Path Planning for a Mobile Robot with a Non-holonomic Constraint

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Abstract

This reseach was carried out as a fundamental study on the path planning of a small mobile robots towing a trailer and navigating in the indoor environment. Application of freely navigating mobile robots to service tasks such as floor cleaning or document transprtation requires specific techniques for path planning and vehicle guidance. This article describes the algorithm to build a graph of environment taking into account the robot shape and its non-holonomic constraint.

I. Introduction

In path planning for mobile robot, it is important how to represent an environment. The model of the environment was developed in such way that can be easily specified by a human operator and also can be easily understood by the robot. Many previous research on the path planning for mobile robot have been reported [1][2][3][4][5]. However, it is not easy to find the research instance of the path planning considering robot shape and its kinematics.

In this paper, the algorithm to build a graph of environment for the real world navigation of the mobile robot towing a trailer is proposed. The algorithm was taken into account the robot shape and its non-holonomic constraint, and based on cell decomposition representation method. Furthermore, the traffic rules were introduced as a restriction for the feasibility of connection between cells. As a result, having the robot initial orientation and position and it desired goal position, and using the developed graph it can be easily found a feasible path for a non-holonomic constraint robot. This feasible path can also full fill other requirement such as being the shortest or the safest.

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Ⅱ. Cell decomposition representation

The robot's workspace was considered as a flat corridor building. The world space is divided into cells. Each cell is connected with the adjacent cell forming a network of cells that represents the corridors of a building. Basically two types of cells are enough to represent all the possible cases.
The cell types are :

1. Corridor cell (CORR)

- A CORR type cell has two or more good reflecting walls.
- The start central point and the final central point of the cell are expressed using map global coordinates.
- The left and right walls of the cell are represented as a succession of vectors. Each time the wall has some irregularity or a change on the reflection properties, a new vector is used to represent it. Both the origin and end of the vectors are expressed using the cell start point as origin.

2. Cross cell (CRSS)

- A CRSS type cell is an intersection between CORR type cell.
- The cell central point coordinate are expressed using map global coordinates.
- Assuming the central point as origin, all the edge points are expressed in local coordinates from it. The type of object at the left of each point and its reflection properties are also specified

In both type of cells an obstacle is represented using vectors. These vectors are expressed in local coordinates from the origin of the cell and its reflection properties are also specified.

Ⅲ. Robot parameters

The analysis of the cell connections depends on the robot shape, hence we define the robot parameters as it is shown in Fig. 1. The trailer-towing robot can be modeled as a a long rectangle. L and △L, respectuvely, are the robot's length and the length from gravity center to its rear, and W is the robot's width. Two lateral spaces α and β were added to the original robot's shape to guarantee a robot's safe navigation.

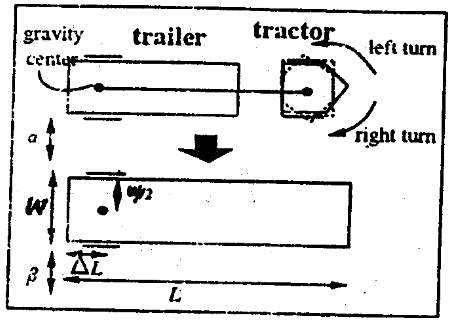

Fig.1 Robot parameters

Ⅳ. Robot traffic rules

In this research, the traffic rules were introduced as a restriction for the feasibility of connection between cells.

The robot must follow the following traffic rules:

1. If the corridor is width enough, to allow the navigation of two robots at the same time the corridor will "2 ways" of navigation. Otherwise it will have "1 way". As in the traffic rules the robot goes on the left and comes back on the right, as it is shown in Fig. 2. Its formulation is:

If $W_c \geq 2W_r + \alpha$ ⇒ Corridor has 2 ways

else ⇒ Corridor has 1 way.

Wc and Wr, respectively, are the corridor's width and the robot's width.

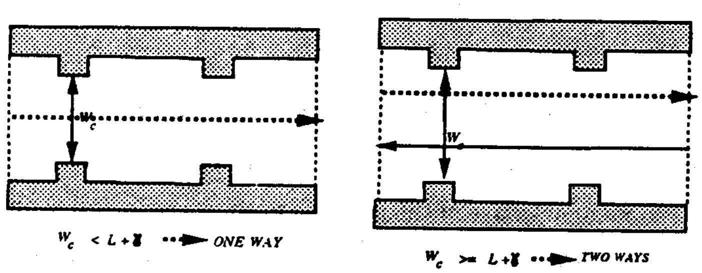

Fig. 2 Corridor attributes definition

2. It is not allowed to pass to a corridor on the wrong way as in the traffic rules (See Fig.3).

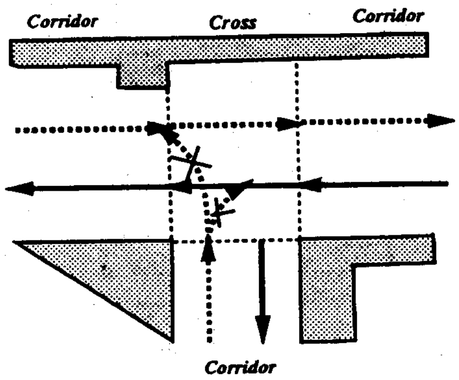

Fig. 3 Wrong way connections are not allowed

3. When the corridor thas two ways the robot is allowed to make U turns only at the beginning and at the end of that corridor(See Fig.4).

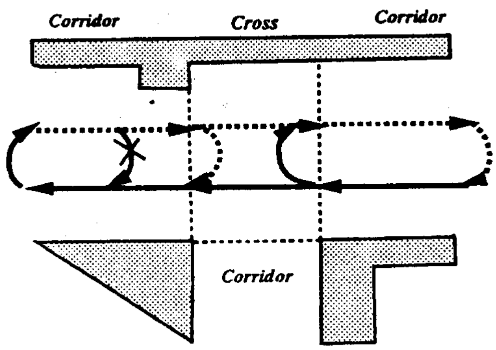

Fig. 4 U-turn rules

V. Graph construction

To model the graph, we consider the robot is non-holonomic constraint as well as the well known traffic rules. The main objective of the graph is to show the logical connections between cells and the cost of each path. This information will be used to perform searches. Since, we already have the word cell decomposition, then we construct the graph automatically based on that environment representation and the robot shape. The CORRIDOR CELL becomes the graph nodes and the CROSS CELL becomes the graph arcs. As some corridors has only one way the graph must be DIRECTED. For example having an environment as the one is shown in Fig.5, the correspondence graph will be as is shown in Fig.6.

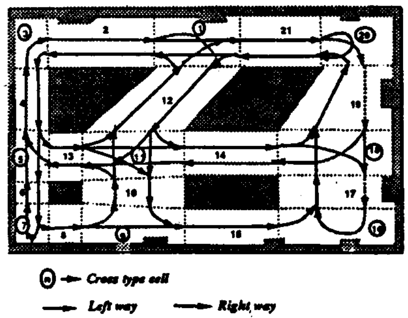

Fig.5 Indoor environment with cell division and routes

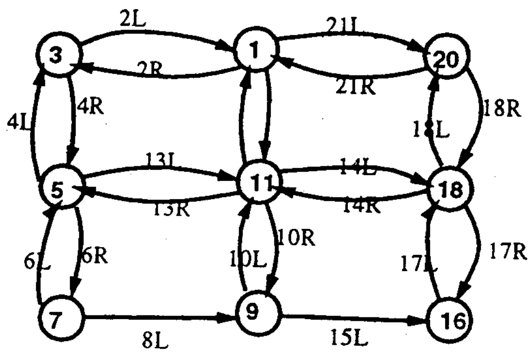

Fig.6 Directed graph

A. *Arcs and Node definition*

This part describes the arcs and nodes of the graph.
The arcs and nodes of the designed graph have the following attributes.

Node attributes	Description
Node number	CRSS cell number
Incoming arcs	Number and orientation of incoming arcs
Outcoming arcs	Number and orientation of outcoming arcs
Arcs transition states	For each incoming arc calculate the feasibility of a path connecting it with each outcoming arc.

Arc attributes	Descripton
Arc number	CORR cell number
Arc type	[2ways — 1way]
Orientation	[Horizontal —Vertical]
Minimun width	Corridor min width
Length	Corridor length
Good reflection avg	Average of good reflecting walls
Tail node	Node at the end of the arc
Head node	Node at the beggining

1) Arc attributes:

·Arcs direction on the corridor.

The corridor cell are defined by a start central point and a final central point. The arcs direction is considered LEFT if the arcs goes from the start point to the final and it is RIGHT if the arcs goes from the final to the start point(See Fig.7).

·The arc minimum width is calculated using the map information.

·The arc length is calculated using the cell limits.

·The average of good reflection walls is calculate using the wall reflection attached to each vector that forms the cell. It is calculated at both sides of the wall.

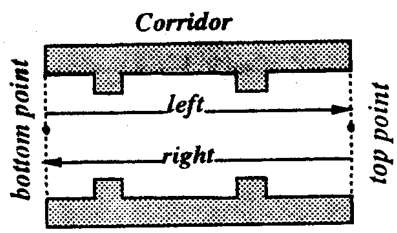

Fig. 7 Arc direction and cell relation

2) Node attributes :

·The node incoming arcs are determinate by finding all the corridors that incidence the node. In order to choose the incoming arc way, we only need to check if the node reach the arc at the bottom point or at the top point. If the arc reach the node at the cell bottom point the incoming arc must be RIGHT oriented otherwise must be LEFT oriented.

•The node outcoming arcs are determinated in a same way as the incoming arcs.

•The node transition states shows the real connection between all the incoming arcs with all the out coming arcs. At this step the turn possibility is considered.

After the transition states were all caiculated we obtain a matrix for cach incoming arcs:

$$
\begin{array}{c} \\ n_1 \\ n_2 \\ n_3 \\ \cdots \\ n_n \end{array}
\begin{array}{c} \begin{array}{ccccc} m_1 & m_2 & m_3 & \cdots & m_m \end{array} \\
\begin{bmatrix} X & 0 & X & \cdots & 0 \\ 0 & X & X & \cdots & 0 \\ 0 & X & X & \cdots & X \\ X & 0 & 0 & \cdots & X \\ \cdots & \cdots & \cdots & \cdots & \cdots \end{bmatrix} \end{array}
$$

The number of incoming arcs is N and the outcoming arcs is M. The "X" means that there is not connection between arcs and the "0" means that exist connection. According with Fig. 8, the algorithm to check the turning possibility will be as follows:

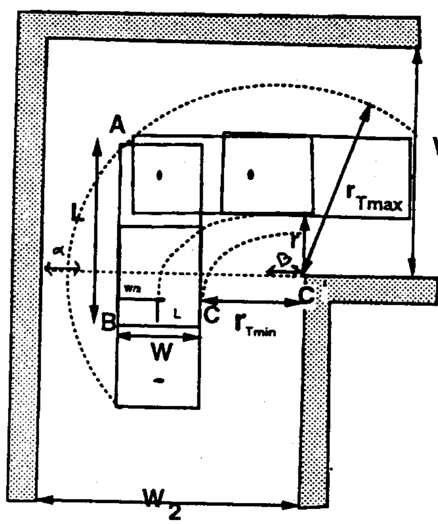

Fig. 8. Robot arc turning

For each incoming arc : Calaulates its orientation and the all outcoming arcs orientation.

- If they have the same orientation the path is feasile.
- If they have different orientation but they are part of the same corridor a U-turn

feasibility is checked.

- If they have different orientation and they are part of different corridors a turn feasibility it is cheked.

• The feasibility of a Turn is given by the following sufficient condition:

$$W_c \geq r_{Tmax} + \alpha \, , \, r_{Tmin} \geq \beta \tag{1}$$

$$r_{Tmax} = \overline{AC} = \sqrt{(\gamma + \frac{W_r}{2})^2 + (L - \triangle L)^2} \tag{2}$$

$$W_c = \min\{W_1, W_2\} \tag{3}$$

$$W_c \geq \alpha + \sqrt{(\beta + W_r)^2 + (L - \triangle L)^2} \tag{4}$$

• The feasibility of a U-turn is given by the following condition:

$$W_c \geq 2L + \frac{W}{2} + r$$

Ⅵ. Conclusions

In this paper, we proposed the algorithm to build a directed graph model that can be used to do path planning for the robot towing a trailer. In this algorithm, the robot shape and its non-holonomic constraint were taken into account, and also the traffic rules were introduced as a restriction for the feasibility of connection between cells. As the results, the graph is formed automatically having the robot dimensions and the map of the environment.

Further work will focus on the path planning take into account the obstacles on the cells and the movements of the robot.

References

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