行政院國家科學委員會專題研究計畫 成果報告

單邊控制策略之擴充與可控性
研究成果報告(精簡版)

計 畫 類 別 ：個別型
計 畫 編 號 ：NSC 98-2221-E-004-002-
執 行 期 間 ：98 年 08 月 01 日至 99 年 07 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

處 理 方 式 ：本計畫可公開查詢

中 華 民 國 99 年 10 月 02 日

行政院國家科學委員會補助專題研究計畫成果報告

單邊控制策略之擴充與可控性

計畫類別：■個別型計畫　　□整合型計畫

計畫編號：98-2221-E-004-002-

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計畫主持人：趙玉

共同主持人：

計畫參與人員：

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中　華　民　國　　99　年　9　　月　30　　日

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一、中文摘要

傳統僵局預防方法受增加太多控制器之苦。 李和周提議把虹吸管分成一初步和依靠的； 後者能更進一步被透過強烈和弱的依靠的虹吸管。 他們顯著降低控制器的數量借由初步虹吸管添加控制器。 不過，計算Petri網的初等虹吸管需要昂貴列舉所有虹吸管。 更進一步，可以達到的狀態的數量是比最佳少得多的。 在一論文內，我們提議一邊理論給一著名的S^3PR三倍的狀態的數量。 這個提議把它延長到更錯綜複雜的資源分發系統(例如ES^3PR， S^2LSPR 和 S^3PMR那樣的系統)。 在另一篇文章，我們消除透過發現新關於初步虹吸管的理論列舉全部虹吸管的問題：（1）任何身體弱依靠的虹吸管已經被控制並且不需要控制器。 （2）任何n(n>3)依靠的虹吸管 已經被控制並且不需要控制器。這工作提議把它延長到更錯綜複雜的資源分發系統 。 更進一步，我們提議延長上述一邊的理論在保留多項式複雜性的優勢沒有完全的虹吸管列舉時是更許可的(即可達到更多的狀態數量)。

關鍵詞:Petri 網，僵局， 控制，虹吸管，最佳化

Abstract

Traditional deadlock prevention approaches suffer from adding too many monitors. Li and Zhou proposed to divide siphons in a Petri net into elementary and dependent ones; the latter can further be distinguished by strongly and weakly dependent siphons. They add monitors to elementary siphons only significantly reducing the number of monitors. However, the computation of elementary siphons in a Petri net is expensive since the complete siphon enumeration is needed. Further, the number of reachable states is much fewer than the optimal. In an earlier paper, we proposed one-sided theory to triple the number of states for a well-known S^3PR. This proposal extends it to more complicated resource allocated systems such as ES^3PR, S^2LSPR, and S^3PMR. In another paper, we eliminated the problem of enumerating all siphons by discovering new theory about elementary siphons: (1) any weakly dependent siphon is already controlled and needs no monitor. (2) any n-dependent siphon (n>3) is already controlled and needs no monitor. This work proposes to extend it to more complicated resource allocated systems. Further, we propose to extend the above one-sided theory to be more permissive while retaining the advantage of polynomial complexity with no complete siphon enumeration.

Key Words: Petri nets, deadlock, control, siphon, optimization

二、緣由與目的

Ezpeleta *et al.* proposed a class of PN called systems of simple sequential processes with resources (S^3PR) [1]. Liveness can be enforced by adding a control place —and associated arcs— to each emptiable siphon *S* to prevent *S* from becoming empty of tokens. However, this method generally requires adding too many control places and arcs to the original Petri net model. Further, to avoid the generation of new SMS, Ezpeleta *et al.* [9] moved all output (called Type-2, or source) arcs of each V_S to the output (called source) transition of the entry (called idle place) of input raw materials to limit their rate into the system, called all-sided, or SMSless approach. This may overly constrain the system so that many reachable states (6287, the same as that by Li *et al.* but with a lot more control elements) are no longer attainable. As a result, system throughput is reduced significantly.

Li and Zhou [2,3] proposed simpler Petri net controllers based on the concept of elementary siphons (generally much smaller than the set of all emptiable siphons in large Petri nets) to minimize the new addition of places. Emptiable siphons can be divided into two groups: elementary and dependent. They added a control place for each elementary siphon S_e without generating new emptiable siphons by the method developed in [1], while controlling all dependent emptiable siphons *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, the number of good states for the S^3PR in Fig. 1(a) is only 6287 around one third of the best one, 21562 in [4] with 19 control places, around 3 times of that by Li *et al.* Thus, the optimal one suffers from too many control nodes and arcs while the elementary approach reaches fewer states.

To reach more good states, in disturbanceless approach, the control (called Type-1) arcs are chosen to disturb the original uncontrolled model as little as possible. However, this policy may generate new SMS and hence requiring adding too many control places and arcs to the original Petri net model.

Li *et al.* proposed [5] a two-stage approach to synthesizing liveness-enforcing supervisors for systems of simple sequential processes with resources (S^3PR), one type of flexible manufacturing systems (FMS). First, they find siphons (and add monitors) that need to be controlled using a mixed integer programming (MIP) method to avoid time-consuming complete siphon enumeration. Second, they rearrange the output arcs of the monitors providing that liveness is still preserved. Experimentally, it is more efficient and results in more permissive and structurally simpler liveness-enforcing supervisors than existing ones.

All output arcs of a monitor for SMS *S* in the first stage are added to the source transitions of the plant net model to avoid new SMS generation (and the associated control elements). However, it may be that all dependent siphons are derived before any elementary siphon in the worst case. In this case, all SMS may need monitors. Further, MIP is NP-hard and in the worst case, the time complexity is exponential and time-consuming. Also, the number of good states for the S^3PR in Fig. 1 is only 15999, less than the best one, 21562 in [4]. Hence, it is desired to reduce the number of MIP iterations as many as possible while making it maximally permissive; i.e., maximizing the number of good states. To do so, the original uncontrolled model should be disturbed as little as possible and each strict minimal siphons (SMS) *S* be allowed to reach its *limit state*; i.e., min $M(S)=1$.

We have proposed an intermediate, called *one-sided*, approach based on our earlier innovative search of SMS to reach more states than the all-sided approach for both *all-siphon* and *elementary-siphon* approaches.

Consider a control circuit $V_{S1}\rightarrow t_1 \rightarrow V_{S2}\rightarrow t_2\ldots V_{Sn}\rightarrow t_n \rightarrow V_{S1}$, where '$\rightarrow$' indicates an output arc from a node. The control policy by Ezpeleta *et al.* is to break the output arc from each V_{Si}, $i=1,2,\ldots,n$, in the above circuit. It is not necessary to break all such arcs, rather only one such arc is sufficient to disrupt the circuit to avoid the generation of new control circuits.

Consider a set of resources shared by two simple processes *i* and *j* with idle places p_i^0 and p_j^0 respectively, and an associated control place V_S with output control arcs (V_S, t_i) and (V_S, t_j), where t_i (t_j) is a transition on process *i* (*j*). We either move t_i to the output transition of p_i^0 on process *i* (i.e., $t_j^0 \in p_i^{0\bullet}$) or move t_i to the output transition of p_j^0 on process *j* (i.e., $t_j^0 \in p_j^{0\bullet}$), but not both as in the all-sided approach.

The proposed approach takes, for the net in Fig. 1, the same number of control places as those of traditional ones, but with 3 fewer control arcs for both the elementary-siphon and the all-siphon approaches, while not producing new SMS. The total number of reachable states roughly doubles using the proposed one-sided approach, compared with the traditional approaches. This confirms that our approach is more permissive.

Further, we propose to extend the above one-sided theory to be more permissive while retaining the advantage of polynomial complexity with no complete siphon enumeration. by exhausting different kinds of resource circuits for each type of RAS.

We will also explore the issue of controllability as we have done in [14] where we discovered very important theory: Any weakly or n-dependent (n>3) siphon is already controlled if a monitor is added for each elementary siphon for it to be limit-controlled. As a result, we need not explore all dependent siphons; only elementary and n=2 dependent siphons are to be explored; the number of which is polynomial.

We will investigate whether the same good theoretical properties hold for one-sided control. We further propose to further reduce the number of arcs that need to be moved. Thus, the net is less disturbed and reaches more states.

三、Results

There are two ways to improve. (1) Selectively move some control arcs. (2) Find better controllability.

(1) For instance, we observe three of new circuits (from which to synthesize new problematic siphons) in Table I contain the path [t_8 V_7 t_{17}]. Hence, it is much effective to move the end (t_{17}) of arc (V_7 t_{17}) to end at t_{15}. While some control arcs should not be moved since the corresponding new SMS is always controlled and need no monitor. In our earlier paper, we uniformly move control arcs on only one side, which is overly conservative. For the net in Fig. 1, we only move two arcs and the resulting reachable states increase from 15999 (the uniform one-sided method) to 16101. This is much better compared with the rearrangement method by Li and Zhou where it takes much time to try different arc arrangements, yet it reaches fewer states. The INA test (the corresponding input file is net02.pnt) indicates that it is live. The issue is that among so many new circuits generated, which of them should we select to move arcs? We propose to solve the problem by analyzing various new control siphons to see which are already controlled and need no monitors. Our earlier work helps to resolve the issue.

We have explored control elements associated with all possible resource siphons and explored their controllability. As a result, some control elements can be eliminated. Based on this result, we identify the minimal amount of control arcs that need to be moved to avoid generation of new SMS.

As a result, fewer monitors are required and the controlled model reaches more states. For instance, we observe three of new control circuits (from which to synthesize new problematic siphons) for the well-known S^3PR contain the path [t_8 V_7 t_{17}]. Hence, it is much effective to move the end (t_{17}) of arc (V_7 t_{17}) to end at t_{15}. While some control arcs should not be moved since the corresponding new SMS is always controlled and need no monitor. In our earlier paper, we uniformly move control arcs on only one side, which is overly conservative. For well-known S^3PR, we only move two arcs and the resulting reachable states increase from 15999 (the uniform one-sided method) to 16101. This is much better compared with the rearrangement method by Li and Zhou where it takes much time to try different arc arrangements, yet it reaches fewer states.

(2) Unfortunately, we find that the good controllability for the elementary-siphon approach cannot be extended to the proposed approach. This is because one formula involving the compensation factor no longer holds. However, the controllability for a 2-compound siphon still holds except that the compensation factor is reduced from c+a to c or a depending on which side is chosen to move

arcs. We are writing a journal paper for the results of this research.

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無研發成果推廣資料

98 年度專題研究計畫研究成果彙整表

計畫主持人：趙玉			計畫編號：98-2221-E-004-002-				
計畫名稱：單邊控制策略之擴充與可控性							
成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	0	0	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		
國外	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	0	0	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	無

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

   ■達成目標

   □未達成目標（請說明，以 100 字為限）

   　　□實驗失敗

   　　□因故實驗中斷

   　　□其他原因

   說明：

2. 研究成果在學術期刊發表或申請專利等情形：

   論文：□已發表 □未發表之文稿 ■撰寫中 □無

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