Research on Modeling of Stereo Warehouse Based on Colored Timed Petri Nets

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Keywords: Colored Timed Petri Net (CTPN), Automated Warehouse, Automated Storage/Retrieval Systems, Modularization.

Abstract. This paper expounds theory and method of constructing the model of Automated Storage/Retrieval Systems (AS/RS) via Colored Timed Petri Net (CTPN), in which token denotes the task number, stacker and RGV. The color domain is described as the sequence during the process of the task execution. Moreover, a process of the AS/RS modularization framework is illustrated in this thesis.

Introduction

As an important part of the plant logistics system and CIMS flexible manufacturing system, the Automated Storage/Retrieval System (AS/RS) has been applied more and more [1], how to improve the efficiency of the entire significance of automated warehouses is critical to manufacturing and logistics have. Study automated warehouse productivity issues must be studied first automated warehouse (AS / RS) delivery system model building and simulation. Automated warehouse delivery system is a typical discrete event dynamic systems (DEDS) [2], while optimizing DEDS system, Petri net is an ideal model, which has a strong relationship skills and conditions, the system is DEDS Computer Simulation powerful modeling tools [3], at home and abroad for its research focuses on the basis of Petri nets to improve on building the model. An object-oriented colored Petri net (OOCPN) [4] was proposed by Tian Guohui et al, which was carried out process modeling, analysis and control. In Italy, F. Basile applies colored Petri net to build the modular model of the AS/RS, the among sub-model through an interface (fusion places) communication [5]; these models have achieved some results, but the automated warehouse (AS/RS) delivery system is based on the time discrete event dynamic systems (DEDS), the implementation process the task at each site or location will take some time to complete, these studies have ignored this; when Italy M. Dotoli [6] and other experts [7-10] applications such as colored timed Petri nets to study the storage AS / RS model building problem, but with domestic practical problems differ; the basis of comprehensive article on previous studies, the application of colored timed Petri net (CTPN) to build automated warehouse conveyor systems modular model, the model is simple, practical, automated warehouse for dynamic studies with more efficiency big help.

Description of the Study

Automated warehouse (AS/RS) delivery systems generally include an elevated stand Reservoir, a stacker automatically access area, a warehousing operation area conveying systems, a RGV (laser guided vehicles for short) car delivery system, a number of out of storage and back libraries and other sites, Figure 1 shows the actual structure of the transfer line factory finished elevated library.

Elevated Reservoir stand by the multiple rows of three-dimensional composition of the shelves, there are container cargo tray shelf grid (expressed on a tray laden, there is no ambiguity in the case is named tray); in each roadway with a stacking machine responsible two rows of goods on the shelves access roadway in the mouth and they all have a desk and a library storage units, the stacker tray out of the station into a library, and can be obtained from the storage tray table and put it places the
corresponding cargo space; Figure 1 represents a tray storage station 203, 202 for the refunding finishing station (when expressed unqualified shape storage tray to withdraw artificial re-organize), 124 for the tray out of the library site, 101, 111 and 134 indicates the storage station at the tunnel mouth, 105,117 and 127 represent a library table at the tunnel mouth.

In order to facilitate the discussion, without changing the original premise of the overall system architecture, the author made a part of this diagram to simplify and logo, as shown in Figure 2. In Figure 2, p1 represents pallet storage site, p2 represents refunding finishing platform, p3 represents the tray out of the library site, p4, p7 and p9 of storage units at the tunnel mouth, p5, p6 and p8 for the mouth of the tunnel a library table, rs1, rs2 and rs3 the stacker, v behalf of RGV car, RGV car responsible for the storage tray platform p1 transported to the site on the p12 or p27 tray on the platform to organize refunding platform p2. RGV car parking position identified as p10 and p11 position; p29, p30 and p31, respectively Stacker rs1, rs2 and origin rs3 the receiving dock; other identification showing the process of conveying the relevant site (FIG. 2 is omitted in FIG. 1 part of the cache site).

Figure 1. Actual Delivery of Finished Overhead Chart Library.

Figure 2. Conveying Line Structure.

Out of storage paths of the roadway are described below.

1) Storage path:
   Lane 1: p1 → p10 → p12 → p13 → p4 → rs1 → specific position of Lane 1;
   Lane 2: p1 → p10 → p12 → p13 → p14 → p15 → p16 → p17 → p18 → p7 → rs2 → specific position of Lane 2;
   Lane 3: p1 → p10 → p12 → p13 → p14 → p15 → p16 → p17 → p18 → p19 → p20 → p21 → p9 → rs3 → specific position of Lane 3;

2) Pickup path:
   Lane 1: specific position of Lane 1 → rs1 → p5 → p15 → p16 → p25 → p28 → p3;
   Lane 2: specific position of Lane 2 → rs2 → p6 → p16 → p25 → p28 → p3;
   Lane 3: specific position of Lane 3 → rs3 → p8 → p19 → p22 → p23 → p24 → p25 → p28 → p3;

3) Refunding path: p12 → p13 → p14 → p15 → p16 → p25 → p26 → p27 → p11 → p2

In addition, in order to discuss the simple, stand in the elevated reservoir area, assuming each stacker is responsible for two-row four cargo out of storage tasks, as shown in Figure 3.

Figure 3. Example of a Crane Servicing Two Opposite Racks.
Fig. 3 depicts the structure of the diagram on the 1st stacker rs1 and 8 cargos, where p_{29} is Stacker origin receiving dock, p_{291} and p_{292}, respectively stacker to track the position of the first and second row other position represents eight specific cargos. How it works: After p_{29} stacker position to accept the goods move to p_{291}, and then placing the goods to the first row of cargo p_{2911}, p_{2912}, p_{2913} and p_{2914}; the second row of cargo storage you need to go through to reach the p_{292} and p_{291}. Place the second row of cargo p_{2921}, p_{2922}, p_{2923} and p_{2924} in the library is the opposite.

Colored Timed Petri Net (CTPN)

CTPN is a multi-component system[6].

CTPN=(P,T,Co,Inh,C^+,C^-,Ω,M_0).

(1) P is a finite set of libraries, usually represented by a circle; T is a finite set of transitions, usually represented by a straight line; F to connect flow relations P and T collection, usually with directed arcs.

(2) Co=Co (P) UCo (T), colour tokens and finite set of transitions is concentrated on a limited library collections.

(3) Inh weights for the arc suppression library P and T between. For example Inh (p, t) = 1, p indicates if the library is not token, can transition t is enabled state.

(4) C represents a correlation matrix, C^+ ∈C(T)→C(P), C^- ∈C(P)→C(T).

(5) Ω=∪_k∈P∪T{C(x)}.

(6) Flag Mo (p) denotes the set of initial state Co (p) elements.

In addition, in order to study the dynamic performance of the system, the introduction of the concept of time in colored Petri net. Namely the introduction of a global clock, the clock value τ ∈N represents a discrete time model. Definitions set of P functions as follows: δ: P → N, δ (p) indicates transition t is enabled in the state library p tokens left in the time required. For token colors, we gave them a given time stamp, represented by s, when the token reaches the library, the timestamp immediately reset (cleared). When: s≥δ (p), by the corresponding token enabled transition t ready to execute (excitation).

Modeling of the System via CTPN

Application CPTN Build System Dynamic Model Approach

Earlier we described the definition CTPN, the following section describes CTPN build automated warehouse delivery system model approach.

Library p_i ∈ P representatives resource location, such as transport stations, cargo, etc. Changes t ∈ T describes the RGV car shuttle pallet stacker pallet flow access uncontrollable events and other goods and transport between the stations. Changes attribute T can be decomposed into two parts: First, T_L said storage platform into the description of the task j Changes t_{0,j} and cargo from the station to leave the library Changes t_{i,0}; second is to use TF, i.e. two adjacent Changes in the flow of goods between the library (with ti, m represents) collection. Wherein Changes t_{0,i} ∈ TL of storage change, it has the attributes: t_{0,i}=∅, and t_{0,i}=[p_i], p_i represents the storage site; Changes t_{i,0} ∈ TL to a library Change, it has the attributes: t_{i,0}=∅, and t_{0,i}=[p_i], p_i expressed library site. In addition, if changes of t_{i,m} in p_i and p_m are adjacent to each other site (position), then t_{i,m} ∈ P_{t_{i,m}} and t_{i,m} ∈ P_{m}; and each library p_m ∈ P and change in t_{i,m} ∈ TF increase between a suppressed arc, to prevent conflicts caused by the same token position, you can set Inh (p_m, t_{i,m}) = 1.

The library storage tokens are shown task sequence, RGV car or stacker. The token representation of color RGV trolley or stacker must undergo a sequence of the remaining region (with pp (V) or a pp (G), respectively), or that the execution of a task in the remaining path or location platform (with pp (j) represented).

Library p_i ∈ P color fields as follows:

Co (p_i) = {<pp>}, where pp sequence library (platform or position), p_i is the first library in the pp;
Changes $t_i, m \in \Gamma$ color fields as follows:
$$\text{Co} \,(t_i, m) = \{\text{pp}\},$$
where pp is the type $(p_i, p_m, \ldots)$ sequence or $(p_m, p_i, p_m \ldots)$, under special circumstances $\text{Co} \,(t_i, 0) = \{\text{pi}\}$.

In CTPN model, the correlation matrix C can be used to describe the dynamic characteristics. The correlation matrix C row vector library $p_i \in \Pi$, and the column vector representation $\text{Changes} \, t \in \Gamma$. Correlation matrix C for each element C $(p_i, t) \text{ means: The Changes color library } p_i \in \Pi \text{ domain Co} \,(p_i)$ elements $t \in \Gamma$ color domain Co $(t)$ allocated to the elements. Correlation matrix C is calculated as $C = C^+ - C^-$

Where C and C’ values as follows:
1) For each $(p_i, t_i, m) \in \Gamma$, $C^-(p_i, t_i, m) = \text{"IDLE"}$, "IDLE" represents library $p_i \in \Pi$ the token leave unchanged, otherwise $C^-(p_i, t_i, m) = \text{"0"}$;
2) For each $(t_i, m, p_m) \in \Gamma$, $C^+(t_i, m, p_m) = \text{"UPDATE"}$, "UPDATE" represented by color $<\text{pp}>$ instead of $<\text{pp}>$, otherwise $C^+(t_i, m, p_m) = \text{"0"}$. Where $<\text{pp}'> = <\text{pp}'> - <\text{pi}>$. When the $p_i$ library tokens left to reach the library $p_m$, its color fields need to be updated.
3) For each $(t_i, m, p_i) \in \Gamma$, $C^+(t_i, m, p_i) = p_i$, that is, when a token left the $p_i$ library and then returned to the original library, its color domain variants became $<\text{pi}>$.

Set $\Omega$ represents the set of all colors. Expressed as $\Omega = \{\text{Co} \,(x): x \in \Pi\}$.

**Transition Events**

According to three-dimensional characteristics of the library overhead conveyor systems, we are divided into the following three types Change event:

1) Type A
   Out of storage task (job): $\sigma_1 = (j, p)$, where $p$ is shown repository or storage operation flag.
   Stacker receive task: $\sigma_1 = (g, p)$, where $p$ represents the path assigned to run the stacker.
   RGV receive task: $\sigma_1 = (v, p)$, where $p$ represents allocated to the running path RGV

2) Type B
   RGV car, stacker or task $j$ flow between adjacent conveyor stations, are represented by $v$, $g$ and $j$.

3) Type C
   Leave the system or on the cargo. Such events are represented as $\sigma_3 = j$.

**AS/RS Model via CTPN**

In the following sections, we modular frame structure, the application of the above analysis CTPN modeling method for automated warehouse subsystems include RGV car, out of storage site and transport equipment and stackers are modeled.

**CTPN Modeling of RGV.** As shown in Figure 1, library $p_{10}$ and $p_{11}$ represents RGV car running area, library $p_{10}$ and $p_{11}$ in token representation RGV car (idle, cargo and instructions issued by the state);

Figure 4 depicts the CTPN model conveyed by RGV in Figure 1, set the token coloring as follows:

- If the RGV car $v$ in "tasking" state, such as storage, the color domain pp $(v) = (p_{11}, p_{10})$, represented RGV car from the current position to a pick-up position $p_{10} p_{11}$ require the path;
- If the RGV car is in the "idle" state, the color domain pp $(v) = (pi)$, where $i = 10$ or $i = 11$, represents the current position of the car RGV $pi$ task awaiting state;
- If the RGV car in the "laden" status, its color domain pp $(v)$ color domain and tasks contained in the same;
- The actual modeling process, we use colored tokens $<\text{pp} \,(j)>$ to describe each task $j \in \Gamma$, and by the state of RGV CTPN flag M to represent. Specifically as follows:
  - $M(pi) = <\text{pp} \,(v)>$, AGV car $v$ represents the library $pi$, and in the "Instructions issued" state;
  - $M(pi) = <\text{pp} \,(j)>$, $v$ represents RGV car in and out of the library $pi$ "laden" status, the task is contained in $j$;
  - $M(pi) = <\text{pi}>$, expressed RGV car on the library $pi$, an idle state;
• $M(\pi_i) = <0>$, that there is no car on RGV library $\pi_i$.

The initial state of $M_0$ are defined as follows:
If $p_\pi(v) = p_i$, then $M_0(p_i) = <p_i>$, otherwise, $M_0(p_i) = <0>$.

For Changes $t_{i,m}$ so that conditions can be as follows:

a) $M(p_m) = <0>$;

b) $M(p_i) \geq C(p_i, t_{i,m}) (p_{pp})$, $M(p_i) = <p_i>$, $pp = (p_i, p_m, ...)$

Wherein $p_i, p_m \in P, i, m=10,11, i \neq m$. Conditions a) shows the effect of suppressing the arc; condition b) shows the flag $M$ CTPN under enabling conditions.

Suppose at time $t$, token $v$ reaches library $p_i$, after $\delta(p_i)$ interval, the time stamp $s(v) = \delta(p_i)$, this case changes of $t_{i,m}$ in $t + \delta(p_i)$ at the moment and ready so that energy state flag $M$. Changes $t_{i,m}$ excited state after the flag is calculated as follows:

$$M'(p_i) = M(p_i) - C(p_i, t_{i,m})(p_{pp}) = <0> \quad (1)$$

$$M'(p_m) = M(p_m) + C+(p_m, t_{i,m})(p_{pp}) = <p_{pp}> = (p_m) \quad (2)$$

Where $pp(v)'$ obtained by updating $pp(v)$ via $C+(p_m, t_{i,m})$ = "UPDATE".

CTPN Modeling of Storage Application Platform. Storage application platform of CTPN dynamic model shown in Figure 5, the figure for the library $P_1$ storage application platform, while $t_{0,1} \in T_L$ expressed into the tray. Figure 5 depicts the new task (tray) from storage application platform delivered to the site $P_{12}$ process by RGV. Changes $t_{1,10} \in T_F$ represents the transfer of the task. $P_{10}$ is one of the receiving dock for RGV car, Change $t_{1,10} \in T_F$ can be described as $t_{1,10} = \{P_{1}, P_{10}\}$, $t_{1,10} = \{P_{0}\}$; when $M(P_1) = <0>$, the storage tray application platform means no occupation, so after receiving the task instruction issued by the host computer Changes $t_{0,1}$ excitation task $j \in J$ into the system. Let color task $j$ <pp $(j)$>, after the Changes $t_{0,1}$ excited, $M(P_1) = <pp(j)> = <P_1, P_{10}, P_{12}, ...>$. In this case, if the following two conditions are met, Change $t_{1,10}$ will be enabled.

1) There is a library $P_1$ token and the token color for <pp $(j)$> = <P_1, P_{10}, P_{12}, ...>;
2) The presence of a library $P_{10}$ token and the token color for <pp$_{10}$>, ie RGV car in $P_{10}$ is idle.

Use strict mathematical expression that describes, if the definition of $C(p_{10},t_{1,10})$ = "ID" ("ID" is "IDLE" shorthand), then $t_{1,10}$ enable conditions are:

1) $M(P_1) \geq C(p_{10},t_{1,10})(<pp>)$, ie, $M(P_1) = <pp(j)> = <P_1, P_{10}, P_{12}, ...>$;
2) $M(P_{10}) \geq C(P_{10},t_{1,10})(<pp>)$, ie, $M(P_{10}) = <pp(v)> = <P_{10}>$.

In this case, if $t_{1,10}$ enabled, then the new state flag $M'$ is calculated as follows:

$$M'(p_1) = M(p_1) - C-(p_1, t_{1,10})(<pp>) = <0> \quad (3)$$

$$M'(p_{10}) = M(p_{10}) + C+(p_{10}, t_{1,10})(<pp>) - C-(p_{10}, t_{1,10})(<pp(v)> = <pp'(j)> = <p_{10}, p_{12}, ...>) \quad (4)$$

Changes from pp$(j)$ to pp$(j)$ can be get via the status "UPDATE" of $C^+(p_{10}, t_{1,10})$. When the task $j$ reaches RGV trolley, token RGV timestamp $s(v)$ is cleared.

Changes $t_{0,12}$ is enabled if:
1) \( M(p_{10}) \geq \mathcal{C}^{+}(p_{10}, t_{10,12})(pp(j)) \), i.e., \( M(p_{10}) = pp(j) =< p_{10}, p_{12}, \ldots >= \); means that there is storage task;
2) \( M(p_{12}) = <0> \), means platform \( p_{12} \) idle.

In this case, if \( t_{10,12} \) is enabled, then the new state flag \( M' \) is calculated as follows:

\[
M'(p_{10}) = M(p_{10}) - \mathcal{C}^{-}(p_{10}, t_{10,12})(pp(j)) =< p_{10} > \quad (5)
\]

\[
M'(p_{12}) = M(p_{12}) + \mathcal{C}^{+}(p_{12}, t_{10,12})(pp(j)) = pp'(j) =< p_{12}, \ldots > \quad (6)
\]

Changes from \( pp(j) \) to \( pp'(j) \) can be get via the status "UPDATE" of \( \mathcal{C}^+ \). When a task \( j \) reaches platform \( p_{12} \), token RGV timestamp \( s(v) \) is cleared.

In Fig. 6, \( p_3 \) is the output place of application platform, \( t_{1,0} \in T_L \) means token is being the output place, the transition \( t_{28,3} \in T \) means the convey task from the \( p_{28} \) tray to the output station. When the \( t_{28,3} \) has been excited, the token at \( p_{28} \) should be sent to \( p_3 \), and the state of \( p_{28} \) is modified as free. Therefore, \( t_{28,3} \in T_F \) can be described as \( t_{28,3} = \{p_{28}\} \) and \( t_{28,3} = \{p_3\} \). Moreover, if the task \( j \) at \( p_{28} \), the state is \( M(p_{28}) = pp(j) =< p_{28}, p_3 >= \), then \( J \) is an output task, And the transition \( t_{28,3} \) enters into the application platform, and an inhibitor arc is arranged between \( p_3 \) and \( t_{28,3} \). The enabling condition for the transition \( t_{28,3} \) is identified as follows:

Figure 6 shows a library application platform CTPN dynamic model, where \( p_3 \) is the platform library application platform, while \( t_{1,0} \in T_L \) expressed tray out of the library. Changes \( t_{28,3} \in T_F \) task tray indicates that the library is delivered from the platform \( p_{28} \) to apply for a library site. When \( t_{28,3} \) is excited, the task of passing on the token \( p_{28} \) given library application platform \( p_3 \), while \( p_{28} \) modify idle. \( t_{28,3} \in T_F \) here can be described as \( t_{28,3} = \{p_{28}\} \), \( t_{28,3} = \{p_3\} \). Therefore, if the region \( p_{28} \) has the task \( j \), its status as \( M(p_{28}) = pp(j) =< p_{28}, p_3 >= \), it belongs to the library mission, after Changes \( t_{28,3} \) enters a library application platform. There is a suppression arc between \( p_3 \) and \( t_{28,3} \), and transition \( t_{28,3} \) is enabled if:

1) \( M(p_3) = <0> \);
2) \( M(p_{28}) = pp(j) =< p_{28}, p_3 > \)

\( \mathcal{C}^+(p_{28}, t_{28,3})(pp) =< p_{28} > \) is defined at the front, if \( t_{28,3} \) is excited, then the new state of the flag \( M' \) is as follows:

\[
M'(p_3) = M(p_3) + \mathcal{C}^+(p_3, t_{28,3})(pp(j)) =< p_{28}, p_3 > \quad (7)
\]

\[
M'(p_{28}) = M(p_{28}) - \mathcal{C}^{-}(p_{28}, t_{28,3})(pp(j)) =<0> \quad (8)
\]

CTPN Modeling of Unloading Platform. Stacker out of storage unloading platform of CTPN Model and warehousing platform model construction is substantially the same. The only difference is that more of the stacker platform. According to the foregoing, warehouse receiving dock of CTPN dynamic model shown in Fig. 7 in accordance with the foregoing description, a stacker, due to space limitations, here only describe the changes of enabling conditions \( t_{4,29} \).

1) \( M(p_{29}) = <p_{29}> \), showing Location stacking machine and its status is idle;
2) M (p_4) = \langle pp (j) \rangle = \langle p_4, p_{29}, \ldots \rangle, expressed stacker warehousing receiving dock stock. If t_{4,29} excited, then the new state flag M 'is as follows:

M(p_{29})=M(p_{29})+C+(p_{29},t_{4,29})(\langle pp(j) \rangle)=\langle p_{29}, \ldots \rangle \quad (9)

M'(p_{4})=\langle 0 \rangle \quad (10)

**CTPN Modeling of Stacker.** Stacker Model and RGV car models have in common, is described here only briefly.

As shown in Figure 7, the library p_{29}, p_{30}, p_{31} as a stacking machine out of storage the receiving dock, the stacker described as a colored token. When the stacker receives commands from the host, which is a token color stacker reach the receiving dock of the path and the path to the specific cargo from the receiving dock. When Stacker perform tasks stacker token color represents the remaining path task execution. Figure 3 depicts the model CTPN stacker perform storage operation. In the library p_{29}, p_{291} and p_{292} at the same time allowing only a token presence, that is, in a practical system Stacker will only appear in the three libraries in one of the positions at the same time. Changes as t_{291,2911}, which enables the following conditions:

1)M(p_{2911})=\langle 0 \rangle
2)M(p_{29})=\langle pp(j) \rangle=\langle p_{291}, p_{2911} \rangle

Stacker perform library operations when CTPN model Fig. 3 is basically the same, only the changes of index change order and change the direction of the arc to connect, not much description here.

**Conclusions**

Logistics warehouse automation system is more typical condition / event system. In this paper, colored timed Petri net (CTPN) Construction of logistics warehouse automation with RGV trolley and stacker (AS / RS) methods and principles of the system model and an example is described in detail for each subsystem modeling CTPN process, the entire CTPN model using a modular construction, the corresponding correlation matrix is updated on the status of each sub-model. Applications CTPN build AS / RS models can be used to solve RGV car, stackers and other sites as well as public resource conflicts and deadlocks performance issues (explained in another article). In addition, real-time control model based on resources, CTPN modular frame modeling method is also very effective.

**Acknowledgement**

This research was financially supported by follows:

1) Zhejiang provincial natural science foundation (LY13G010006)
2) The second batch of MOOCs/SPOC-based flip classroom reform—production system modeling and optimization (GK168800299098-027)
3) The humanities and social sciences base project of Zhejiang University--Study on the dynamic relationship between urban commercial housing price and labor—intensive enterprises' elastic employment (KYF035616001)

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