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Research on static path planning method of small obstacles for automatic navigation of agricultural machinery

Changqing Liu*, Xueyan Zhao*, Yuefeng Du*, Chao Cao*, Zhongxiang Zhu*, Enrong Mao*

** Beijing Key Laboratory of Optimized Design for Modern Agricultural Equipment, College of Engineering，Beijing 100083*
(Corresponding author: Xueyan Zhao, e-mail: xyzhao@cau.edu.cn)

Abstract: In order to enable the automatic navigation agricultural machinery effectively avoid the local static small obstacles in the field operation process, obstacle avoidance path planning method is studied for agricultural machinery in the case of known environmental information in this paper. Firstly, the obstacle avoidance path for a single small obstacle is proposed as the path consisting of three circular arcs, which solves the problem that agricultural machine holds minimum turning radius and is difficult to achieve line turning in the driving path. Then, the different situations of many small obstacles in the same driving path are analysed and the obstacle avoidance path planning method for many small obstacles is proposed when the obstacles are on the same driving path and in the relatively far distance. Finally, simulation study is conducted and the result proves that the proposed methods can plan effective path to avoid obstacles for automatic navigation agricultural machinery in complex conditions such as multiple obstacles with relatively far distances. The research works in this paper can provide essential references for obstacle avoidance path planning in other relevant fields.

Keywords: Path planning; Obstacle avoidance; Small obstacle; Agricultural machinery; Automatic navigation

1. INTRODUCTION

With the rapid development of technology, modern agricultural production is progressively going towards automation, informatization, and refinement (Ji Changying and ZhouJun, 2014). The agricultural machinery automatic navigation technology is the foundation of agricultural machinery automation, informatization and refinement. Therefore, in order to enable agricultural machinery autonomous navigation to accomplish tasks successfully and efficiently, a reference operation path has to be planned. And the quality of planning path directly affects the quality of operation. So path planning is one of the most important parts in automatic navigation of agricultural machinery (Wu Yanxia et al., 2009).

Extensive researches have been conducted on the path planning method of agricultural navigation. According to whether environmental information was known, Choset divided the full coverage path planning into two parts: online and offline (Choset H, 2001). Carvalho et al. presented a new algorithm of operating path planning with the environment information totally known to solve the problem of incomplete coverage (De Carvalho R N, 1997). Jin et al. (2006, 2010) investigated the boundary consumption cost of agricultural machinery for different turning modes, and introduced a new optimal path planning algorithm. With regard to the problem of mechanical path optimization in field operation, Meng et al. explored the evaluation index, and tested the whole area coverage path planning algorithm for different evaluation indexes (Meng Zhijun et al., 2012). TaÏx and Souères proposed Hamiltonian method and geometry method for full coverage path planning, but the geometric method was used with a higher frequency because the Hamiltonian method was more complex and did not conform to the actual work habits (Michel Taïx et al., 2006).

Agricultural machinery may come across certain obstacles in field operation, such as gully, wire pole, tree and ground well, but agricultural machinery cannot drive through obstacles. Therefore, local obstacle avoidance path has to be considered on the basis of the global planned path. According to the relationship between the obstacle size and the width of agricultural machinery operation, the obstacles are divided into two categories: small obstacles and large obstacles (Michel Taïx et al., 2006). The large obstacle avoidance path is planed mainly by region segmentation method, which means that the blocks which contain large obstacles are divided into several subregions and then path planning is conducted separately in each subregion. And the main segmentation methods include trapezoid segmentation method, bottom-up method and cell division method (Choset H, 2000, Garcia E and Santos P G D, 2004). For the path planning of small obstacles, the shortest tangent line method is one of most commonly used method. However, the obstacle avoidance path planned by this method contains fold lines, and is not suitable for the agricultural machinery which holds the minimum turning radius (Huo Yinghui and Zhang Lianming, 2003, Huo Yinghui et al.,2003). Therefore, Liu proposed an improved tangent obstacle avoidance path which is composed of circular arc and tangent line (Xiangfeng Liu, 2010). Meanwhile, Yuan also improved the shortest tangent

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line method by using the circular arcs to construct the obstacle avoidance path, and applied it in the small obstacles path planning of rice transplanter. This method shortens the length of obstacle avoidance path and reduces the consumption due to obstacle avoidance, but does not involve multiple obstacles in the same operation path (Yuan Jiahong, 2016). Therefore, in this paper, the obstacle avoidance path planning method for multiple small obstacles is studied.

This paper is organized as follows. After this introduction, the single small obstacle avoidance path planning method is studied in Section 2. Section 3 analyzes different situations of multiple small obstacles and proposes the obstacle avoidance path planning method for multiple small obstacles. The effectiveness of the new method is verified by numerical simulation study in Section 4. Finally, the conclusions are presented in Section 5.

2. OBSTACLE AVOIDANCE PATH PLANNING ALGORITHM FOR A SINGLE SMALL OBSTACLE

Obstacle avoidance path can be planned according to the size of the obstacle. The obstacles with the diameter of the minimum circumscribed circle less than 1 working width can be defined as small obstacles while other obstacles are defined as large obstacles (Yuan Jiahong, 2016). This study mainly focuses on the obstacle avoidance path planning for the small obstacles. In addition, it is assumes that the information of the working block is known and the radius and center position of minimum circumscribed circle of small obstacles are also known.

The obstacle avoidance area is assumed as a circle area. The centre position of the obstacle circle area is the same as centre position of minimum circumscribed circle of small obstacles. Because agricultural machinery holds the minimum turning radius and the equipment carried by the machine holds a certain working width, determination of the radius of the small obstacle circle area should consider these factors. When the minimum turning radius of agricultural machinery is denoted by r, working width of the equipment carried by the machine is denoted by w, and the radius of minimum circumscribed circle of small obstacle is denoted by R, the radius of the small obstacle circle area R_c is defined as:

障碍物半径的计算公式

$$R_c = max\{R, r - w/2\} \tag{1}$$

The straight-line of the original operation path through small obstacles can be expressed by the following equation.

$$y = kx + b \Leftrightarrow ax + by + c = 0 \tag{2}$$

where k is determined by the direction of operation and k=a=tan(θ), where θ denotes the direction angle of operation, that is, the clockwise angle between the operation path line and the positive x axis.

Small obstacle circle center coordinate is denoted by (x_o,y_o), then the distance between the circle center of obstacle region and working path can be calculated by :

$$d = \frac{|ax_o + by_o + c|}{\sqrt{a^2 + b^2}} \tag{3}$$

Whether the obstacle avoidance strategy should be adopted depends on the relationship between the operation width of agricultural machinery, the radius of the circle area of the small obstacle, and the distance between the circle centre of the obstacle circle and the operation path, namely:

(1)When R_c+w/2<=d, agricultural machinery can work along the original operation path without taking any obstacle avoidance strategy.

(2)When R_c+w/2>d, if the farm machinery still works along the original operation path, the machinery and equipment will collide with the small obstacles, which will affect the normal operation of agricultural machinery. Therefore, it is necessary to take the corresponding strategy to avoid the obstacles.

This paper investigates obstacle avoidance path planning for second situation. The principle of obstacle avoidance algorithm is that when the agricultural machinery bumps into the static small obstacle, it can avoid the small obstacles with the shortest path, and can turn smoothly when avoiding the obstacles. In the process of obstacle avoidance, due to the minimum turning radius, the agricultural machinery cannot drive in the broken line path. Therefore, the obstacle avoidance path in this paper is composed of three circular arc segments with the radius greater than the minimum turning radius of the agricultural machinery.

To facilitate understanding, the example shown in Figure 1 is considered to illustrate obstacle avoidance path planning. The obstacle avoidance path is composed of arc AB arc BC and arc CD. When planning the obstacle avoidance path, three auxiliary circles, one auxiliary straight-line and four feature points are identified firstly. The auxiliary circle 1 represents the auxiliary circle related to begin to turn away from the original operation path. The auxiliary circle 2 denotes the auxiliary circle related to return to the original operation path. And the main function of the auxiliary circle 3 and the auxiliary straight-line is related to the determination of the centre of the auxiliary circle 1 and circle 2.

Four feature points are denoted by Point A, Point B, Point C and Point D. Point A is the point where the agricultural machinery start to turn to void obstacle. Point B is the starting point of the obstacle avoidance path. Point C is the stop point of the obstacle path. Point D is the end point of the obstacle avoidance path.

In order to avoid the obstacle in the shortest path, the auxiliary line has to be parallel to the original work path, and the distance in the direction far away from the centre of the small obstacle circle is r. The equation of the auxiliary line shown in Fig. 1 is:

$$y = kx + b + r/\cos(\arctan(|k|)) \tag{4}$$

The auxiliary circle 3 is located on the centre of the small obstacle area, and the radius of the auxiliary circle 3 is $Rc+w/2+r$. Then, the corresponding equation is as follows:

$$(x-x_o)^2+(y-y_o)^2=(R_c+w/2+r)^2 \tag{5}$$

Two intersection points of auxiliary circle and auxiliary line can be obtained by simultaneous equations (4) and (5). And the first and the second intersection points along the direction of operation are defined as point O1 which is the centre of auxiliary circle 1 and point O2 which is the centre of auxiliary circle 2, respectively. Moreover, the radial of the auxiliary circle 1 and the auxiliary circle 2 are both the minimum turning radius of agricultural machinery, namely r.

When the coordinate of the centre O1 is denoted by (x_{o1}, y_{o1}), then the equation of the auxiliary circle 1 is:

$$(x-x_{o1})^2+(y-y_{o1})^2=r^2 \tag{6}$$

When the coordinate of the centre O2 is denoted by (x_{o2}, y_{o2}), then the equation of the auxiliary circle 2 is:

$$(x-x_{o2})^2+(y-y_{o2})^2=r^2 \tag{7}$$

The coordinates of the feature point A and the feature point D can be obtained by simultaneous equations (2) and (6) and simultaneous equations (2) and (7), respectively. And the feature point B is the intersection point between the auxiliary circle 1 and the line segment OO1 while the feature point C is the intersection point between the auxiliary circle 2 and the line segment OO2.

After determining the feature points of each arc path, the algorithm steps of local obstacle avoidance are as follows:

1) When agricultural machinery moves to point A, the local obstacle avoidance begins.
2) Starting from point A, agricultural machinery drives along the arc AB (the point O1 as the centre of the circle and r as the radius) to point B.
3) Starting from point B, agricultural machinery drives along the arc BC (the point O as the centre of the circle and $R_c+w/2$ as the radius) to point C in a shortest path.
4) Starting from point C, agricultural machinery drives along the arc CD (the point O2 as the centre of the circle and r as the radius) to point D.
5) Starting from point D, agricultural machinery continued to go along the original operation path.

Eventually, the obstacle avoidance path for a small obstacle is determined as a segmented arc composed of arc AB, arc BC and arc CD.

In the same way, a segmented circular arc avoiding path, composed of arc A'B', arc B'C' and arc C'D', can be achieved on the opposite operation line.

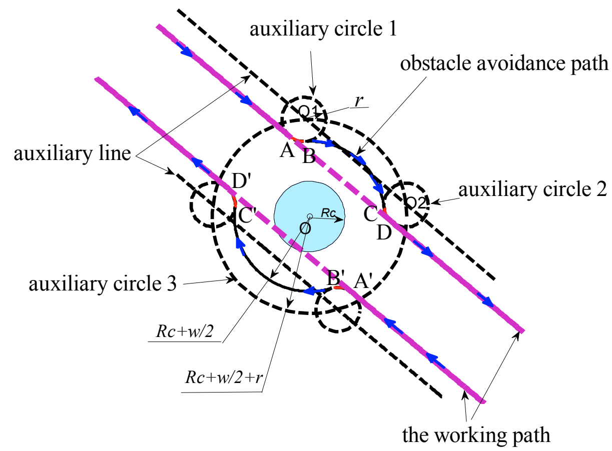


Fig. 1. Obstacle avoidance path of a single small obstacle.

3. OBSTACLE AVOIDANCE PATH PLANNING ALGORITHM FOR MULTIPLE SMALL OBSTACLES

When there are many small obstacles in the same operation line, the obstacle avoidance path planning cannot be carried out by the same algorithm as the obstacle avoidance algorithm for a single small obstacle but should be conducted according to the position relationships among the multiple small obstacles.

When there are N (N>=2) obstacles, according to the order of obstacles, the obstacles along the direction of operation are defined as obstacle 1, obstacle 2, …, and obstacle N, respectively. Firstly, the obstacle avoidance path of each obstacle without considering other obstacles is planned by the method of obstacle avoidance path planning for a single obstacle in Section 2, and the corresponding feature points are marked as A_1, B_1, C_1, D_1, A_2, B_2, C_2, D_2……A_N, B_N, C_N, D_N, respectively. Then according to the location relationship between two adjacent obstacles, the obstacle avoidance path considering multiple obstacles at the same time is determined. For the obstacle i (i=1,2,3...N-1), when the projection distance of the vector C_iB_{i+1} in the operating line is greater than or equal to $2r$, and if the angle between vector C_iB_{i+1} and operation direction is less than 90°, the obstacle avoidance path for each obstacle is the same as that of a single obstacle on the operation line; if the angle between the vector C_iB_{i+1} and the operation direction is less than 90°, two obstacles can be regarded as one obstacle to carry out the obstacle avoidance path planning; and if point C_i coincides with point B_{i+1}, two obstacles are also considered as one obstacle to plan obstacle avoidance path.

In order to explain the above algorithm, the example shown in Fig. 2 is considered. When only the obstacle i in the same operation line is taken into account but other obstacles are ignored, the four obstacle avoidance feature points for the obstacle i are A_i, B_i, C_i, D_i, respectively. And when only the obstacle i+1 in the same operation line is considered and other obstacles are ignored, the four obstacle avoidance feature points for the obstacle i+1 are A_{i+1}, B_{i+1}, C_{i+1}, D_{i+1}, respectively. In the case shown in Fig.2, the projection distance of the vector C_iB_{i+1} in the operation line is greater than $2r$, and the angle between the vector C_iB_{i+1} and the working direction is less than 90°, thus, the obstacle avoidance path between the obstacle i and the obstacle i+1 is: arc A_iB_i → arc B_iC_i → arc C_iD_i→ straight line D_iA_{i+1}→ arc $A_{i+1}B_{i+1}$→ arc $B_{i+1}C_{i+1}$ → arc $C_{i+1}D_{i+1}$.

Similarly, the method mentioned above can also be applied to 2 adjacent obstacles on other operation lines.

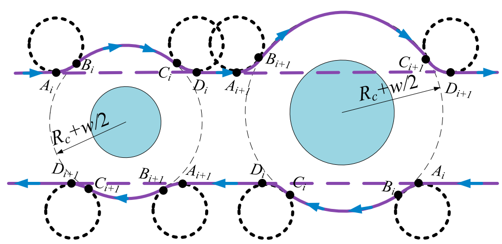


Fig. 2. Obstacle avoidance path planning of adjacent obstacles.

It should be pointed out that the proposed obstacle avoidance path planning algorithm for multiple small obstacles is only suitable to the case when the obstacles are far apart from each other and there is no consideration on the nearer situation of the small obstacles in operation line. Moreover, the algorithm mainly aims to avoid obstacles and protect the safety of agricultural machinery; therefore, operation path repetition and consumption in the process of obstacle avoidance are not taken into account.

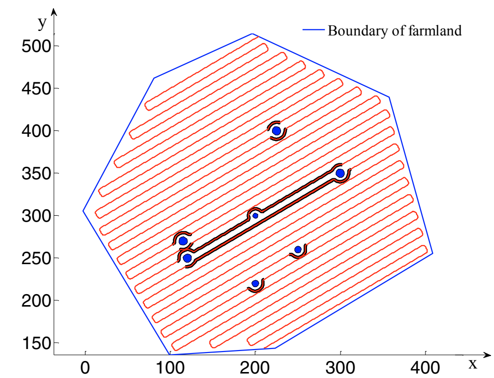
4. SIMULATION STUDIES

In order to verify the effectiveness of the proposed method, simulation studies are conducted in this section. For this purpose, an operation block with seven obstacles, as described in Table 1, is considered.

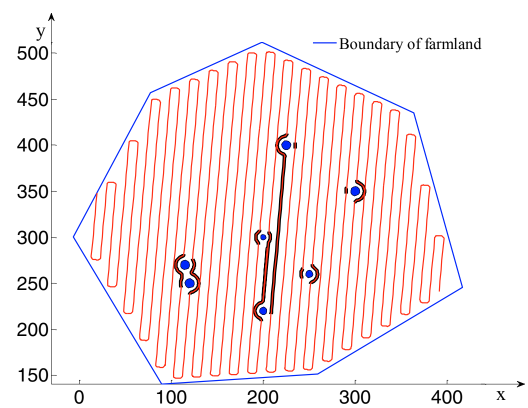
Table 1. Information about 7 small obstacles and farmland

Position of farmland (Vertex coordinates)	Minimum circumscribed small obstacles	
	Radius	Center coordinates
(100,150)	5	(200,220)
(250,160)	4	(250,260)
(400,250)	5	(225,400)
(200,500)	4	(300,350)
(90,450)	3	(200,300)
(10,300)	5	(120 250)
(350,430)	5	(115,270)

In this simulation study, the job width is set as w=10 and turning radius is set as r=3. When the operation direction angle is 30.5° and 85°, the simulation results are shown in Fig.3. In Fig. 3, when there is only one small obstacle on the operation line, the path is planned according to the situation of a small obstacle; when there are many small obstacles on the same operation path, the path needs to be adjusted several times to avoid obstacles. The path of bold lines in Fig. 3 is based on the obstacle avoidance path planned by proposed method in this paper. It can be seen that the algorithm proposed in this paper can successfully avoid obstacles in both cases of one obstacle on the operation line and multiple obstacles on the operation line, proving that the algorithm is effective and feasible.



(a)The angle of operation direction is 30.5°



(b) The angle of operation direction is 85°

Fig. 3. Obstacle avoidance path planning for multiple small obstacles

5. CONCLUSIONS

In this paper, the obstacle avoidance algorithm for single small obstacle is investigated, and the corresponding obstacle avoidance path is consisting of three circular arcs. The position relationships among the multiple small obstacles are analyzed and the obstacle avoidance algorithm for multiple small obstacles which are far away from each other in the same operation line is proposed. Simulation study shows that the path planed by the proposed method can avoid small obstacles in the same working path and is benefit to guarantee the safety of agricultural machinery. The research works in this paper can provide essential references for obstacle avoidance path planning in other relevant fields.

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