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Mathematics base for mobile robot navigation using mirror petri net Method

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Abstract. The movement of the robot will be even more challenging if on the mobile journey the robot gets a lot of obstacles, there are many choices to turn left or turn right and be able to go back to the place of origin, for that purpose precise and fast navigation is needed. This research offer new methods robot mobile navigation modeled using the mirror petri net method. This method is the development of the petri net method, which is a graphical and mathematical modeling method that is very suitable for modeling a contradictory movement system. The final result will be obtained a mathematical model with the same marking value, which is used as a mobile robot navigation. This same marking value will have a different meaning when departing and when return.

1. Introduction
Currently the development of mobile robot technology is very rapidly developing, various technologies developed to make this technology very easy to use and run, currently mobile robot navigation technology is developing very strongly in outdoor environments because of technology that supports GPS technology that can realize or monitor the update and navigation of the mobile robot. Then with navigation technology in indoor systems, indoor technology is very limited because this technology if using GPS will get a small signal.

Therefore this paper will explain mobile robot navigation for indoor systems. Petri nets have been utilized for a long time to show complex procedures. Models are programming plan, work process the board, information investigation, simultaneous programming, unwavering quality building, PC design, PC systems, continuous figuring frameworks, working frameworks, circulated frameworks, equipment frameworks and organic procedures.

Several studies related to navigation and petri net: research [1][2][3] describe simulation using petri net, [4] describes the work of robots using petri for simulation for robot static, [5][6] describes mobile robot using petri for simulation for robot dinamic, [7] describes the research of robots to go to target goals for going one target goal for the movement of robots from one place to another.

Therefore this paper will present a challenge for how mobile robots will move from the start position to the finish position and return to the starting position using mirrors petri net method, namely by using marking values/positions to be used as mobile robot navigation.
2. Mirror Petri Net Method

General Petri net structure is formed by 5 main elements [8] that can be written in the following group.

\[ PN = (P, T, I, O, M) \]  

In our mirror petri net application we can propose, where the movement will be in the opposite direction.

\[ PN = (P, T, I^*, O^*, M) \]  

* Means there are two conditions when departing and when returning, we must calculate (O-I) each departure and return.

\[ (O - I) \neq 0 \]  

Direct calculation on departure and when returning will get a value (O-I) = 0, this will be a problem because we will not get the desired model, but if at the time of departure and when we count each (O-I) then we will produce information required.

- \( P = \{ p_1, p_2, \ldots, p_n \} \) is the set of \( n_p \) places (drawn as circles in the graphical representation);
- \( T = \{ t_1, t_2, \ldots, t_n \} \) is the set of \( n_t \) transitions (drawn as bars);
- \( I \) is the transition input relation and is represented by means of arcs directed from places to transitions;
- \( O \) is the transition output relation and is represented by means of arcs directed from transitions to places;
- \( M = \{ m_1, m_2, \ldots, m_n \} \) is the marking. The generic entry \( m_i \) is the number of tokens (drawn as black dots) in place \( p_i \) in marking \( M \).

A Petri net (PN) is defined as a directed bipartite graph having a structure, \( PN \), and a marking, \( M \). The structure, \( PN \), has five components: \( P \), a set of places; \( T \), a set of transition; \( I \), a set of input arcs that connect places to transitions; \( O \), a set of output arcs that connect transitions to places and \( M \) is markingis a way of showing the current state of the net. Notationally, we use the definition. Each of these concepts has a graphical representation. The place is represented by a circle, the transition by a bar, and the input and output mapping by a set of directed arcs. The marking, \( M \), is a way of showing the current state of the net, where the state of the net defines which places are active.

Changes in the markings of a PN portray its components, or changes in state after some time. The rules of Petri net components are essential. A PN changes its state by changing its stepping. A stepping changes when a token moves beginning with one spot then onto the following spot. This is done by ending an advancement. An advancement may fire when it is enabled. An advancement is engaged when there is a token in most of its data places. Right when the advancement fires, it ousts a token from all of its data places and adds a token to all of its yield places.

The PN depicted above is known as a standard petri net. In this class of PN, when a change fires, one token is accepted from every data position and one token is spared into each yield place. An ordinary Petri net has a twist weight of 1, where the bend weight demonstrates the amount of tokens that cross the roundabout fragment when its encouraging flames. A PN can have any essentialness, dependent upon the explanation given it by the customer. Presently it is worthwhile to consider the spots practices that occur over some unclear time period. The advances can be thought of as events that occur at a minute in time.

We have as of late communicated that the dynamic direct of PN is described by changes in its stepping. The checking changes when an advancement fires. An advancement fires when its data states are checked. Even more formally, an advancement \( t_j \) is enabled in checking \( M_{last} \) if \( M_{last} (p_i) \geq I (p_i, t_j) \).

Exactly when a change \( t_j \) fires it results in another checking, \( M_{new} \), which occurs by removing \( I(p_i, t_j) \) tokens from all of its information puts and including \( O(p_i, t_j) \) tokens to all of its yield places. Even more formally, \( M_{new} \) is reachable from \( M_{last} \) according to the condition:

\[ M_{new} = M_{last} + (O-I) T_{fire} \]  

(4)
3. Algorithm design
The algorithm design starts by converting the robot mobile travel map to petri net modeling, the modeling will be divided into two parts, namely at the time of departure and upon return, therefore, we will be in the opposite direction.

Completion of algorithm using net petri mirror will began from determination of map invironment conversed to petri net to each events when departure and when return, results of models from petri net will get value marking, this marking value will be used when departure calculations and return as a navigation mobile robot.

![Algorithm Design](image)

**Figure 1.** Algorithm Design.

A. Case Study
The mobile robot robot will move from the start position to the finish position and return to the starting position, A → B, B → C, C → D, D →E and E → D, D → C, C → B, B → A, for this case the petri net mirror strategy isn't utilized.

![Case Study](image)

**Figure 2.** map environment for departure and return (a) Mobile robot Travel from A position to Target goal E and return to A position (b) Convert to petri net model.
From the picture, there are 2 lines written simultaneously, namely at the time of departure and when returning, the result of conversion to the petri net model also shows that there are 2 arrows that indicate the time of departure and when returning from the mathematical results a result \((O-I) = 0\), things this indicates that the calculation of the petri net close loop model will not produce a mathematical model, for this reason, each model is made when departing and when returning.

Input values and output values are obtained:

\[
I = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}, \quad O = \begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \quad O-I = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 \end{pmatrix} - \begin{pmatrix} 0 & 0 & 0 \\ 1 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 \end{pmatrix} - \begin{pmatrix} 0 & 0 & 0 \\ 1 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}
\]

From the mathematical model above the results obtained are \((O-I) = 0\), the conclusion that this mathematical model cannot be used to calculate the movement of the mobile robot from position A to position E for departure and when returning. By using the mirror petri net method we will convert the respective map environment to departure and return

**B. Mobile Robot Map Environment When Departing**

The mobile robot's movements will start from the position A \(\rightarrow\) B, B \(\rightarrow\) C, C \(\rightarrow\) D, and D \(\rightarrow\) E.

**Table 1. Information place and transition for departure mobile robot.**

| place | transition | information |
|-------|------------|-------------|
| P1    | T1         | mobile robot at A position move straight |
| P2    | T2         | mobile robot at B position move turn right |
| P3    | T3         | mobile robot at C position move turn left |
| P4    | T4         | mobile robot at D position move turn right |
| P5    |            | mobile robot at E position stop |

**Table 2. Information value marking for departure mobile robot.**

| Marking | Value   | Position | Describe |
|---------|---------|----------|----------|
| M0      | 1 0 0 0 0 | A        | Straight |
| M1      | 0 1 0 0 0 | B        | Turn right |
| M2      | 0 0 1 0 0 | C        | Turn left |
| M3      | 0 0 0 1 0 | D        | Turn right |
| M4      | 0 0 0 0 1 | E        | Stop     |

This analytical mathematic for mobile robot move from petrinet figure 3.
When departing:

\[
I = \begin{pmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{pmatrix} = O = \begin{pmatrix}
0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0
\end{pmatrix}
\]

When T1 firing:

\[
M_{\text{new}} = M_{\text{last}} + (O - I) T_{\text{firing}}
\]

\[
M_1 = M_0 + (O - I) T_1
\]

These outcomes show that the portable robot moves from position A to position B

When T2 firing:

\[
M_2 = M_1 + (O - I) T_2
\]

These outcomes show that the portable robot moves from position B to position C

When T3 firing:

\[
M_3 = M_2 + (O - I) T_3
\]

These outcomes show that the portable robot moves from position C to position D

When T4 firing:

\[
M_4 = M_3 + (O - I) T_4
\]

These outcomes show that the portable robot moves from position D to position E
C. Mobile Robot Map Environment When Return

The mobile robot’s movements will start from the position E → D, D → C, C → B, B → A and when return the method mirror petri net is used

![Diagram of robot movements](image)

Figure 4. Map environment travel robot and conversion model petri net when return (a) Travel from E position to Target goal A  (b) Convert to petri net model.

| Place  | INFORMATION                  | Transition | INFORMATION                  |
|--------|------------------------------|------------|------------------------------|
| P1     | mobile robot at A position   | T1         | mobile robot move straight   |
| P2     | mobile robot at B position   | T2         | mobile robot move turn right |
| P3     | mobile robot at C position   | T3         | mobile robot move turn left  |
| P4     | mobile robot at D position   | T4         | mobile robot move turn right |
| P5     | mobile robot at E position   |            |                              |

Table 3. Information place and transition for return mobile robot.

| Marking | Value | Position | Describe   |
|---------|-------|----------|------------|
| M0      | 1 0 0 0 | A        | Stop       |
| M1      | 0 1 0 0 | B        | Turn left  |
| M2      | 0 0 1 0 | C        | Turn right |
| M3      | 0 0 0 1 | D        | Turn left  |
| M4      | 0 0 0 1 | E        | Straight   |

Table 4. Information value marking for return mobile robot.

When return:

\[
I = \begin{bmatrix}
0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0
\end{bmatrix} \quad O = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0
\end{bmatrix} \implies O-I = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0
\end{bmatrix}
\]

When T4 firing:

\[
M_{\text{new}} = M_{\text{last}} + (O-I) T_{\text{firing}} \\
M3 = M4 + (O-I) T4
\]

These outcomes show that the portable robot moves from position E to position D.
When T3 firing:
\[ M_2 = M_3 + (O - I) T_3 \]

These outcomes show that the portable robot moves from position D to position C

When T2 firing
\[ M_1 = M_2 + (O - I) T_2 \]

These outcomes show that the portable robot moves from position C to position B

When T1 firing:
\[ M_0 = M_1 + (O - I) T_1 \]

These outcomes show that the portable robot moves from position B to position A

4. Conclusion
This method is proposed to navigate the mobile robot to run from the start to the target destination and return to the starting position using the petri net mirror method. From the results of mathematical calculations, the results of robot movements at departure and when returning, indicate when going and returning will produce navigation the opposite and with the petri net mirror method it is very good to use for traveling robots that move and return to their place of origin, for implementation of marking value navigation can use rfid [9] as mobile robot navigation information.

| Table 5. Information value marking for departing and return. |
|-------------------------------------------------------------|
| From A to E position | From E to A position | Marking | Direction | Marking | Direction | Conclusion |
|----------------------|----------------------|---------|-----------|---------|-----------|------------|
| M0                   | straight             | M0      | stop      | Oposite direction |
| M1                   | turn right           | M1      | turn left | Oposite direction |
| M2                   | turn left            | M2      | turn right| Oposite direction |
| M3                   | turn right           | M3      | turn left | Oposite direction |
| M4                   | stop                 | M4      | straight  | Oposite direction |

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