行政院國家科學委員會專題研究計畫 成果報告

藉由控制地區精煉和錯誤恢復到達更多的狀態
研究成果報告(精簡版)

計 畫 類 別 ： 個別型
計 畫 編 號 ： NSC 98-2221-E-004-004-
執 行 期 間 ： 98 年 08 月 01 日至 99 年 09 月 30 日
執 行 單 位 ： 國立政治大學資訊管理學系

計 畫 主 持 人 ： 趙玉

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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

藉由控制地區精煉和錯誤恢復到達更多的狀態

計畫類別：■個別型計畫　　□整合型計畫

計畫編號：98-2221-E-004-004-

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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

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一、中文摘要

我們報告著名的FMS 的另一控制模型到達與文獻內最好的Uzam 等等(基於區域的理論和 reachability 有分析受狀態爆炸問題之苦)相同的好狀態的數量。但是有更少的控制器和控制 電弧借著以精煉一些控制器到幾個， 在綜合的更晚的階段，與更小的控制區。因爲控制地區 被較少擾亂，所以更多的狀態可以被達到，借著只包括一個亞區裡一個地方–在任何可以達到的狀態一個亞區裡只有一個地方被標明的。 因此， 控制區比補充虹吸管小，這不過，可能引起這只虹吸管在綜合的起初時期變得未含標記。 我們發展一個正式的理論解決兩難。但是，可以達到的狀態的數量， 比最佳的仍然更少，在最壞例子中要求的控制器的數量仍然可能是指數的， 新成問題的虹吸管可能被控制器產生並且引起更多的控制器被增加。 地區理論以Uzam 等等 能在所有方法中間達到最多狀態的數量。 我們更進一步提議運用僵局恢復透過增加控制器(並且控制電弧)到達與原先的未受控制的模型相同的狀態的數量–類似於預防方法。 因此，它是一種靜止的方法並且迅速地運轉。 當一只成問題的虹吸管到達臨界狀態時，一次事件將被起動返回一個以前的狀態； 如此從一個僵局中恢復。 與所有方法(包括Uzam 等的方法)相比較，因此它更許可。 更進一步，沒有新成問題的虹吸管由於增加的控制器被產生。 因此,與其他方法 (也Uzam 等等) 比較,需要更少的控制器。 它已經適用於一個著名的例子。 我們進一步研究發展正式的理論並且把它延長到任意的S_3PR和更錯綜複雜的RAS(例如ES_3PR，S2LSPR 和S_3PMR)。

關鍵詞:Petri 網，僵局， 控制，虹吸管，最佳化

Abstract

We reported an alternative control model of a well-known FMS to reach the same number of good states as that by Uzam et al. (based on the theory of regions and reachability analysis suffering from the state explosion problem) – the best in the literature– but with fewer monitors and control arcs by refining some monitors into several, in the later stages of the synthesis, with smaller controller regions. More states can be reached since the controller region is less disturbed by covering only a place in a subregion where only one place is marked at any reachable marking. As a result, the controller region is smaller than the complementary siphon, which, however, may cause the siphon to become unmarked in the initial stages of the synthesis. We develop a formal theory to resolve the dilemma. The number of reachable states, however, is still fewer than the optimal one and the number of monitors required in the worst case may still be exponential since new problematic siphons may be generated by the monitors and cause more monitors to be added. The region theory by Uzam et al. can reach the most number of states among all approaches. We further employ deadlock recovery to reach the same number of states as the original uncontrolled model by adding monitors (and control arcs) similar to the prevention approach. Thus, it is a static approach and runs fast. When a problematic siphon reaches a critical state, an event will be initiated to return to a previous state; thus recovering from a deadlock. Hence it is more permissive than all current, including that by Uzam et al., approaches. Further, no new problematic siphons are generated due to added

monitors. Thus, fewer monitors are required than other (also Uzam et al.) approaches. It has applied to a well-known example. We develop formal theory.

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.* [2] but with a lot more control elements) are no longer attainable.

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; characteristic T-vectors of the latter are linear combinations of that of the former. 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.

To prevent deadlocks, some control places and related arcs are added to strict minimal siphons (SMS) so that no siphon can be emptied. The number of minimal siphons grows in general exponentially with respect to a Petri net size. Unlike other techniques, Li *et al.* [2, 3] add control nodes and arcs for only elementary siphons greatly reducing the number of control nodes and arcs.

However, the number of good states for the well-known S^3PR is only 6287 around one third of the best one, 21562 in [4] (region theory) with 19 control places, around 3 times of that by Li *et al.* [2] Thus, the best one suffers from too many control nodes and arcs while the elementary approach reaches fewer states. It is interesting (as we propose in this paper) to construct a siphon-based controlled model with the same best (21562) number of states.

The theory of regions [4] has been used to design best liveness-enforcing Petri net supervisors. Although it can handle the plants with uncontrollable transitions, but it depends on the complete state enumeration and needs to solve linear programming problems whose number is exponential with respect to the size of a plant net model. Further, the number of monitors may not be minimal; some of them are redundant.

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 well-known S^3PR 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. Even though this policy may generate new SMS, many of them are redundant and need no control places and arcs.

In an earlier paper [7], we propose to synthesize elementary (dependent) siphons from resource (I) circuits. They are also called *basic (compound) siphons*. Several basic siphons make up a compound siphon. We proposed to add monitors to each basic siphon built from elementary resource circuits [8] and find conditions for a compound siphon built from compound resource circuits to be already controlled. We showed that if we assign monitors to basic siphons first, then many compound siphons (all but S_{15} for the above example discussed) are already controlled and need no monitors. The converse is not true; even though a compound siphon is controlled; all basic siphons remain uncontrolled and need monitors for each of them.

We have directed output arcs of a control place related to a minimal siphon S to the sink transitions of S to disturb the original uncontrolled model as little as possible to maximize the number of good states.

However, the resulting model reaches less (21363) states than the one (21562 in [4], but with 11 monitors and 50 control arcs less than 19 monitors and 120 control arcs reported in [4].

However the best number (21562) of reachable states is still fewer than the optimal (21581). This proposal employs deadlock recovery to reach the same number of states as the original uncontrolled model by adding monitors (and control arcs) similar to the prevention approach. When a problematic siphon reaches a critical state, an event will be initiated to return to a previous state; thus recovering from a deadlock. Hence it is more permissive than all current, including that by Uzam et al., approaches. Further, it does not generate new problematic siphons. Thus, fewer monitors are required than other (also Uzam et al.) approaches.

This work proposes to extend it to other S^3PR and more complicated RAS such as ES^3PR, S^2LSPR, and S^3PMR as well.

三、Results

The approach [9] improves the MIP test by adding monitors to each basic siphon and finding conditions for a compound siphon to be already controlled. Afterwards, one may start the traditional MIP test. This 1) relieves the problem of siphon enumeration since the number of problematic siphons grows exponentially, 2) reduces the number of time-consuming mixed integer programming (MIP) iterations, 3) avoids the need to rearrange control arcs, 4) avoids the state-space explosion using reachability analysis, 5) reduces the number of monitors relative to that in [4], and 6) reaches more number of states than the two-stage approach [5].

Furthermore, we propose an approach (taking less computation time than the one in [4] since no reachability analysis is required) to reach the same number of states as the near optimal model in [4] for a well-known S^3PR. This is achieved by refining one monitor into three with smaller controller regions. The same idea can be extended to more complicated resource allocated systems such as ES3PR, S2LSPR, and S3PMR as well.

We [10] have proposed a recovery policy with the advantage to reach as many states as the uncontrolled model (never achieved before in the literature) and yet using fewer monitors. This approach, however, suffers from material loss by aborting some operation. We further propose a lossless approach to avoid the material loss by coloring some arcs.

Furthermore, in the worst case, each problematic siphon may require a monitor leading to too complicated controlled systems since the number of problematic siphons grows exponentially (hence the complexity of Algorithm I is exponential) with the size of the system. Although we have discussed how to handle this problem above, future work may be addressed toward developing the controllability of a dependent siphon so that by adjusting control depth variables of elementary siphon, the dependent siphon may already be controlled and need no monitor and control arcs.

We have tested the proposed policy against a well-known S^3PR first proposed by Ezpeleta *et al*. The INA (Integrated Net Analyzer) analysis indicates that the resulting controlled model is live and reaches 26750 states more than the 21581 states by Piroddi et *al*. Only 7 monitors are employed compared with 13 monitors by Piroddi et *al.*

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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-004-004-
計畫名稱：藉由控制地區精煉和錯誤恢復到達更多的狀態	

成果項目			量化：實際已達成數（被接受或已發表）	量化：預期總達成數(含實際已達成數)	量化：本計畫實際貢獻百分比	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）
國內	論文著作	期刊論文	2	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 專利：□已獲得 □申請中 ■無 技轉：□已技轉 □洽談中 ■無 其他：（以 100 字為限）
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