A smart guidance navigation robot using petri net, database location, and radio frequency identification

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ABSTRACT

The objective of this research is to explain a new framework to navigate the movement of the robot towards a target goal. This involves the need for the robot to move from the initial position to 1 out of 30 rooms. Therefore, the strategy used involves the combination of the room database stored in the RFID data using the petri net (PN) method to simulate and model the movement of the robot for navigation after which the dynamic behavior of the robot is moving to the desired location was analyzed. The process started from the creation of an environmental map determined by the user followed by modeling through PN and the result was used to produce a marking value which explains and navigates the movement of the robot towards the selected room. The marking value was also used as the database for the robot’s movement and later substituted with the RFID to be used as the sensor input in the implementation stage. It was concluded that the robot has the ability to move to the target position according to the database stored in RFID and designed to move forward and turn left and right. For example, it followed the marking value M1 M2 M3 M13 M12 M11 M10 M9 M8 to Room 1 and M1 M2 M46 M47 to Room 29.

Keywords:
Marking
Petri net
Place
RFID
Robot
Transition

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1. INTRODUCTION

This research was conducted to describe the navigation system for mobile robots assumed to be moving autonomously in man-made environments such as hallways in a building. The main focus is on global and local path planning. The key function of global path planning is to dictate a direction towards a goal at a particular place such as the intersection of two hallways in a building while the local path planning plays a role in moving the robot along walls to avoid obstacles. The navigation system, therefore, requires a mechanism to recognize these places in the building and locating them on a world map to provide course directions to the goal.

There is also a need for the function to generate a free space map in a hallway. Moreover, the two common approaches to global path planning are metric-based and landmark-based navigation [1]. Metric-based navigation relies on metric maps of the environment and this results in navigation plans such as moving forward five meters, turning ninety degrees right, and moving forward another eight meters. Meanwhile, this approach relies on dead-reckoning for position-sensing schemes based on information on the motion of the robot derived from the wheel encoders [2]. These metric data are, however, likely to be corrupted by sensor noise and this navigation method is vulnerable to inaccuracies in position estimates.

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This means navigation is one of the important problems needed to be resolved in developing mobile autonomous robot technology towards supporting its mobility. This problem involves several important components starting from the issues of perception which is indicated by the method required by an autonomous robot to obtain certain data from the surrounding environment and be able to interpret them into useful information for the next process. This is, however, closely related to the sensor and recognition problems.

The next problem is localization which is a method or way for an autonomous robot to know its position or existence in an environment it is required to complete a mission or achieve the objectives assigned. Meanwhile, the last problem related to the development of a navigation module in autonomous robots is the problem of cognition and motion control. This is related to the methods applied by the autonomous robots to move towards reaching a destination position required to complete a mission. These are, therefore, associated with the development of computational problem-solving algorithms to determine the steps required to be taken by an autonomous robot from its initial position to its final destination position based on its ability to interact and control its motor components.

Radio frequency identification (RFID) is the wireless non-contact use of radiofrequency waves to transfer data. Tagging items with RFID tags allows users to automatically and uniquely identify and track inventory and assets and the concept has taken the auto-ID technology to the next level by allowing tags to be read without a line of sight with the range observed to be between a few centimeters to several meters depending on the type of the RFID. This technology has come a long way from its first application and this makes it more cost-effective and efficient.

Every RFID system contains at least the following four components, readers, antennas, tags, and cables even though each system varies in terms of type and complexity of the device. RFID tags communicate with readers and antennas via electromagnetic waves in the vicinity with the energy from the waves harnessed by the RFID tag’s antenna used in forming a current which moves towards the center of the tag to energize the integrated circuit (IC). This IC is turned on, modulates the energy with data from its memory banks, and directs a signal back out through the tag’s antenna.

Petri nets (PN) are graphical and mathematical modeling tools applicable to several systems [3]-[6]. They are a promising tool to describe and study the information processing systems characterized as being concurrent, asynchronous, distributed, parallel, nondeterministic, and/or stochastic. Moreover, PN also serve as a graphical tool to provide visual-communication aid which is similar to flow charts, block diagrams, and networks. They also have tokens to simulate the dynamic and concurrent activities of systems.

Many studies have been conducted on mobile robots with only one goal target control as observed with the use of fuzzy logic [7]-[11], particle swarm optimization [12], odometry [13], the need for precise motor rotation constraint, database using RFID for only one goal target [14]-[19], motion robot [20]-[23], navigation gps [24], merging between PN and RFID for navigation with 1 destination and 4 destinations [25]-[27].

The objective of this research is, to explain a new framework to navigate the movement of the robot towards a target goal. This involves the need for the robot to move from the initial position to 1 out of 30 rooms. Therefore the strategy used involves the combination of the room database stored in the RFID data using the PN method to simulate and model the movement of the robot for navigation after which the dynamic behavior of the robot is moving to the desired location was analyzed.

2. PETRI NET FUNDAMENTALS

A PN is a graphical and mathematical tool used in modeling concurrent, asynchronous, distributed, parallel, non-deterministic, and/or stochastic systems. A formal definition of a PN [3] is, therefore, presented in (1).

$$\text{PN}=(\text{P}, \text{T}, \text{I}, \text{O}, \text{M})$$  \hspace{1cm} (1)

a. $\text{P}=\{p_1, p_2, p_3 \ldots p_n\}$ is a group of a place with $n \geq 0$.
b. $\text{T}=\{t_1, t_2, t_3 \ldots t_m\}$ is a group of a transition with $m \geq 0$.
c. I is mapping input $\text{P} \times \text{T} \rightarrow \{0, 1\}$ relating to the group of arrow originating from $\text{P}$ to $\text{T}$, and the arrow is also called the input.
d. O is mapping output $\text{T} \times \text{P} \rightarrow \{0, 1\}$ relating to the group of arrow originating from $\text{T}$ to $\text{P}$, and the arrow is also called the output.
e. M: P is marking places with the number of token in place.

The movement of the token through the PN represents the dynamical behavior of the system and the position of the token can be changed using the following transition firing rule:
a. A transition \( t \in T \) is enabled if every input place \( p \in P \) of \( t \) has \( w(p, t) \) tokens or more where \( w(p, t) \) is the weight of the arc from \( p \) to \( t \).

b. An enabled transition \( t \) will fire if the event represented by \( t \) takes place.

c. When an enabled transition \( t \) fires, \( w(p, t) \) tokens are removed from every input place \( p \) of \( t \) and \( w(t, p) \) tokens are added to every output place \( p \) of \( t \) where \( w(t, p) \) is the weight of the arc from \( t \) to \( p \).

2.1. **Modeling of the petri net**

In modeling a graph from a PN, there are 4 components involved and they include:

a. Place (P) which is represented by a circle,

b. Transition (T) which is represented by a rectangle or bar,

c. Token which is represented by a dot, and

d. Arrow which is the connection between place and transition.

2.2. **Benefits of petri net**

PN is useful to model a system with the following characteristics as:

a. Conflict, conflict modeling in Figure 1 (a) is very suitable when actions like selecting a path need to be defined such as going straight, turning left, or turning right. It is, therefore, possible to implement the sequence of movement of the PN model step by step to achieve the goal.

b. Sequence, in Figure 1 (b), transition \( t_2 \) can fire only after the firing of \( t_1 \). This imposes the precedence constraint “\( t_2 \) after \( t_1 \)”.

Such precedence constraints are typical of the execution of the parts in a dynamic system. Also, this PN construct models the causal relationship among activities.

![Figure 1. Modeling for PN, (a) conflict, (b) sequence](image)

2.3. **To run a petri net**

A PN causes changes to the previous marking and it is executed by firing at a possible marking. Meanwhile, a transition is enabled when each input place has a minimum of one token and the firing is marked by the movement of the token from place input to place output for the transition. This is usually followed by the movement of the token through an arrow from one place to another.

It has been previously shown that the dynamic direct effect of PN is described by the changes in its stepping and markings when advancement fires after the data states are checked. Even more formally, an advancement \( t_j \) is enabled in checking \( M_{last} \) if \( M_{last}(pi)\neq I \) \( (pi, tj) \), and \( M_{new} \) is reachable from \( M_{last} \) according to the following condition.

\[
M_{new}=M_{last}+(O-I) T_{firing} \tag{2}
\]

A change in \( t_j \) fires produces exactly another checking, \( M_{new} \), which occurs by removing \( I(pi, tj) \) tokens from all of its information and replace them with \( O(pi, tj) \) tokens in all the yield places.

3. **PROPOSED APPROACH**

The combination of PN and RFID is very possible due to the potentials of RFID to function as navigation for robot movement using the place, transition, and token models. The following flowchart, however, explains the process of filling-in the room data based on the RFID after the PN model has been formed. All the activities of the robot starts from the home position to the desired position, for example, the movement towards room 1 requires the robot moves from the home position to the target goal which is room 1. Figure 2 explains how the conversion process from the landmark environment into the PN model. After obtaining the place, transition, arrow, and token direction models will be generated the marking values, which will be inputted into RFID as a mobile robot navigation database. The desire of the mobile robot will be triggered using RFID. To get to the desired room.
3.1. Worked example

Figure 3 explains the movement of a robot from the home position to the target room out of 30 rooms and this landmark image was later converted into a PN model. The robot is shown in the image to be available in the home position and to later move to 30 spaces precisely after which the landmark map was converted to a PN model. Figure 4 describes the results of the landmark image conversion to show the natural conversion model of robot movement after which this image was used to comprehensively explain each place and transition. The token in place 1 (P1) indicates the beginning of the movement starting from the home position.
Table 1 shows the place value and the marking value used in explaining the position of the robot while the transition value was used to describe its motion. The three main movements observed were straight, turning left, and turning right. The Table 2 shows each room to be addressed as a database when moving to a certain room starting with marking M1 and total rfid usage is 48 RFID for marking and 30 RFID for database so total 78 rfid for models like this.

**Figure 4. PN model from Figure 3**

**Table 1. The place, transition, and marking models**

| Place | Marking | Position Robot | Transition | Move Robot | Place | Marking | Position Robot | Transition | Move Robot |
|-------|---------|----------------|------------|------------|-------|---------|----------------|------------|------------|
| P1    | M1      | Home position  | T1         | Straight   | P25   | M25     | Choose turn left/right/straight | T25        | Turn left  |
| P2    | M2      | Choose turn left/right/straight | T2         | Straight   | P26   | M26     | Choose turn left/right/straight | T26        | Straight   |
| P3    | M3      | Choose turn left/right/straight | T3         | Turn right | P27   | M27     | Choose turn left/right/straight | T27        | Straight   |
| P4    | M4      | Robot at room 5 | T4         | Turn left  | P28   | M28     | Choose turn left/right/straight | T28        | Straight   |
| P5    | M5      | Robot at room 4 | T5         | Turn right | P29   | M29     | Robot at room 22               | T29        | Straight   |
| P6    | M6      | Robot at room 3 | T6         | Turn left  | P30   | M30     | Robot at room 23               | T30        | Turn right |
| P7    | M7      | Robot at room 2 | T7         | Turn left  | P31   | M31     | Robot at room 24               | T31        | Turn right |
| P8    | M8      | Robot at room 1 | T8         | Turn left  | P32   | M32     | Robot at room 25               | T32        | Turn right |
| P9    | M9      | Choose turn left/right | T9         | Turn left  | P33   | M33     | Robot at room 26               | T33        | Turn right |

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obtains the navigation directly from the RFID. Based on the markings which contains straight movement, turning left, and turning right as indicated by M1 M2 M3 M13 M12 M11 M10 M9 M8.

Figure 6 (b) The robot also moved from the home position to room 29 and this required the database was filled with a program to follow the marking which contains straight movement, turning left, and turning right as indicated by M1 M2 M46 M47. The robot moves to the room based on the PN and the RFID database and obtains the navigation direction from the RFID. Figure 7 explaining the test room robot moves into the room based on PN and RFID databases, the robot moves to the room based on the PN and the RFID database and obtains the navigation directly from the RFID.

### Table 1. The place, transition, and marking models (continue)

| Place | Marking | Position Robot | Transition | Move Robot | Place | Marking | Position Robot | Transition | Move Robot |
|-------|---------|----------------|------------|------------|-------|---------|----------------|------------|------------|
| P10   | M10     | Choose turn left/right/straight | T10 | Turn left | P34 | M34 | Robot at room 11 | T34 | Turn right |
| P11   | M11     | Choose turn left/right/straight | T11 | Turn left | P35 | M35 | Robot at room 12 | T35 | Turn right |
| P12   | M12     | Choose turn left/right/straight | T12 | Straight | P36 | M36 | Robot at room 13 | T36 | Turn right |
| P13   | M13     | Choose turn left/right/straight | T13 | Straight | P37 | M37 | Robot at room 14 | T37 | Turn right |
| P14   | M14     | Robot at room 10 | T14 | Straight | P38 | M38 | Robot at room 15 | T38 | Straight |
| P15   | M15     | Robot at room 9 | T15 | Straight | P39 | M39 | Robot at room 16 | T39 | Straight |
| P16   | M16     | Robot at room 8 | T16 | Turn right | P40 | M40 | Robot at room 17 | T40 | Turn left |
| P17   | M17     | Robot at room 7 | T17 | Turn right | P41 | M41 | Robot at room 18 | T41 | Turn left |
| P18   | M18     | Robot at room 6 | T18 | Turn right | P42 | M42 | Robot at room 19 | T42 | Turn left |
| P19   | M19     | Robot at room 5 | T19 | Turn right | P43 | M43 | Robot at room 20 | T43 | Turn left |
| P20   | M20     | Robot at room 17 | T20 | Turn right | P44 | M44 | Robot at room 21 | T44 | Turn left |
| P21   | M21     | Robot at room 18 | T21 | Turn left | P45 | M45 | Robot at room 22 | T45 | Straight |
| P22   | M22     | Robot at room 19 | T22 | Turn left | P46 | M46 | Robot at room 23 | T46 | Turn left |
| P23   | M23     | Robot at room 20 | T23 | Turn left | P47 | M47 | Robot at room 24 | T47 | Turn left |
| P24   | M24     | Choose turn left/right/straight | T24 | Turn left | P48 | M48 | Robot at room 25 | T48 | Turn left |

### Table 2. Database based on target room destination

| RFID   | Target Room | Database Navigation | RFID   | Target Room | Database Navigation |
|--------|-------------|---------------------|--------|-------------|---------------------|
| Tag 1  | R1          | M1 M2 M3 M13 M12 M11 M10 M9 M8 | Tag 16 | R16         | M1 M2 M3 M9 M8 M3 M7 M34 |
| Tag 2  | R2          | M1 M2 M3 M13 M12 M11 M10 M7 | Tag 17 | R17         | M1 M2 M4 M25 M26 M27 M28 M19 |
| Tag 3  | R3          | M1 M2 M3 M13 M12 M11 M6 | Tag 18 | R18         | M1 M2 M4 M25 M26 M27 M28 M20 |
| Tag 4  | R4          | M1 M2 M3 M13 12 15 | Tag 19 | R19         | M1 M2 M24 M25 M26 M27 M28 |
| Tag 5  | R5          | M1 M2 M3 M13 M4 | Tag 20 | R20         | M1 M2 M24 M25 M26 |
| Tag 6  | R6          | M1 M2 M3 M13 M12 M11 M10 M9 M18 | Tag 21 | R21         | M1 M2 M4 M23 |
| Tag 7  | R7          | M1 M2 M3 M13 M12 M11 M10 M17 | Tag 22 | R22         | M1 M2 M24 M25 M26 M27 M28 M29 |
| Tag 8  | R8          | M1 M2 M3 M13 M12 M11 M16 | Tag 23 | R23         | M1 M2 M24 M25 M26 M27 M30 |
| Tag 9  | R9          | M1 M2 M3 M13 M12 M15 | Tag 24 | R24         | M1 M2 M24 M25 M26 M31 |
| Tag 10 | R10         | M1 M2 M3 M13 M14 | Tag 25 | R25         | M1 M2 M24 M25 M32 |
| Tag 11 | R11         | M1 M2 M3 M39 M34 | Tag 26 | R26         | M1 M2 M24 M33 |
| Tag 12 | R12         | M1 M2 M3 M39 M38 M35 | Tag 27 | R27         | M1 M2 M46 M43 |
| Tag 13 | R13         | M1 M2 M3 M39 M38 M37 M36 | Tag 28 | R28         | M1 M2 M46 M45 M44 |
| Tag 14 | R14         | M1 M2 M3 M39 M40 | Tag 29 | R29         | M1 M2 M46 M47 |
| Tag 15 | R15         | M1 M2 M3 M39 M38 M41 | Tag 30 | R30         | M1 M2 M46 M45 M48 |

### 4. RESULTS

Figure 5 indicates the laying of marking position starting from the starting position of home position M1 until the final position of room 30 M48. Figure 6 (a) shows the robot moved from the home position to room 1 and this required filling the database with a program to follow the marking which contains the straight movement, turning left, and turning right as indicated by M1 M2 M3 M13 M12 M11 M10 M9 M8. Figure 6 (b) The robot also moved from the home position to room 29 and this required the database was filled with a program to follow the marking which contains straight movement, turning left, and turning right as indicated by M1 M2 M46 M47. The robot moves to the room based on the PN and the RFID database and obtains the navigation direction from the RFID.
Figure 5. Marking position (RFID) for guidance navigation

Figure 6. Simulation of mobile robot movements; (a) from the home position to room 1 and, (b) from the home position to room 29
5. CONCLUSION

The mobile robot movement using the PN was successfully simulated by converting the landmark/map environment into a PN model, using simulations from the model to describe the place, transition, token, and marking after which the robot was made to move based on the model database in the form of the marking value which was used to navigate the robot to move straight, turn right, and turn left. The marking was later replaced with RFID with the design that the robot movement will change when the RFID is detected.

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