Design of Trajectory Planning System for River Crab Farming with Automatic Feeding Boat

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Abstract. The bait feeding of river crab farming needs to be covered evenly on the whole pond. At present, feeding is mainly carried out by manual driving or remote control ship-borne feeding machine on the pond. The feeding accuracy and efficiency are relatively low, and it is difficult to guarantee feeding effect. In view of the above situation, based on the mobile automatic feeding boat equipped with GPS, this paper proposes a complete coverage trajectory planning method with irregular quadrilateral pond, and a trajectory planning system based on SuperMap Objects is designed to generate reciprocating traverse feeding trajectory automatically. The simulation is performed to verify the feasibility of the trajectory planning method. The results show that the trajectory planning system can meet the requirements of automatic and uniform feeding on the crab pond.

1. Introduction
In recent years, with the rapid development of China's river crab farming industry, the farming scale of various regions is constantly expanding, and the labor demand is also continuously increasing. Feeding is a heavy and critical task in river crab farming. Due to the strong geographical limitations of river crab farming, river crabs cannot move in large areas and can only forage in areas close to themselves[1]. Therefore, the baits should be evenly distributed on the whole pond [2].

Regarding aquaculture feeding, several automatic feeding equipments have been developed[3-5], such as remote control automatic feeding boat, aquaculture robot, and automatic shrimp feeding boat. Among them, some can perform automatic feeding to a certain extent and save manpower. However, when feeding on the pond, feeding quantity and driving route can only be determined by manual experience, the specific principle and method of route planning are not carried out. The sailing route is highly random and it is difficult to ensure the uniformity of bait distribution[6]. Because the automatic and uniform feeding operation route of the pond is a completely covered path, unlike the general "point to point" linear path planning, it needs to completely cover the planar path of a given pond area[7,8]. In addition, feeding uniformity of on-board feeding machine is related to feeding speed, boat speed, distance between adjacent feeding routes and rotation speed of the casting disk, which should be analyzed and matched in the process of trajectory planning.

In view of the above situation, this paper proposes a complete coverage trajectory planning method for automatic and uniform feeding on river crab farming ponds. According to the environmental information of a given pond area, using feeding uniformity as an index, the optimal operating
parameters of the automatic feeding system are solved. Combining with GIS, GPS and GPRS technology, the optimal feeding trajectory is calculated, then uniform feeding are performed by automatic feeding boat with the optimal operating parameters.

2. Research Approach of Coverage Uniform Feeding Trajectory Planning Method

This article aims at a automatic mobile feeding system based on GPS (global positioning system). The feeding speed is controllable, the throwing amplitude of the thrower is adjustable, and the remaining weight of baits in the hopper is measurable. A reciprocating traversal planning method for completely covering the area of the pond is adopted to generate the optimal feeding trajectory. The process of automatic uniform feeding trajectory planning method for river crab farming is shown in Figure 1.

![Flow chart of automatic uniform feeding trajectory planning method on the pond.](image)

**Figure 1.** Flow chart of automatic uniform feeding trajectory planning method on the pond.

Firstly, the GPS coordinates of the quadrilateral pond vertexes are obtained, and the GPS latitude and longitude coordinates of the four vertexes are converted to plane coordinates using the Gauss-Kruger projection formula respectively, then the plane coordinate system of the pond area is established. Secondly, the working area is determined by setting the safety distance and introducing the direction vector, the objective function of feeding uniformity is created, and the optimal operating parameters of the feeding system are solved, then the intersection points are calculated by pushing parallel lines into the pond along the vertical working direction. The coverage uniform feeding trajectory is generated including the feature point coordinates and operating parameters. If the parameters do not meet the feeding requirements, it is necessary to adjust the variable parameters corresponding to the objective function of uniform feeding and re-optimize the calculation. When feeding requirements are met, feeding trajectory information will be sent to the automatic feeding boat for operation to perform the automatic uniform feeding on the pond.

3. The Plane Coordinate System of the Pond Area Establishment

Because the crab ponds require a rectangular east-west direction, the ponds that are generally naturally formed or manually excavated are not rectangular, and may be irregular quadrilaterals. In order not to lose generality, suppose that the four vertexes of a quadrilateral pond are \( P_1, P_2, P_3 \) and \( P_4 \) respectively, the plane coordinates of the four vertexes are \((x_{P_1}, y_{P_1}), (x_{P_2}, y_{P_2}), (x_{P_3}, y_{P_3})\) and \((x_{P_4}, y_{P_4})\) correspondingly. The latitude and longitude coordinates of the four vertexes of the pond are measured by RTK-GPS BD982, suppose the longitude and latitude coordinates of \( P_1, P_2, P_3, P_4 \) are \((L_{P_1}, B_{P_1}), (L_{P_2}, B_{P_2}), (L_{P_3}, B_{P_3})\) and \((L_{P_4}, B_{P_4})\) respectively. Because the positioning data received by the system is the latitude and longitude coordinates of the earth in the WGS-84 coordinate system, which is an ellipsoidal coordinate and cannot be used directly for the analysis and calculation of plane path planning. Therefore, the received GPS geodetic latitude and longitude coordinates should be projected onto the gauss plane by Gauss-Kruger formula and expressed in cartesian coordinates. In this paper, 6° band Gaussian projection is adopted. Gauss coordinates take the intersection of the central meridian and the equator.
as the origin, $x_i$ represents the ordinate, $y_i$ represents the abscissa. The Gaussian projection formula which is used to convert the longitude and latitude coordinates $(L, B)$ into Gaussian coordinates $(x_i, y_i)$ is described as:

$$
\begin{align*}
  x_i &= a(1 - e^2) \left[ k_B B - k_e \sin 2B + k_b \sin 4B - k_b \sin 6B + k_b \sin 8B \right] + \frac{a}{4 \sqrt{1 - e^2} \sin^2 B} \times \sin 2B i \\
  y_i &= \frac{a}{\sqrt{1 - e^2} \sin^2 B} \cos B \times \left[ 1 + \frac{1}{12} l^2 \cos^2 B \times (5 - \tan^2 B + 9e^2 \cos^2 B + 4e^4 \cos^4 B) + \frac{1}{360} l^4 \cos^4 B \times (61 - 58 \tan^2 B + \tan^4 B) \right] \\
  &\quad + \frac{a}{6} \cos B \times [1 + \frac{1}{12} l^2 \cos^2 B \times (1 - \tan^2 B + e^2 \cos^2 B) + \frac{1}{120} l^4 \cos^4 B \times (5 - 18 \tan^2 B + \tan^4 B + 14e^2 \cos^2 B - 58e^4 \cos^4 B)] + 500000 \times N \\
\end{align*}
$$

where, $l = L - L_0$, $e = \sqrt{\frac{a^2 - b^2}{a^2}}$, $e' = \sqrt{\frac{a^2 - b^2}{b^2}}$, $k_a = 1 + \frac{3}{4} e^2 + \frac{45}{64} e^4 + \frac{175}{256} e^6 + \frac{4105}{16384} e^8$, $k_b = \frac{1}{2} \left( \frac{3}{4} + \frac{15}{2} e^2 + \frac{525}{16} e^4 + \frac{2205}{2048} e^6 \right)$, $k_e = \left( \frac{1}{4} e^2 + \frac{105}{64} e^4 + \frac{2205}{256} e^6 + \frac{4009}{1024} e^8 \right)$, $k_n = \frac{1}{6} \left( \frac{35}{512} e^4 + \frac{315}{2048} e^8 \right)$, $a = 6378137m$, $b = 6356752.314m$, $L_0 = (6 \times N - 3) / 180 \times \pi$, $N = [(L / \pi \times 180 + 3) / 6 + 0.5]$, $\lfloor \rfloor$ means the integer operation.

Because the Gaussian coordinates are not consistent with the Cartesian coordinate system, the Gaussian coordinates $(x_i, y_i)$ are need to be converted to Cartesian coordinates $(x, y)$ as follows:

$$
\begin{align*}
  \begin{bmatrix}
  x \\
  y 
  \end{bmatrix} &= 
  \begin{bmatrix}
  0 & 1 \\
  1 & 0 
  \end{bmatrix} 
  \begin{bmatrix}
  x_i \\
  y_i 
  \end{bmatrix} 
\end{align*}
$$

The plane coordinate system of the pond area is shown in Figure 2, where, $x, y$ denote the abscissa and ordinate of the pond area respectively; $P_1, P_2, P_3, P_4$ denote four vertexes of the pond; $\theta_1, \theta_2, \theta_3, \theta_4$ denote four vertex angles of the pond; $d$ is safe distance from feeding area to the border of the pond; $P'_1, P'_2, P'_3, P'_4$ denote four vertexes of the feeding area; $(x'_1, y'_1), (x'_2, y'_2), (x'_3, y'_3), (x'_4, y'_4)$ denote the coordinate of four vertexes for feeding area respectively.

**Figure 2.** The plane coordinate system of the pond area

The slope of the four sides are $k_{P_1P_2}, k_{P_2P_3}, k_{P_3P_4}$ and $k_{P_4P_1}$ respectively, then four top corners of the pond are described as:

$$
\theta_1 = \arctan\left( \frac{k_{PP_1} - k_{PP_2}}{1 + k_{PP_1} \cdot k_{PP_2}} \right) + \pi \cdot \text{sign}\left( \frac{k_{PP_1} - k_{PP_2}}{1 + k_{PP_1} \cdot k_{PP_2}} \right)
$$

(3)
\[
\begin{align*}
\theta_2 &= \arctan\left(\frac{k_{x_P} - k_{x_{P'}}}{1 + k_{x_P} \cdot k_{x_{P'}}}\right) + \pi \cdot \text{sign}(\frac{k_{x_P} - k_{x_{P'}}}{1 + k_{x_P} \cdot k_{x_{P'}}}) \\
\theta_3 &= \arctan\left(\frac{k_{y_P} - k_{y_{P'}}}{1 + k_{y_P} \cdot k_{y_{P'}}}\right) + \pi \cdot \text{sign}(\frac{k_{y_P} - k_{y_{P'}}}{1 + k_{y_P} \cdot k_{y_{P'}}}) \\
\theta_4 &= \arctan\left(\frac{k_{x_P} - k_{x_{P'}}}{1 + k_{x_P} \cdot k_{x_{P'}}}\right) + \pi \cdot \text{sign}(\frac{k_{x_P} - k_{x_{P'}}}{1 + k_{x_P} \cdot k_{x_{P'}}})
\end{align*}
\]  

(4) \quad (5) \quad (6)

where \(\text{sign}(x) = \begin{cases} 0, & x \geq 0 \\ 1, & x < 0 \end{cases}\).

4. Coverage Path Planning Method of Automatic Feeding on the Pond

The path planning schematic diagram of reciprocating traversal mode is shown in Figure 3. Where, \(d_s\) is distance between adjacent feeding travel; \(R_b\) is distance from starting feeding travel to the border \(PP_P; PP_1^\ast\) denote direction vector; solid points “●” are feature points of the trajectory; dotted lines show automatic feeding path by planning; sector show distribution shape of feed on the water at one point.

Assuming that feeding is carried out with reciprocating traversal method along the longest side \(PP_2\), when a series of straight lines parallel to \(PP_2\) are made, the intersections of parallel straight lines and the boundary of the operation area can be calculated. Therefore, it can be translated with \(PP_2\) along the \(x\) axis to obtain the intersection points of these straight lines and the boundary of the operation area, and these intersection points are used as the starting and ending points of the straight line path, that is, the path trajectory feature points of the feeding operation.

Suppose the distance between the \(n\)th parallel line and side \(PP_2\) is \(d(n)\), then the intersection of the parallel line and the side \(PP_3' (x_{PP_3}(n), y_{PP_3}(n))\) is calculated as:

\[
\begin{align*}
x_{PP_3}(n) &= x_{PP} - \frac{k_{x_{PP}}}{k_{x_{PP'}}} \cdot d(n) - \frac{y_{y_{PP}} - y_{y_{PP'}}}{\sin(\theta_{PP})} (x_{PP}(n) - x_{PP}) \cdot (y_{PP}(n) - y_{PP}) \leq 0 \\
y_{PP_3}(n) &= y_{PP} - \frac{k_{y_{PP}}}{k_{y_{PP'}}} \cdot d(n) - \frac{x_{x_{PP}} - x_{x_{PP'}}}{\sin(\theta_{PP})} (y_{PP}(n) - y_{PP}) \cdot (x_{PP}(n) - x_{PP}) \leq 0
\end{align*}
\]  

(7)

The intersection of the parallel line and the side \(PP_3' (x_{PP_3}(n), y_{PP_3}(n))\) is calculated as:
\[
\begin{align*}
\begin{cases}
x_{P_i}(n) &= x_{P_i} - \frac{k_{P_i}}{d(n) \sin \theta_{P_i}} y_{P_i} - y_{P_i} \\
y_{P_i}(n) &= y_{P_i} - \frac{k_{P_i}}{d(n) \sin \theta_{P_i}} (x_{P_i} - x_{P_i}) (y_{P_i} - y_{P_i}) \\
end{cases}
\end{align*}
\]

Since the lengths of sides \( PP_i \) and \( PP'_i \) are uncertain, so if \( n \leq n_{\text{min}} \), line that translates along edge \( PP'_i \) intersects edges \( PP'_i \) and \( PP'_i \) simultaneously, else if \( n_{\text{max}} + 1 \leq n \leq n_{\text{max}} \) (\( n_{\text{max}} > n_{\text{min}} \)), line will intersect edge \( PP'_i \) and it will intersect the longest side between \( PP'_i \) and \( PP'_i \).

Where:
\[
\begin{align*}
n_{\text{min}} &= \min\left[\frac{d_{P_i} - (2R_0 - d_i) / \sin \theta_i}{d_i / \sin \theta_i}, \frac{d_{P_i} - (2R_0 - d_i) / \sin \theta_i}{d_i / \sin \theta_i}\right] + 1 \\
n_{\text{max}} &= \max\left[\frac{d_{P_i} - (2R_0 - d_i) / \sin \theta_i}{d_i / \sin \theta_i}, \frac{d_{P_i} - (2R_0 - d_i) / \sin \theta_i}{d_i / \sin \theta_i}\right] + 1
\end{align*}
\]

The coordinate calculation method of feature point \( PP'_i (x_{P_{P_i}}(n), y_{P_{P_i}}(n)) \) refers to the previous formulas.

5. Design of Trajectory Planning System Based on SuperMap Objects
SuperMap Objects is composed of several ActiveX controls and a large number of automation objects, so it can be easily embedded in the visual advanced development language environment for secondary development. In this article, SuperMap Objects 6 is used to develop GIS-based automatic uniform feeding trajectory planning system, as shown in Figure 4.

Figure 4. Interface of automatic feeding trajectory planning system based on GIS

This system can obtain the latitude and longitude coordinates of four vertices of the pond through RTK-GPS measurement, and then determine the pond operation area. Users can also download the GOOGLE non-offset satellite map through BIGEMAP software, and use the SuperMap DeskPro software to create a vector map of the operation area. Then the pond operation area can be selected directly on the map of the automatic feeding trajectory planning system. According to the analysis of the pond boundary coordinate information, users can set the relevant parameters of the feeding boat, and select the reciprocating traversal method. Then the trajectory plan system recognizes the longest side of the pond automatically. The method of finding the intersection points by pushing parallel lines along the longest side calculates the feature point coordinates of the reciprocating traversal feeding trajectory, which can generate the coverage feeding path and related trajectory information automatically, and calculate the total length of the path, the number of turns, the time required to complete the operation, the feeding coverage. After the automatic feeding trajectory is generated, the trajectory planning system sends the trajectory information to automatic feeding boat through GPRS module to implement the operation.
6. Simulation and Analysis
An irregular quadrilateral pond is selected as the simulation area. Firstly, the automatic uniform feeding trajectory planning system is used to determine the four vertices of a quadrilateral area in the pond, and the latitude and longitude coordinates of the four vertices are converted to plane coordinates, the results are shown in Table 1.

By setting the safety distance, the working area of the pond is determined. Expected value of bait distribution density is set as $\rho_s = 9g/m^3$, after the operating parameters of the feeding boat are set in the trajectory planning system, the coordinates of feature points are calculated automatically, the results are shown in Table 2. After calculation, the total length is 126.90m, the length of the feeding path is 102.28m, the total operation time is 443.02s, the average bait density is 8.82g/m$^2$, and the feeding coverage rate is 89.29%.

| Table 1. Pond vertex coordinates. |
|----------------------------------|
| Vertex number | Longitude/ (°) | Latitude/ (°) | Abscissa x/m | Ordinate y/m |
|---------------|----------------|---------------|--------------|--------------|
| $P_1$         | 119.51744361   | 32.1975820    | 3566541.70   | 20737402.89  |
| $P_2$         | 119.51700896   | 32.19759716   | 3566542.85   | 20737361.84  |
| $P_3$         | 119.51698740   | 32.19785174   | 3566571.04   | 20737359.15  |
| $P_4$         | 119.51740220   | 32.19784642   | 3566571.37   | 20737398.29  |

| Table 2. Feature point coordinates of trajectory planning. |
|------------------------------------------------------------|
| Feature point number | Longitude/ (°) | Latitude/ (°) | Abscissa x/m | Ordinate y/m |
|----------------------|----------------|---------------|--------------|--------------|
| 1                    | 119.51744361   | 32.19757820   | 3566541.70   | 20737402.89  |
| 2                    | 119.51741367   | 32.19763365   | 3566547.79   | 20737399.92  |
| 3                    | 119.51702569   | 32.19765057   | 3566548.81   | 20737363.28  |
| 4                    | 119.51701955   | 32.19772303   | 3566556.83   | 20737362.51  |
| 5                    | 119.51740245   | 32.19770633   | 3566555.83   | 20737398.68  |
| 6                    | 119.51739123   | 32.19777900   | 3566563.86   | 20737397.43  |
| 7                    | 119.51701342   | 32.19779548   | 3566564.86   | 20737361.75  |

7. Conclusion and Discussion
In this research, the method of automatic uniform feeding trajectory planning for complete coverage of crab farming pond are automatically generated after obtaining the vertex coordinates of quadrilateral pond area. Then the feeding trajectory information are sent to the automatic feeding boat through GPRS module to perform coverage uniform feeding on the pond, which improves the accuracy and efficiency of trajectory planning, improves the feeding uniformity, and increases the benefits for river crabs. It also provides important reference for the research on trajectory planning of automatic uniform feeding along or in the whole pond in river crab farming and other aquaculture.

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9. References
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