行政院國家科學委員會專題研究計畫 成果報告

彈性製造之最佳控制
研究成果報告(精簡版)

計 畫 類 別 ：個別型
計 畫 編 號 ：NSC 97-2221-E-004-009-
執 行 期 間 ：97 年 08 月 01 日至 98 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：此計畫無其他參與人員

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 98 年 12 月 07 日

行政院國家科學委員會補助專題研究計畫成果報告

彈性製造之最佳控制

計畫類別：■個別型計畫　　□整合型計畫

計畫編號：NSC　97-2221-E-004-009-

執行期間：　97 年 8 月　1 日 至 98　年 7　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　　98　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

彈性製造之最佳控制

Optimal Control of Flexible Manufacturing Systems

計 畫 編 號：NSC 97-2221-E-004-009-
執 行 期 限：**97 年 8 月 1 日 至 98 年 7 月 31 日**
主 持 人：趙玉 政治大學資管系
共 同 主 持 人：
計畫參與人員：

一、中文摘要

吾人提議改進混合線性規劃方法，就是先對基本本虹吸管加入控制元件，再考慮對複合元件加入控制元件。如此 (1)減輕列舉虹吸管的數量 迅速成指數隨著網的大小增長的嚴重性。(2) 減少接下混合線性規劃的執行次數。(3) 避免重新調整控制弧。(4) 避免可達分析引起的狀態爆炸問題。(5) 減少控制器的數量。(6) 比二行程的方式可達更多狀態數。吾人進一步將研討最佳化。

關鍵詞:Petri 網，僵局， 控制，虹吸管，最佳化

Abstract

In this work, we propose an approach to improve the mixed integer programming (MIP) method by adding monitors to each basic siphon and find conditions for a compound siphon to be already controlled. This (1) relieves the problem of siphon enumeration which grows exponentially, (2) reduces the number of subsequent 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) reduce the number of monitors, and (6) achieve more number of states than the two-stage approach. We will further investigate how to optimize.

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 result 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 p lant 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 $M(S)=1$.

Huang *et al.* [6] propose a more permissive siphon-based algorithm for deadlock prevention of a subclass of Petri nets, S^3PMR. It iteratively [based on a mixed integer programming (MIP) technique] adds two kinds of control places called ordinary control (OC) places and weighted control (WC) places to the original model to prevent siphons from becoming unmarked. Numerical experiments indicate that the proposed policy appears to be more permissive than closely related approaches in the literature. The presence of WC renders the net a generalized Petri net, which is harder to analyze, and it is unclear how the above traditional MIP must be modified.

三、Results

We show that all monitors with WC places in all cases presented are redundant and can be removed while maintaining the maximal number of good states. We also (1) show that OC places and WC places are associated with resource and mixture siphons, respectively, (2) identify the condition and examples for a WC places to be redundant, (3) explore different

types of problematic siphons, and (4) identify the correct sequence of adding monitors to avoid redundant monitors. The work jas been accepted in [7].

In an earlier paper [8], we propose to synthesize elementary (dependent) siphons from resource (compound) circuits. They are also called basic (compound) siphons. Several basic siphons make up a compound siphon. We show that if all such basic siphons are controlled, so are most of the compound siphons. 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 propose an approach to improve the MIP one by adding monitors to each basic siphon and find conditions for a compound siphon to be already controlled. This **(1) relieves the problem of siphon enumeration which grows exponentially, (2) reduces the number of subsequent 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) reduce the number of monitors, and (6) achieve more number of states than the two-stage approach.**

We discover that (1) by removing all monitors with WC places in [6], the net remains live and maximally permissive and (2) all OC places and WC places are monitors for resource and mixture siphons, respectively. We have developed a theory to determine the sequence of adding monitors to avoid redundant monitors and the conditions where a WC place is redundant.

It has been assumed that any two strict minimal siphons intersect at most at a single resource place so that there are no weakly dependent siphons (where the controllability involves negative terms). It remains to be seen (a future research subject) whether the same conclusion can be extended to weakly dependent siphons. Further work should investigate how to avoid WC places or transform a WC place into an OC place when a WC place is not redundant.

四、參考文獻

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封 面 樣 式

①

出國報告（出國類別：（B）開會、談判）

②

赴西班牙參加 ETFA2009 INTERNATIONAL CONFERENCE

③

服務機關：國立政治大學資訊管理

姓名職稱：趙玉

派赴國家：西班牙

出國期間：98 年 9 月 20 日至 98 年 9 月 25 日，共 6 日

報告日期： 98 年 9 月 29 日

附件一

出國報告審核表

<table>
<tr><td colspan="3">出國報告名稱：赴西班牙參加 ETFA2009 INTERNATIONAL CONFERENCE</td></tr>
<tr><td>出國人姓名（2 人以上，以 1 人爲代表）</td><td>職稱</td><td>服務單位</td></tr>
<tr><td>趙玉</td><td>教授</td><td>資訊管理</td></tr>
<tr><td colspan="2">出國期間：98 年 9 月 20 日至 98 年 9 月 25 日</td><td>報告繳交日期： 98 年 9 月 29 日</td></tr>
<tr><td>出國計畫主辦機關審核意見</td><td colspan="2">☐1.依限繳交出國報告
☐2.格式完整（本文必須具備「目的」、「過程」、「心得」、「建議事項」）
☐3.內容充實完備
☐4.建議具參考價值
☐5.送本機關參考或研辦
☐6.送上級機關參考
☐7.退回補正，原因：☐□不符原核定出國計畫 ☐□以外文撰寫或僅以所蒐集外文資料爲內容 ☐□內容空洞簡略 ☐□電子檔案未依格式辦理 ☐□未於資訊網登錄提要資料及傳送出國報告電子檔
☐8.本報告除上傳至出國報告資訊網外，將採行之公開發表：
☐辦理本機關出國報告座談會（說明會），與同仁進行知識分享。
☐於本機關業務會報提出報告
☐9.其他處理意見及方式：</td></tr>
<tr><td>層轉機關審核意見</td><td colspan="2">☐1.同意主辦機關審核意見 ☐全部 ☐部分_____（填寫審核意見編號）
☐2.退回補正，原因：_____
☐3.其他處理意見：</td></tr>
</table>

說明：

一、出國計畫主辦機關即層轉機關時，不需填寫「層轉機關審核意見」。

二、各機關可依需要自行增列審核項目內容，出國報告審核完畢本表請自行保存。

三、審核作業應儘速完成，以不影響出國人員上傳出國報告至「出國報告資訊網」爲原則。

四、出國人員免填灰色部份。

國立政治大學發展國際一流大學及頂尖研究中心計畫

出國成果報告書（格式）

計畫編號[1]		執行單位[2]	商學院
出國人員	趙玉	出國日期	98 年 9 月 20 日至 98 年 9 月 25 日，共 6 日
出國地點[3]	Palma de Mallorca, Spain	出國經費[4]	55000.00

2009 Emerging Technology and Factory Automation conference 在**西班牙** Palma 島舉行. 由 IEEE Industrial Society 舉辦 本次會議特別注能源問題探討 集中一天在**西班牙** Tirmes(**再生**能源中心) 舉行.了解到**西班牙是最佳風力及太陽**能運用國家 建設廣大分散式電力格系統 因此深刻了解到其中問題在於如何作有效的分散式管理 其中 voltage dip (電壓突降)**是**一嚴重問題 一法國學者討論如何作其模擬 其他問題**是** power electronics and storage system. **接著參觀**了附近**西班牙自己設計建造**的垃圾發電系統 (台灣只是分類) 由此可見**西班牙善於自己設計建造**自動化系統 次日本人**參與論文發表**(1 MD-000531 Controllability for Siphons in S3PGR2Daniel Y Chao) 得到一些研究新主意

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西班牙漢堡約是美國兩倍 台灣四**倍 雖是海島 卻不見海鮮餐館 及農園果樹 難怪物價較貴 多數**人 愁眉不展 不如台灣

次日之後 本人**參與論文發表**(1 MD-000531 Controllability for Siphons in S3PGR2Daniel Y Chao) 得到一些研究新主意 (automatic implementation, performance evaluation, GMEC modeling, etc)

本人在回程中 瀏覽了會議所發的資料 包括 power electronics 之介紹及其電路 只是了解大概離研究貢獻 還差了一段

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[1] 單位出國案如有 1 案以上，計畫編號請以頂大計畫辦公室核給之單位計畫編號 +「-XX（單位自編 2 位出國案序號）」型式為之。如僅有 1 案，則以頂大計畫單位編號為之即可（出國人員免填）。

[2] 執行單位係指頂大計畫單位編號對應之單位（出國人員免填）。

[3] 出國地點請寫前往之國家之大學、機關組織或會議名稱。

[4] 出國經費指的是實際核銷金額，單位以元計。

採行之建議事項：

能源管理也許是個很好的研究課題 能替本院爭取到國科會經費

出國人簽名：　　日期：

連絡人：　　分機：