行政院國家科學委員會專題研究計畫 成果報告

S2NPGR2 和 S3PGR2 的僵局控制
研究成果報告(精簡版)

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一、中文摘要

當今 S^3PGR^2 的僵局控制受苦于基于致命標記的虹吸管之錯誤活性(liveness)特徵化。 我們的 93 &94 計劃發現非活過渡(transitions) 可能存在，即使沒有致命標記。 那就是在沒有致命標記下，這網模可能是弱活或者在活鎖(livelock)狀況下。這在一種新 liveness 條件下這網模是活的： 全部 siphons 都必須是 max-controlled。 為了確立我們在此領域的領先地位，本計劃以類似于 S^3PR 的方式，對 S^3PGR^2 借著增加控制節點和電弧來作僵局控制。更進一步，李等人提議適合 S^3PR 的一僵局預防方法。此法僅對所謂初等虹吸管增加控制節點和電弧，因此大大降低架構的複雜性。 不過，怎樣把它延長到 S^3PGR^2 和 S^2CPGR^2，迄今是不清楚的，並且沒被研究。 我們已開拓這樣的研究。

關鍵詞: 僵局 控制 預防 活的 虹吸管

Abstract

Current deadlock control approaches for S^3PGR^2 suffers from incorrect liveness characterization based on the concept of deadly marked siphons (DMS). Our 93&94 proposals discover that nonlive transitions may exist even though there are no DMS. That is the net model may be weakly live or in livelock states under no DMS. It is live under a new liveness condition: all siphons must be max'-controlled. We propose to consolidate our leading position by further working out the deadlock control for S^3PGR^2 (systems of simple sequential processes with general resources requirement) by adding control nodes and arcs similar to that for S^3PR. Next we will extend it to S^2CPGR^2 (systems of Synchronized Choice processes with general resources requirement)). Further, Li et. al. proposed a deadlock prevention approach for S^3PR to add control nodes and arcs for elementary siphons only greatly reducing the structural complexity. However, it is unclear how to extend it to S^3PGR^2 and S^2CPGR^2 and have not been studied so far. We have pioneered such study.

Keywords: deadlock control prevention live siphons

二、緣由與目的

Liveness in Flexible Manufacturing Systems (FMS) modelled by Petri nets (PN) are closely related to bad siphons [1] whose tokens can be emptied completely. The FMS model consists of a set of working processes (WP) competing for resources. Circular wait for resources can bring the system into a deadlock where some WP can never finish. Prevention is preferred to avoidance because the computational effort is carried out once and off-line. Hence it runs much faster in real-time cases. Ezpeleta et al. [1] proposed a class of PN called Systems of Simple Sequential Processes with Resources (S^3PR) and a deadlock prevention approach. Most recent deadlock control approaches extend Ezpeleta's work. In our 93 NSC proposal, we proposed to extend it to S^3PGR (systems of simple sequential processes with general resources), S^2NPGR (Systems of Synchronized choice Net processes with General Resource) and S^2WPGR (Systems of Weighted Synchronized choice Net processes with General Resource) and improve its computational efficiency. In addition, we generalized some siphon-related theory of Ordinary PN (OPN) to General PN (GPN) and improve our synthesis rules for GPN.

Our 93 NSC proposal is successful. The most distinguished result is that we have developed a new liveness condition called max'-controlled siphons to replace that of the absence of empty siphons. This beats the result of deadly marked siphons in the literature, which is incorrect as we have found. Note that the proposal did not deal with deadlock control. Yet, we attempt to do a preliminary study on such topic. The result is encouraging and hence we propose this year to continue the study consolidating our leading position. We will investigate deadlock control issues for S^2NPGR^2 (Systems of Synchronized choice Net processes with General Resource) and S^3PGR^2 (Systems of Weighted Synchronized choice Net processes with General Resource). We will study how to add control nodes and arcs upon S^2NPGR and S^3PGR^2 to avoid deadlocks and the properties of the controlled net.

Abdallah and Elmaraghy [2] proposed S^4R, which are a generalization of S^3PR nets, to extend S^3PR and production Petri nets (PPNs) nets to model systems that can use not only alternative resources, as in S^3PR nets, but they can also utilize more than one resource simultaneously. They adopted deadlock prevention policy by adding a control place for each siphon to remain marked for all reachable markings. Further, they introduced a deadlock avoidance policy (DAP) to control the augmented S^4R nets using a resource allocation policy based on the unsafe marking concept. With a look-ahead procedure, the controller determines one step of future evolution before making a resource allocation decision. However, it may be in deadlock in some cases and a recovery procedure may be started.

Park and Reveliotis [3] proposed S^3PGR^2 (*systems of simple sequential processes with general resources requirement*) based on a new siphon construct, called deadly marked siphons (DMS). They developed, based on the derived siphon-based liveness characterizations, a sufficiency test for the correctness of CD-RAS DAP that can be expressed a set of invariants imposing control places, superimposed on the PN modeling the original RAS behavior. However, the absence of DMS is only necessary, but not sufficient, to the liveness of the model. A S^3PGR^2 net without DMS is deadlock-free but may be in livelock states.

Tricas and Martinez [4] proposed a similar system, called WS^3PSR (*weighted systems of simple sequential processes with several resources*). It differs from S^3PGR^2 in two aspects: 1. a place can represent the use of various resources simultaneously. 2. there is no need of releasing resources used in the present state before advancing to the next state. However, the policy is very restrictive so that it sequentializes the flow in the siphon. The marking imposed to the control places limits the number of processes that can flow in the problematic areas to the minimum. They admitted that further work must be done to find better control places and better markings.

All these approaches suffer from incorrect theory based on deadly marked siphons (DMS). A net with DMS is not live and conversely, a live net does not have DMS. However the absence of DMS does not guarantee all transitions in the net be live; it may be weakly live or in livelock states. In order to provide optimum control, we need first to find the correct condition for liveness. The theory is proposed with new definitions and lemmas below. Afterwards, we present a preliminary proposal for adding control nodes and arcs. We admit that they may not be rigorously correct and hence subject to further research.

Li *et al.* [5] proposed simpler Petri net controllers based on the concept of elementary siphons (generally much smaller than the set of all *strict minimum siphons* (*SMS*) in large Petri nets) to minimize the new additions of place. SMS can be divided into two groups: elementary and redundant; characteristic *T*-vectors of the latter are linear combinations of that of the former.

They add a control place for each elementary siphon with no new SMS generation by the method in [5]. In the mean time, it controls all other SMS (i.e., always marked) too. Thus, the number of control places is much smaller and, therefore, is suitable for large-scale Petri nets.

However, it is unclear how to extend it to S^3PGR^2 and S^2CPGR^2 and have not been studied so far. We propose to pioneer such study.

三、Results

1. Deadlock Control for Systems of Simple Sequential Processes with General Resources Requirement (1 SCI paper, 1 submitted)

We extend the liveness analysis for S^3PR [6] to S^3PGR^2. We develop a new liveness condition called max*-controlled siphons to replace that of the absence of empty siphons. We propose further a deadlock control policy for $S^3PGR^2$by adding control nodes and arcs similar to that for *S^3PR* [1].

2. Supervisory Control of S^3PGR^2 Based on Max*-Controlled and Elementary Siphons (2 SCI papers accepted, 1 submitted)

We propose [11] further a deadlock control policy for *S^3PGR^2* by adding control nodes and arcs only for elementary siphons only [6], significantly reducing the number of supervisory monitors compared with existing methods. By adjusting the control depth variables of its elementary siphons, other (dependent) siphons also satisfy the max*- controlled-siphon property. We proposed the controlled model for *S^3PGR^2* and prove its liveness property.

3. Equivalence of deadlock-freeness and liveness for S^3PGR^2&S^2CPGR^2 (2SCI papers submitted, good comments)

The equivalence problem has been difficult for even OPN. We excelled on this by finding the key structure involved and proposed NV-nets as the maximal class of the above equivalence. We have further extended it to GPN including S^3PGR^2&S^2CPGR^2.

4. Advanced theory of search of elementary siphons (1 SCI paper awaiting EIC decision, 1 submitted)

In [9], we extend our work in [18] for BS^3PR to arbitrary S^3PR. In [8], we propose to solve the open problem: the condition for an S^3PR to have no weakly dependent siphons.

5. Near optimal control policy and less monitors (1 paper in preparation)

In [7], we propose a better sufficiency test for adjusting control depth variables in an *S^3PR* to avoid the time-consuming integer programming test (NP-complete problem) required previously for some cases. In [19], we propose a simple yet effective, called one-sided, approach for *S^3PR* that modifies the elementary siphon approach slightly based on our unique concept of siphon synthesis. Comparing to the two-stage approach by Li *et al.*, we do not need the time-consuming mixed integer programming (MIP) test and rearrangements of control arcs, but with the same number of good states and control elements for a well-known *S^3PR*. The time complexity can be polynomial if we can find all elementary siphons in a polynomial time as we have done earlier. In [20], we argue that the mixed integer programming (MIP) method may find unmarked minimal siphons in a way that most emptiable siphons need monitors. We need a better way to derive the correct sequence of unmarked minimal siphons using the two-stage approach and to minimize the number of monitors. In [21], we report some errors in a paper by Huang et al. Other errors will be reported in the near future. In [22], like Li *et al.,* we propose to replace weighted control arcs (WC) by ordinary control arcs (OC). We explain why it results in slightly fewer states than that with WC. Modifying control arcs to end at sink transitions of siphon *S* (rather than source transition of a process net) to make *S* maximally permissive, it will produce more states and the net remains live for two cases by Huang *et al*. In [23], we propose to add monitors to each basic siphon and find conditions for a component siphon to be already controlled. This (1) relieves the problem of siphon enumeration which grows exponentially and (2) reduces the number of subsequent time-consuming mixed integer programming (MIP) iterations.

6. S^3PR and its weighted S^3PR have the same sets of elementary and dependent siphons and

systems of equations of characteristic T-vectors.

The theory and example are shown in [10]. This greatly simplifies the search of elementary siphons and the control policy for weighted S^3PR and S^3PGR^2.

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附件：封面格式

行政院國家科學委員會補助專題研究計畫成果報告

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共同主持人：

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執行單位：

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