On Computation of the Strict Minimal Siphons in a Subclass of Petri Nets Using Resource Digraphs," has dealt with the problem with SMS search for a Subclass of Petri Nets called S3PMR, which is the problem that I proposed in the NSC proposal this year. Fortunately, I could exploit their results and extend it to find elementary siphons.

The talk "Wholesale Power Trading through Concurrent Multiple-Issue Negotiation" by Mrs. Lu is not my current research. It is PN (Petri nets) application to wholesale power trading by allowing concurrent negotiation. By talking to Mrs. Lu, I know of other applications. This is very interesting since Petri net is no longer academic in nature, but it can also be practical.

Also the talk "Modeling and Analysis of Air Traffic Control Systems Using Hierarchical Timed Colored Petri Nets" by Prof. Huang from Defense University of ROC applies color Petri nets to Air Traffic Control Systems is not my current research. This helps me to do research in PN areas other my current one of FMS control.

The talk "A Hybrid Approach to Design Deadlock-Free Petri Net Controller for Discrete Event Systems" by Dr. Zeng is interesting and useful. I read the paper before the presentation. Hence, I was able to understand and enjoy the talk. I now know that some specification (similar to deadlock control) can also be designed using P-invariants. Because deadlocks can be induced, they have to apply deadlock prevention technique to avoid deadlocks. This inspires to propose new research to do uniform control that is application to both specification and deadlocks. I will continue musing in this direction to come up with new ideas.

I am quite inspired by the talk "Matrix Formulation for Dempster-Shafer Evidence Computations: Application in Free-Choice Petri Nets for Intelligent Diagnostics " by F.L. Lewis. It is applied to ubiquitous network containing mobile sensors and robots. This is an advanced research area. I will propose to apply my unique research advantages to get NSC funding in this area.

三、 建議 1. To support to attend this conference every year.

2. To prepare and plan to participate and organize

this conference; i.e., to be the 會議主辦單位. This helps to enhance the reputation and visibility of NCCU.

3. Conference organizer, Dr. ZW Li, has 11 phd students and seems to be the most productive PN author in the world. As a result, his student is also trained in the research of Petri nets theory and application. Taiwan is now lagging behind PRC.

相關聯結(活動網頁、與本學術活動有關聯結…) http://ictt.xidian.edu.cn/atpn2008/Pages/ATPN_main.jsp

四、

1. 檢附資料請以電子檔為優先
2. 補助出席國際會議者，另應檢附攜回資料名稱及內容

One Proceeding (book) that contains all the papers.

3. 如有活動照片，可檢附