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Obstacle Detection for Agricultural Robot Based on Vector Field Histogram

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Abstract
The deployment of autonomous robots has increased in the agricultural industry to replace human labour and increase production yields. A self-sufficient robot is designed to perform certain tasks in various places of the working field area; hence, a cost-effective and efficient navigation system for differential wheeled mobile robots is of the utmost necessity. In this research, an autonomous navigation system for a mobile agricultural robot is suggested utilizing the pure pursuit algorithm (PPA) and vector field histogram (VFH). The PPA algorithm steers autonomously toward waypoints, while the VFH algorithm helps the car avoid obstacles. The VFH method uses 2-dimensional light detection and ranging (LiDAR) sensors for monitoring. PPA specifies a minimum amount of waypoints for map setup simplicity. Using the variable settings of the PPA algorithm, a variety of indicators, including as the distance travelled by the robot, the number of iterations necessary to complete the journey, etc., are examined. The examination of the results indicates that agricultural mobile robots can travel at speeds upto 2.5 km/hr while avoiding obstacles.

I.INTRODUCTION

Despite being an agricultural giant, India's agricultural water management is inefficient. 62% of the water comes from precipitation, whereas 37% comes from irrigation [1]. In rural areas, around 85 percent of water is often lost. Younger generations are migrating away from agriculture and toward urban occupations, resulting in labour shortages for farmers. Consequently, autonomous navigation robots will play a crucial role in agriculture, With the proliferation of mobile robot applications, researchers have concentrated on robot navigation research. Obstacle avoidance increases the challenge of mobile robot navigation. Numerous navigation systems based on remote controls, radio frequency identification (RFID) systems, and wireless network devices have been created for agriculture; nevertheless, they are continuously improved.

Simple operations, such as the application of pesticides and irrigation, need straightforward navigation. India's harsh climate has worsened the challenges of agricultural labour; extreme noon heat waves make it impossible for farmers to work in the field. Farmers adopt technology in a methodical, incremental approach. Advanced technologies based on machine learning and data science will be prohibitively expensive and challenging for farmers to run. The capacity of Internet connections in rural locations is inadequate for high-speed applications. The VFH and PPA hybrid systems based on a geometric algorithm and utilising modern LIDAR sensors can be sufficient technology for Indian farmers.

Certain heuristic approaches for identifying obstructions and regulating direction have been implemented using intelligent techniques such as fuzzy logic control technique [2], neural network technique [3], and others. Due of imprecise results, fuzzy logic control methods are not always applicable. Regular rule modifications and intensive testing and validation are necessary to enhance precision. For a suitable and optimal output, the neural network approach requires a vast quantity of training and data. Controlling heuristic algorithms also requires the assistance of a trained operator [4]. A single-camera vision and ultrasonic sensor-based interior navigation system for mobile robots is described [5]. Some agricultural robots employ computer vision in combination with other sensors to improve GPS data for autonomous navigation, but these methods are vulnerable to ambient illumination, which is a significant disadvantage in an outdoor setting [6]. A gaze-controlled architecture features a fuzzy-integrated and condition-clarified preference for robot navigation, allowing the fuzzy degree sets to be dynamically activated when the state next to the robot changes [7]. A quadrupole potential field (QPF) technique is offered [17] to prevent collisions in the planned trajectory. The VFH algorithm is utilised to aid the system in guiding the steering. A 2D 360-degree LiDAR sensor is used to scan the environment. PPA is a straightforward method that follows the waypoint coordinates till the final destination is reached. PPA The method is executable on a 16/32-bit microcontroller, making it appropriate for use in a tiny autonomous robot system. PPA waypoints were given as distinct (x,y) objective coordinate sites in the actual world, similar to GPS position coordinates. Using LiDAR sensors, the VFH algorithm is a rapid solution that helps robots avoid obstacles. It is implementable in 8/16-bit microcontroller-based devices.

II.PURE PURSUIT ALGORITHM

PPA commands the vehicle to follow a series of waypoints in a certain order until they have all been reached. In terms of deviation from the reference trajectory, the speed of the robot and the look-ahead distance of path points are crucial parameters. Incorrect selection of the look-ahead distance value may result in damage to the PPA controller. Numerous sophisticated PPA systems have been developed [3,5]. Using GPS data, a fuzzy controller-based PPA autonomously drove at speeds more than 70 kilometres per hour [3]. A curve-fitting PPA steering method [5] can be developed to overcome the steering actuator delay. Although employing a mathematical technique to replace the kinematic model with a dynamic model is a precise way to control robots, some research [8] indicate that the kinematic model performs rather well for slow-speed pure pursuit robots. The combination of PPA with the Kuhn-Munkres (KM) ideal matching algorithm produces an optimal guiding approach for the interception of moving objects by unmanned aerial vehicles [9]. Utilizing the PPA and a curvature velocity technique, local navigation for electric cars has been achieved. The system is able to handle complicated manoeuvres and overcome the issue of local minima [10].

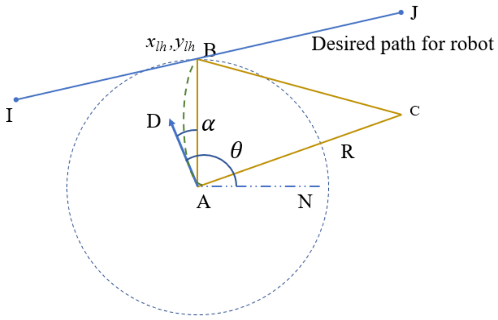

Figure 1.Geometric representation of PPA

The PPA algorithm is represented theoretically in Figure 1. The lookahead distance from the robot's position (x,y) to the junction point of two paths is lAB (xlh,ylh). The LBJ line segment reflects the robot's intended course. The automobile is initially aimed in the direction of AD. Using the radius of curvature R, the arc AB with the centre point C is created. The angle formed by the vehicle and the radial line lAB is denoted by DAB. The angle shows the orientation of the vehicle with respect to the x-axis. Equation (1) is obtained [11] using the following geometrical methods:

$$R = l_{AB}/(2sin\alpha) \qquad (1)$$

where

$$\alpha = \theta - \arctan((y_{lh} - y)/(x_{lh} - x)) \qquad (2)$$

Equation (2) is for the angle α between lookahead direction and orientation of robot. Considering length of the robot is L, the steering angle γ is given as,

$$\gamma = \arctan(\frac{L}{R}) \qquad (3)$$

For the mobile robot to travel toward the lookahead spots, the steering angle must be applied. Based on the notion, PPA is designed to generate lookahead points on lines linking waypoints, and then to pursue the lookahead points until the final waypoint is reached.

III.VECTOR FIELD HISTOGRAM

The vector field histogram (VFH) is a quick computable two-stage data reduction method for radial sensor data. The data depict the surrounding area and barriers in two-dimensional space. For a more straightforward form, VFH translates the Cartesian coordinate map to a polar density map. Based on the potential field approach, Borenstein and Koren [12] created the virtual force field (VFF) method. The objective of the work is the creation of a PPA-based mobile robot supported by a VFH algorithm to prevent collisions with obstacles [13]. Dynamic vector-based repulsive field technique can be employed to enhance obstacle avoidance decision making [14]. Next, the algorithm selects the sector with the lowest density of polar obstacles and gives the robot's steering angle for movement [15]. VFH algorithm employs force field to generate an object-repelling force vector.

$\beta_{m,n} = tan^{-1}\frac{(y_n - y_0)}{(x_m - x_0)}$ (4)

$\beta_{m,n}$ is the orientation of obstacle, where the total angular steps $n = 360/A_\alpha$, any discrete angle $\rho = k.A_\alpha$, where A_α is the resolution angle, $k = 0, 1, \ldots, n\text{-}2, n\text{-}1$, sector k is given as $k = integer(\beta_{m,n}/\ \alpha)$. h_k is the histogram polar obstacle density bearing the summation of all grid coordinate forces in a particular sector k as expressed by $F_{m,k}$

$h_k = \sum_{m,n} F_{m,k}$ (6)

The sector with the least value and near to target direction is chosen as right direction for propagation of mobile robot.

IV.LiDAR technology

A typical LiDAR uses laser beams to scan a given field of view (FoV). A rapid optical transmitter-receiver device uses a modulated near infrared beam to identify objects in the environment. To rotate and fast scan a vast region, a mechanical or solid-state beam steering mechanism is used. LiDAR technology is resistant to the effects of ambient lighting, making it suitable for agricultural use. Furthermore, the seeing range is greater than that of vision cameras. The lower cost of LiDAR devices in recent years has sparked interest in their use [16]. A study published in [17] used a 3D LiDAR-based navigation system that can also scan maize plant structure for phenotyping. However, the technology was limited to a single plant, and the operation also limited the pace of the mobile robot. Using the hough transform and a LiDAR sensor, a real-time guidance system was created [18]. The Hough transformation found a straight line for steering the vehicle by extracting plant rows. Curved row portions and other items in the way presented difficulties. A tractor was navigated through a citrus grove alleyway using machine vision and a LiDAR system [19].

V.METHODOLOGY

In the Matlab/SIMULINK environment, the simulation was conducted. During execution, the real-time values of observations are logged and saved in a CSV (Comma-delimited) data file. Typically, the loop iterations are measured every 100 milliseconds. PPA and VFH algorithm functionalities are implemented using the navigation platform's toolbox. The mobile robotic simulation toolkit is employed for the LiDAR sensor application. In the simulation, PPA is employed to accomplish autonomous lateral navigation. It was an obstacle-avoiding waypoint-seeking system that employs a steer guidance VFH algorithm. The steer-guided robot is designed to navigate a row-gap path while avoiding obstacles in a lateral, two-dimensional environment. As indicated in Figure 3, various waypoints are established (P1, P2, P3, P4, P5, and P6). In real-world applications, these waypoints may be transformed into GPS-tagged points by adjusting the amount of their coordinate data. Robotic localisation of the vehicle is predicted to be effective, disregarding wheel slippage and drift. In real-world models, odometry sensors, GPS, and motion sensors might be utilised. The route will cover points P1 through P6 sequentially. At the U-bend of the plant row seen in Figure 2, the waypoint coordinates are produced as alternate tip points (b). The robot will travel the field while avoiding obstacles; large obstacles that cannot be avoided will produce a strong repulsive force field around the vehicle, rendering it immobile. The experiment is done on a 50 × 50 m^2 vegetable field. The robot experiment is conducted at different speeds. For each experiment, the robot's speed varied from 0.5 to 2.75 km/hr F_(m,k) at a constant rate. This speed range is appropriate for slowly operating irrigation robots. In order to traverse all plant rows in the field, the robot will cycle in a zigzag pattern. The differential wheel robot's wheelbase is 0.40 metres and its wheel radius is 10 centimetres.

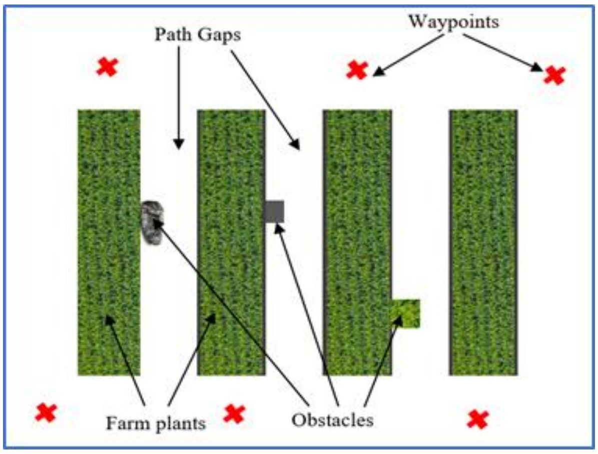

Figure 2: Field view of plantation

The VFH parameters of histogram threshold value and number of angular sectors were calibrated and fixed at 20

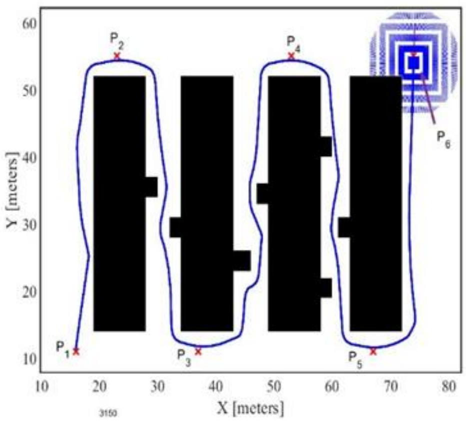

Figure 3: 2D Grid Occupancy Map

after many tests and observations. A field picture (Figure 2) is transformed to a grid occupancy map (Figure 3) using image conversion from colour to black-and-white. As the robot progresses through row gaps, various impediments like as rocks, solid objects, and overgrown vegetation may be present on the path. The VFH algorithm aids in the detection and strategic avoidance of static and moving obstacles. The method is based on the forces of repulsion generated by neighbouring barriers. Each experiment is documented using LiDAR sensor readings and redetermined PPA parameter settings. On various desired velocity settings, several sets of readings for distance covered and number of iterations taken was observed.

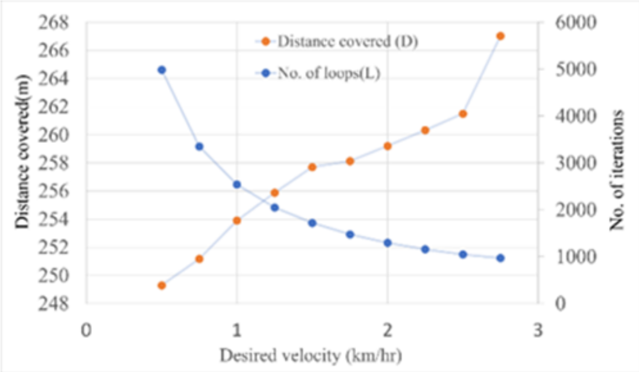

Figure 4. Performance characteristics.

VI.OBSERVATIONS

The fastest coverage of field is conducted within N_L=973 loops at D_{LV}= 2.75 Km/Hr. The slowest coverage is done in N_L= 4988 loops achieved at a low desired linear velocity of 0.5 Km/Hr. The vehicle gives an optimum speed D_{LV}=1.25km/hr with 2049 number of iteration loops. It can be seen in graph shown at Figure. 3, where the crossover point of two identifiers N_L and D_C. The N_L and D_C are intersecting for best performance results. Optimum lookahead distance was chosen as L_D =20 meters.

CONCLUSIONS

Based on the requirements for a simpler navigation system for an autonomous irrigation robot, we conducted a basic performance evaluation of our LiDAR-based navigation system. Based on the preceding study and experimental investigation, the following qualities have been summarised:

(1) The VFH-based steering controller was used effectively with PPA to avoid obstacles along the plantation gap.

Keeping a modest number of waypoints decreased the setup time and oscillations of mobile vehicles. Lookahead distance and velocity are crucial characteristics that are determined by the robot maneuverability, and field type. (3) The 2D grid occupancy mapping offers a simple way for overcoming autonomous navigation with less complicated sensor data processing. The technique may be executed on 16/32-bit computers with little energy consumption. Due of its minimal computing requirement, this technology may be applicable to effecient robust agriculturally-focused electric vehicles.

REFERENCES:

[1] V. B. Hans, “Water Management in Agriculture: Issues and Strategies in India,” *SSRN Electron. J.*, Nov. 2017.

[2] X. Kan, T. C. Thayer, S. Carpin, and K. Karydis, “Task Planning on Stochastic Aisle

Graphs for Precision Agriculture," *IEEE Robot. Autom. Lett.*, vol. 6, no. 2, pp. 3287–3294, Apr. 2021.

[3] I. Susnea, A. Filipescu, G. Vasiliu, G. Coman, and A. Radaschin, "The bubble rebound obstacle avoidance algorithm for mobile robots," *2010 8th IEEE Int. Conf. Control Autom. ICCA 2010*, pp. 540–545, 2010.

[4] T. S. Abhishek, D. Schilberg, and A. S. Arockia Doss, "Obstacle Avoidance Algorithms: A Review," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1012, p. 012052, 2021.

[5] A. Ohya, A. Kosaka, and A. Kak, "Vision-based navigation by a mobile robot with obstacle avoidance using single-camera vision and ultrasonic sensing," *IEEE Trans. Robot. Autom.*, vol. 14, no. 6, pp. 969–978, 1998.

[6] S. A. Hiremath, G. W. A. M. van der Heijden, F. K. van Evert, A. Stein, and C. J. F. Ter Braak, "Laser range finder model for autonomous navigation of a robot in a maize field using a particle filter," *Comput. Electron. Agric.*, vol. 100, pp. 41–50, Jan. 2014.

[7] J. K. Yoo and J. H. Kim, "Gaze Control-Based Navigation Architecture with a Situation-Specific Preference Approach for Humanoid Robots," *IEEE/ASME Trans. Mechatronics*, vol. 20, no. 5, pp. 2425–2436, Oct. 2015.

[8] N. Gupta, M. Khosravy, S. Gupta, N. Dey, and R. G. Crespo, "Lightweight Artificial Intelligence Technology for Health Diagnosis of Agriculture Vehicles: Parallel Evolving Artificial Neural Networks by Genetic Algorithm," *Int. J. Parallel Program.*, pp. 1–26, Jul. 2020.

[9] C. Hajdu, "Novel Pure-Pursuit Trajectory Following Approaches and their Practical Applications," pp. 597–602, 2019.

[10] X. Wang, G. Tan, Y. Dai, F. Lu, and J. Zhao, "An Optimal Guidance Strategy for Moving-Target Interception by a Multirotor Unmanned Aerial Vehicle Swarm," *IEEE Access*, vol. 8, pp. 121650–121664, 2020.

[11] M. J. Gilmartin, "INTRODUCTION TO AUTONOMOUS MOBILE ROBOTS, by Roland Siegwart and Illah R. Nourbakhsh, MIT Press, 2004, xiii+321 pp., ISBN 0-262-19502-X. (Hardback, £27.95)," *Robotica*, vol. 23, no. 2, pp. 271–272, Mar. 2005.

[12] J. Lopez, P. Sanchez-Vilarino, R. Sanz, and E. Paz, "Efficient Local Navigation Approach for Autonomous Driving Vehicles," *IEEE Access*, vol. 9, pp. 79776–79792, 2021.

[13] T. Bouwmans, "Traditional and recent approaches in background modeling for foreground detection: An overview," *Comput. Sci. Rev.*, vol. 11–12, pp. 31–66, May 2014.

[14] J. S. Kulchandani and K. J. Dangarwala, "Moving object detection: Review of recent research trends," *2015 Int. Conf. Pervasive Comput. Adv. Commun. Technol. Appl. Soc. ICPC 2015*, Apr. 2015.

[15] G. Qi, H. Wang, M. Haner, C. Weng, S. Chen, and Z. Zhu, "Convolutional neural network based detection and judgement of environmental obstacle in vehicle operation," *CAAI Trans. Intell. Technol.*, vol. 4, no. 2, pp. 80–91, Jun. 2019.

[16] J. Borenstein and Y. Koren, "Real-Time Obstacle Avoidance for Fast Mobile Robots," *IEEE Trans. Syst. Man Cybern.*, vol. 19, no. 5, pp. 1179–1187, 1989.

[17] J. Borenstein, Y. Koren, and S. Member, "The Vector Field Histogram-Fast Obstacle A voidance for Mobile Robots," 1991. Accessed: Jun. 04, 2021. [Online]. Available:

http://www-personal.umich.edu/~ykoren/uploads/The_Vector_Field_HistogramuFast_Obstacle_Avoidance.pdf

[18] W. Zhang, H. Cheng, L. Hao, X. Li, M. Liu, and X. Gao, “An obstacle avoidance algorithm for robot manipulators based on decision-making force,” *Robot. Comput. Integr. Manuf.*, vol. 71, no. March, p. 102114, 2021.

[19] Z. J. Chong, B. Qin, T. Bandyopadhyay, M. H. Ang, E. Frazzoli, and D. Rus, “Synthetic 2D LIDAR for precise vehicle localization in 3D urban environment,” *Proc. - IEEE Int. Conf. Robot. Autom.*, pp. 1554–1559, 2013.