

# Path Planning Methods for Auto-Guided Rice-Transplanters

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**Abstract.** Paddy field operation asks for robotization due to labor shortage. In this paper, a set of path planning methods were developed and tested on a guidance for transplanters. Path planning of fieldbody and headland were generated and experimented for 3 years. The path outside field consist of farm lanes connecting garage to paddy field, and a ARC-NODE structure method was proposed. Method of optimal coverage path planning should be researched in near future.

**Keywords:** Guidance system · Transplanter · Path planning

## 1 Introduction

There is an increasing demand for autonomous and robotic systems in agricultural domain, such as ridging, seeding, transplanting, and tilling. Due to constraint of field shape and machine size, some research has carried out in coverage path planning (CPP) for agriculture [1], which looks for paths from a starting point to a target point with maximum cover, minimum repetition and omissions as little as possible, while headland turning is a fact that cannot be ignored. The basic task of a CPP method is producing paths for a single machine. For example, Kise [2] set minimum turning radius and maximum rotation rate as the goal, and used a third-order spline function to create two kinds of path of end turning, namely the forward turning and back turning. Oksanen [3] divided the path planning algorithm into 2 layer: the upper one divided the whole fields into small plots, while the lower one produce path for every plot. Hou [4] proposed two path planning methods of cultivation. Huang [5] proposed turn strategies of parallel line paths of agricultural machinery with  $\Omega$  shape and  $\Pi$  shape, and a path planning method of convex plots. Han [6] made a predefined path including C-shape headland turning for his auto-guided tractor.

A number of literatures discussed optimal algorithms. Noguchi [7] applied neural network algorithm to learn the movement of the tractor, and used genetic algorithm to find a optimal path. Jin [8] employed a genetic model to generate a optimal path. For a 3D terrain application [9], Jin modeled the terrain, and constructed a cost function based on a “seed curve” to find the optimal path. Hameed [10] also divided this problem into two stages. The first stage expressed geography relations, and the second one made optimal path. Mariano [11] developed an optimal path for reducing fuel consumption in weed and pest control. Linker [12] used the A\* algorithm to determine the optimal path for vehicles operation in orchards. Jensen [13] developed an algorithmic approach for the optimisation of capacitated field operations using the case of liquid fertilising, which optimised in a post-process stage that the nonproductive travelled distance in headland turnings is further minimised. Liu [14] applied a bidirectional link table to express a complex polygon, and then it was divided into simple polygons, and made optimal path to cover subarea. Bochtis [15] generated routing plans for intra- and inter-row orchard operations, based on the adaptation of an optimal area coverage method developed for arable farming operations. However, an optimal solution cannot be guaranteed commonly due to several constraints, including soil compaction, contour of field, and agronomic constraints.

To cooperate working with other agricultural machines, or in form of multi-robot, CPP methods were also proposed. Volos [16] proposed a chaotic path generation methods to cover whole area, whose advantage is that can quickly adapt to the changes in the environment. Bochtis [17] divided the field into grids and then used optimal method to plan paths. Jensen [18] proposed a path planning method for transport units in agricultural operations involving in-field and inter-field transports with an optimization criterions of time or traveled distance.

In the case of irregular field shapes and the presence of obstacles within the field area, Zhou [19] develop a planning method with multiple obstacles.

It could be seen that CPP method for machines of paddy fields is still scarce. The objective of this paper is developing in-field and inter-field path planning methods for autonomous rice transplanters.

## 2 Materials and Methods

### 2.1 Platform

Two transplanters, one is a PZ60 (ISKI, Japan, Fig. 1.a), and another is a NSD8 (KUBATA, Japan, Fig. 1.b), were used for the verified the path planning methods. The guidance system consisted of a RTK GPS receiver (Beidou, Qiwei), an attitude sensor (Xi'an) and an electric steering wheel [20]. The RTK GPS receiver was mounted above the steering wheel with height to ground of 2.5 meters. The attitude sensor was installed in a box with shock absorption device.

As more than 90 % paddy fields are rectangle shape, it is a fundamental function to plan path for a rectangular field. In our previous research, we proposed a coordinate transformation method [20], which established a local coordinate system as shown in Fig. 2. A transplanter generally plants rice seedling row by row perfect straight, and



## 2.2 Path Planning in Fieldbody

If the operating width is  $L_w$ , and distance from the GPS point to the seedling point is  $L_G$ , then the distance between two neighbor rows is:

$$L_{dl} = L_w \quad (1)$$

As the minimum turning radius of the transplanter is only 0.8 meters, the guidance system could rotate the steering wheel with the maximum rotate angle that the transplanter could be in the correct position of the next row, named a pi-turn. When the transplanter is ready to plant in a new row, coordinate of the starting point should be:

$$\begin{cases} P_{snx} = L_e + L_w/2 + n \cdot L_{dl} \\ P_{sny} = L_e + L_G \end{cases} \quad (2)$$

Where,  $P_{snx}$  and  $P_{sny}$  are the coordinates of the starting point in the  $n^{\text{th}}$  rows.  $L_e$  is the length of track in this row.

Coordinate of the ending point of every row should be:

$$\begin{cases} P_{enx} = L_e + L_w/2 + n \cdot L_{dl} \\ P_{eny} = L_p + L_{sny} \end{cases} \quad (3)$$

Where,  $P_{enx}$  and  $P_{eny}$  are the coordinates of the ending point in the  $n^{\text{th}}$  rows.  $L_p$  is the length of every rows in this field, which should be:

$$L_p = L_f - 2L_e \quad (4)$$

Where,  $L_f$  is length of the field. If  $L_{fw}$  is width of the field, the total rows number is

$$N \geq \frac{L_{fw} - 2L_e}{L_{dl}} \quad (5)$$

## 2.3 Path Planning in Headland

After finishing planting the last row in the fieldbody, the machine should start a round planting, which might be clockwise or anticlockwise. As shown in Fig. 3, coordinate of the starting point and ending points of the new first row should be:

$$\begin{cases} P_{rs1x} = L_{fw} - 3L_{dl} \\ P_{rs1y} = 1.5L_{dl} \end{cases} \quad (6)$$

$$\begin{cases} P_{re1x} = 2L_{dl} \\ P_{re1y} = P_{rs1y} \end{cases} \quad (7)$$

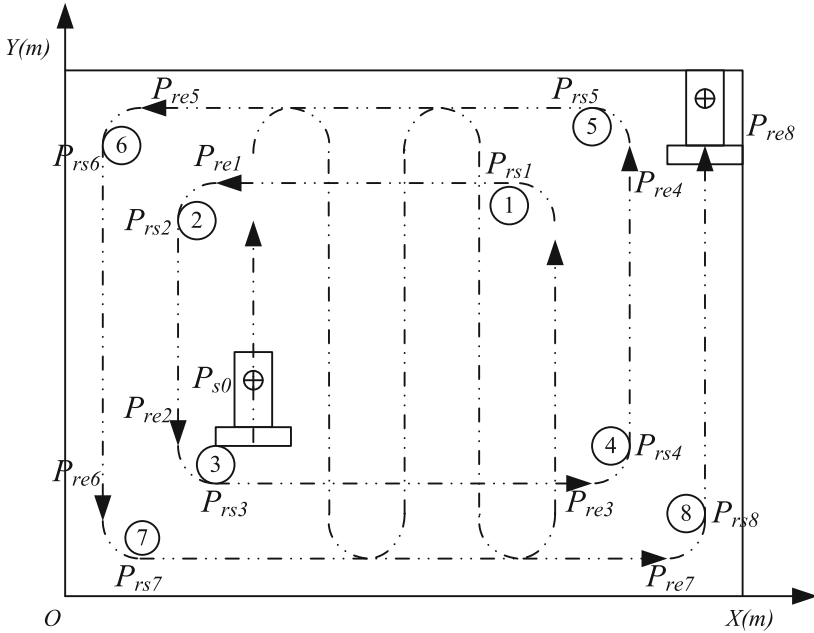


Fig. 3. Path plan in headland

Where,  $(P_{rs1x}, P_{rs1y})$  and  $P_{re1x}, P_{re1y}$  are the coordinates of the starting point and ending point in the 1st row of SR working respectively.

Other points could be produced like similar method as Eqs. 6 and 7.

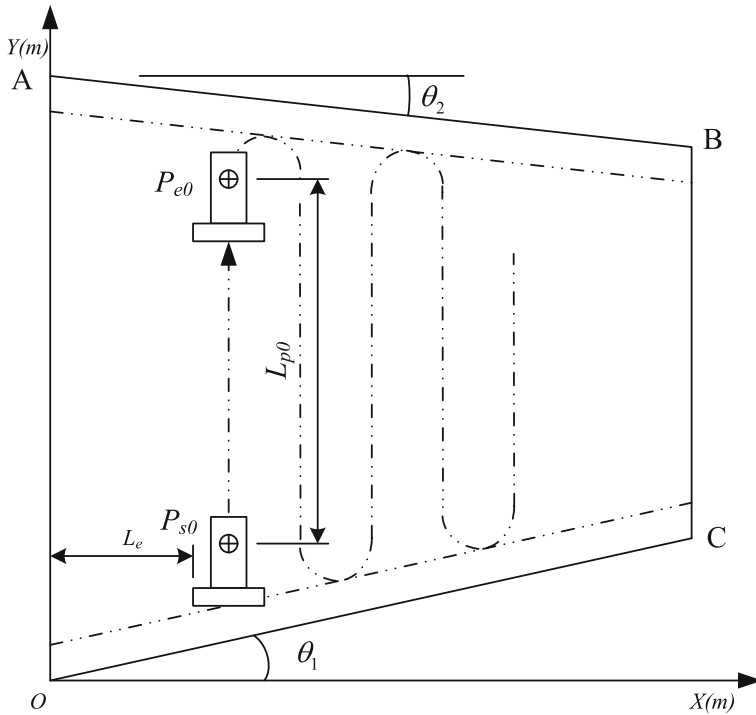
### 2.4 Path Plan for Triangular Shape Field

Some fields neighbor to field lanes might be triangular shape or diamond shape due to topography restraint. If the machine moves parallel to upper base line of the field, such as OA or BC shown in Fig. 4, it would cover field as much as possible. Two slopes of the bevel edges of triangular are:

$$\tan \theta_1 = \frac{y_C}{x_C} \tag{8}$$

$$\tan \theta_2 = \frac{y_B - y_A}{x_B - x_A} \tag{9}$$

If the working path parallel to line OC is  $y = x \cdot \tan \theta_1 + b_1$ , and  $b_1 = L_w/2 \cos \theta_1$ , then the equation of this road would be  $y = x \cdot \tan \theta_1 + L_w/2 \cos \theta_1$  For any working path, coordinate of the starting point is:



**Fig. 4.** Path plan of triangular shape field, where  $\theta_1$  and  $\theta_2$  are intersection angle between OC and x axis, AB and x axis respectively

$$\begin{cases} P_{snx} = L_e + L_w/2 + n \cdot L_{dl} \\ P_{sny} = P_{snx} \tan \theta_1 + L_w/2 \cos \theta_1 + L_G \end{cases} \quad (10)$$

With the similar way, we could get the working path parallel to line AB, which is:  $y = x \cdot \tan \theta_2 + L_{OA} - L_w/2 \cos \theta_2$ . For any working path, coordinate of the ending point is:

$$\begin{cases} P_{enx} = L_e + L_w/2 + n \cdot L_{dl} \\ P_{eny} = P_{enx} \tan \theta_2 + L_{0A} - L_w/2 \cos \theta_2 \end{cases} \quad (11)$$

### 2.5 Path Plan for Farm Lane

Generally, path between garage of transplanter and paddy field consists of straight line lanes, which might be two-way roads or one-way farm lanes, whose feature is that they are parallel or vertical to each other as shown in Fig. 5. If latitude and longitude of two points in every farm lane were measured and an original point was set, the road model of any farm lane could be expressed as

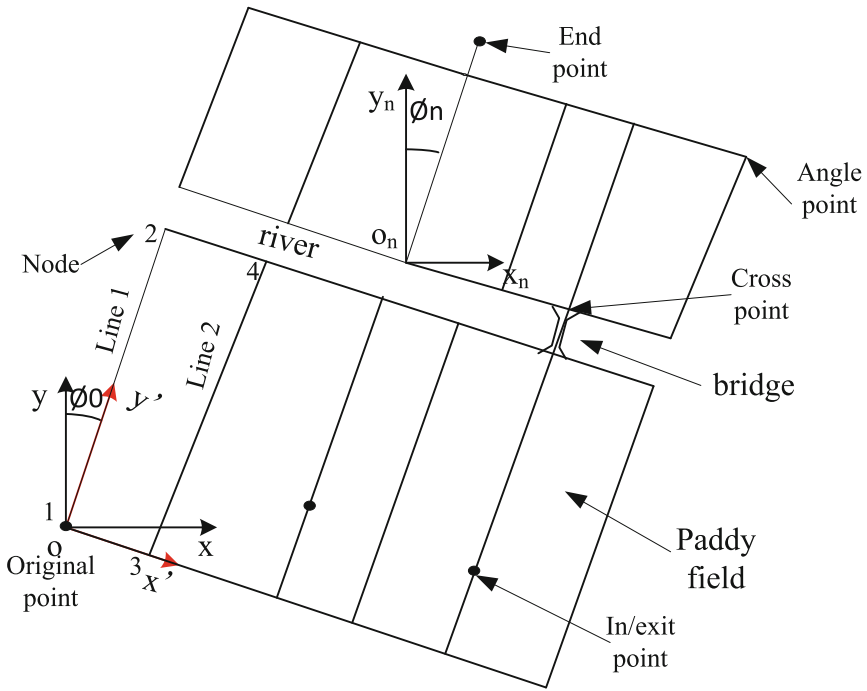


Fig. 5. Map of farm lanes

$$y = x \cdot \tan(90 - \Phi) + b \tag{12}$$

Where,  $\Phi$  is angle between the road and north direction  
 $b$  is intercept of this line.

ARC-NODE structure [21], consisted of 3 tables, which were node table, topology table, and road section table, is a normal method to express the spacial relationship of different lanes, in other words that these 3 tables construct a navigation map. Structure of node table was defined as

Point_ID	x	y	Point_Type	Number_Info
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Where Point\_Type were divided into 4 categories, which are Cross (intersection point), Angle (quarter turn crossing), Number (In/Exit station), and End (terminal of a lane). Number\_Info is a serial number if the point belongs to Number type.

Structure of road section was defined as

Point_ID	Count	Point1	Point2	Point3	Point4
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Where Count is the number that connected with this point.

Structure of road section was defined as

Line_ID	S_Point	E_Point	Line_Type	Heading angle/curvature radius
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Where S\_Point and E\_Point are starting point and ending point of this Line\_ID. Line\_Type are divided into 3 categories, which are two-way straight road, one-way straight lane, and arc lane. Heading angle is corresponding to straight line type, while curvature radius is for arc lane.

Depth-first search method was used after a starting point and an ending point were set, which traverses from a starting point to a new point that connects with the starting one, and from the new point it would be another starting point if there was any line be not traversed yet. Two shortest paths would be constructed in the map for decision.

### 3 Results and Discussion

Path planning for rectangular field, including the one in fieldbody and headland, were successfully tested on in summer of 2013 with the PZ60 transplanter at Yinzhou, Zhejiang Province. The operation width is 1.8 meters, and the width of headland is 3.6 meters. Two kinds of path planning were experimented, which called three-points guidance and four-points guidance. In the experiment of three-points guidance, a driver steered the transplanter and planted the first row, which formed a reference line for the guidance system. He pressed a button on the guidance controller to get the first point 'A' when starting to plant. He pressed the button again to get the second point 'B' when arrived at end of this row. The 3<sup>rd</sup> point 'C' was got after a headland turn to the 2<sup>nd</sup> row. After that, the path planning module generated paths for fieldbody. Figure 6 is one set of testing track diagram, that the autonomous transplanter moved on north or south direction in diagram (a), and on east or west direction in diagram (b). Among them, the red is the planned path, blue is a trace of RTK - GPS. It shows the blue points do not overlap with the red line in straight moving stage, which caused by position of the RTK-GPS, who was not fixed in the middle of the transplanter precisely, and calculation error when transformed from latitude-longitude angles to Cartesian Coordinates.

In the experiment of four-points guidance, the driver got latitude and longitude of 4 corners of the field before planting operation. Point 'A', 'B', 'C', and 'D' were got with

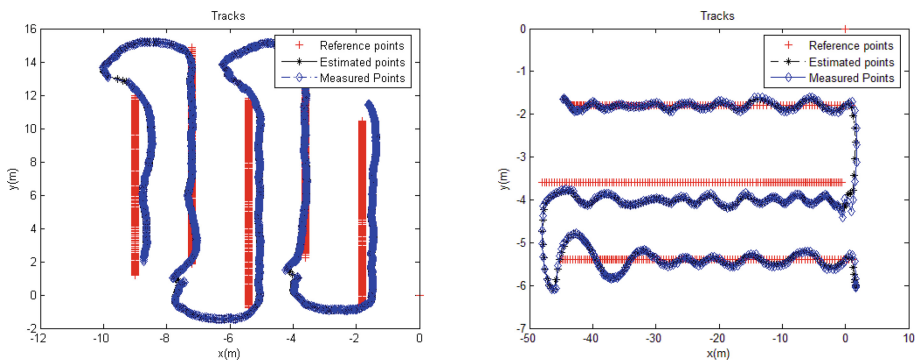


Fig. 6. Planned path and measured track in north-south and west-east direction (Color figure online)



sequence of position at southwest corner, northwest corner, northeast corner, and southeast corner. When the transplanter moved into any corner of this field, the path planning module generated paths in fieldbody and headland. The guidance system guided the machine in fieldbody firstly, and turned to headland after finishing operation in fieldbody that cover whole area automatically. In summer of 2013 and 2014 those experiments were carried out successfully too.

Path planning for farm lane have been testing on the NSD8 machine in summer of 2015 at Cixi, Zhejiang Province. A series of experiments will be done in recent days.

## 4 Conclusions

A path planning method for rice transplanter has been developed and validated partly. Paths for fieldbody and headland in rectangular field were generated and had been used in practice for recent three years. Offset of row following was less than 5 cm, and row-to-tow error was less than 5 cm too. From the experiments, it shows the guidance system could replace human driver for steering controlling.

The path for triangular shape field and farm lanes were proposed, while experiments will be done in autumn of 2015. However, optimal method for path planning, and method for collision avoidance in condition of cooperated multi-robots should be research in future that human can control transplanters, tractors, and combines at off-vehicle place.

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## References

- Galceran, E., Carreras, M.: A survey on coverage path planning for robotics. *Rob. Auton. Syst.* **61**, 1258–1276 (2013)
- Kise, M., Noguchi, N., Ishii, K., et al.: Field Mobile Robot navigated by RTK-GPS and FOG (Part 3): enhancement of turning accuracy by creating path applied with motion constrains. *J. Jpn. Soc. Agric. Mach.* **64**(2), 102–110 (2002)
- Oksanen, T., Kosonen, S., Visala, A. Path planning algorithm for field traffic. In: 2005 ASAE Annual Meeting, Paper number 053087 (2005)
- Hou, J., Song, Z., Mao, E.: GIS-based path planning method for automated tractor. In: *Proceeding of 2005 CSAE Annual Meeting, Beijing*, pp. 141–144 (2005)
- Huang, X., Ding, Y., Zong, W., Liao, Q.: Turning method and algorithm of agriculture vehicles. In: *Proceeding of 2005 CSAE Annual Meeting, Chongqing* (2005)
- Han, X., Kim, H., Kim, J., et al.: Path-tracking simulation and field tests for an auto-guidance tillage tractor for a paddy field. *Comput. Electron. Agric.* **112**, 161–171 (2015)
- Noguchi, N., Terao, H.: Path planning of an agricultural mobile robot by neural network and genetic algorithm. *Comput. Electron. Agric.* **18**(2–3), 187–204 (1997)
- Jin, J., Tang, L.: Optimal coverage path planning for arable farming on 2D surfaces. *Trans. ASABE* **53**(1), 283–295 (2010)

9. Jin, J., Tang, L.: Optimal coverage path planning on 3D terrain. In: ASABE Annual Meeting, Paper number 1009220 (2010)
10. Hameed, I.A., Bochtis, D.D., Sorensen, C.G.: Driving angle and track sequence optimization for operational path planning using genetic algorithm. *Appl. Eng. Agric.* **27**(6), 1077–1086 (2011)
11. Mariano, G., Luis, E., Isaias, G., Pablo, : Reducing fuel consumption in weed and pest control using robotic tractors. *Comput. Electron. Agric.* **114**, 96–113 (2015)
12. Linker, R., Blass, T.: Path-planning algorithm for vehicles operating in orchards. *Biosyst. Eng.* **101**, 152–160 (2008)
13. Jensen, M., Bochtis, D., Sørensen, C.: Coverage planning for capacitated field operations, part II: optimisation. *Biosystems Engineering*, 1–16 (2015). (article in press)
14. Liu, X.: Optimal Path Planning Method for GPS Guided Tractors. Liaoning Technical University, Fuxin (2011)
15. Bochtis, D., Griepentrog, H.W., Vougioukas, S., Busato, P., Berruto, R., Zhou, K.: Route planning for orchard operations. *Comput. Electron. Agric.* **113**, 51–60 (2015)
16. Volos, Ch.K., Kyprianidis, I.M., Stouboulos, I.N.: A chaotic path planning generator for autonomous mobile robots. *Rob. Auton. Syst.* **60**, 651–656 (2012)
17. Bochtis, D.D., Sørensen, C.G., Vougioukas, S.G.: Path planning for in-field navigation-aiding of service units. *Comput. Electron. Agric.* **74**(1), 80–90 (2010)
18. Jensen, M., Bochtis, D., Sørensen, C., Blas, M., Lykkegaard, K.: In-field and inter-field path planning for agricultural transport units. *Comput. Ind. Eng.* **63**, 1054–1061 (2012)
19. Zhou, K., Jensen, A.L., Sørensen, C.G., Busato, P., Bothtis, D.D.: Agricultural operations planning in fields with multiple obstacle areas. *Comput. Electron. Agric.* **109**, 12–22 (2014)
20. Zhang, F., Shin, B., Feng, X.: Development of a prototype of guidance system for rice transplanter. *J. Biosyst. Eng.* **38**(4), 255–263 (2013)
21. Wu, X.: Study on Path Planning of Logistic System Base on Multiple AGV Systems. Jinling University, Changchun (2003)