Energy Efficient Autonomous Field Vehicle for Complete Coverage

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Abstract

Nowadays, service vehicles are being implemented for various functionalities such as tour guidance vehicles [1] & vehicles for search and rescue, vacuum cleaners [3], tractors, automotive painting etc. To make these vehicles autonomous, the amount of human control and interference is to be reduced significantly. Normally, the cost of agricultural materials and systems cannot be controlled; however it should be taken into consideration during the system design. Power consumption is also another major factor to be taken into account. This paper presents a system model that aims to reduce the power consumption of the farming vehicle and to implement complete coverage of agricultural field. This type of system would gain scope for huge precision farming applications such as harvesting, seeding, spraying, applying fertilizers, tillage, and the like.

1. Introduction

ROBOTS to be designed for agricultural techniques must replace human operators and must be built with limited set of tools. A completely autonomous robot must be capable of understanding its environment, work for unlimited time without any intervention, adapt to environmental changes and provide human safety. Autonomous path and motion planning being one of the fields with wider scope, lots of research works are been undertaken in it. A number of complete coverage path planning methodologies have been implemented for agricultural farms [8][9][11], in which path planning and obstacle avoidance are of significant importance in these aforementioned systems.

In this paper the following features are considered

- Path planning
- Complete coverage
- Obstacle Avoidance
- Power Optimization

2. Existing Methodologies

Several systems were implemented using advanced AI (Artificial Intelligence) and fuzzy logic such as Neural network approach [1], swarm intelligence [6] with biological system inspirations [4][11]. Though nearly 100% optimality can be achieved using such techniques, the main drawback of the aforementioned techniques is that those require a learning phase which incurs additional cost to the system design process.

In case of large field of about acres and hectares, learning cost grows much worse. Hence the main objective of vehicle design is to develop a geometric approach that computes path on the fly without prior learning.

Even Image processing techniques (Vision-based navigation systems)[10] are being used for covering larger terrains. Owing to poor performance of image processing with changing environmental conditions, it cannot be considered as better choice for such vehicles. But a system as the one proposed here is capable of achieving the objective, irrespective of the day/night time, poor visibility due to climatic conditions.

3. System Workflow

The system components consist of a planner node and the controller node [Fig.1]. The planner node takes the geometric map as the input and all the path planning and computations are carried out in this node. Typically a computer system is used as the host planner node.

The controller node is the one implemented in the vehicle. It includes a controller, interfaced with drivers for motors, GPS receiver modules, Sensors to detect obstacles, and a battery level monitoring sub-unit. The traversal instructions are executed by the controller. The battery level is monitored for power estimation.

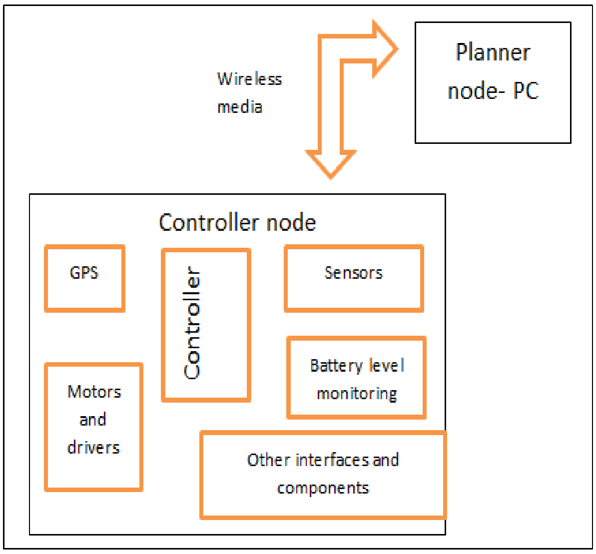

Fig. 1. The proposed system structure

An emergency stop provision may also be provided, in order to pause the vehicle in case of emergency. The communication between the planner node and controller node takes place with the help of any suitable wireless communication media.

4. Path Planning and Complete Coverage

4.1 Path planning

It is the process of finding an optimal path that covers the entire field and such that it minimizes certain costs, especially in case of an agricultural environment. Basically farming costs depends on time and area coverage. Hence finding the shortest path computation is concerned with the optimality to be obtained. In this model two phases are involved in path planning process, namely

- Offline or global planning
- Online or local planning

4.2 Offline planning

The offline planning or global planning refers to computation of optimal path without taking the obstacles into consideration. In this model, the field dimensions are fed into the system as the set of co-ordinates those describe the boundaries of the filed. From these co-ordinates, the boundary edges of the field are calculated using interpolation methods such as trapezoidal co-ordinate transformation and inverse transformations.

4.3 Online planning

This refers to planning of path dynamically when the systems traverse through the field. Wall following technique can be considered for obstacle avoidance. Finding obstacles along the path can be carried out with the help of combination of sensors. However, sensing pits in fields is not considered in this model. Different types of sensors can be used for various features of the fields and type of application to be carried out.

Fig. 2 gives various steps involved in system workflow. The metric map is the world file where the co-ordinates can be located either using global map service or by entering the latitude, longitude co-ordinates obtained using the GPS receivers placed at requires field boundaries.

The cellular decomposition is used for transforming the metric map into topological map. The topological map takes the form of graph which consists of cells, making it suitable for computation. Localization and orientation of vehicle is achieved with the help of Differential Global Positioning System (GPS) that achieves accuracy with error percent lesser than 1%. The global path planning is completed once the topological map is constructed. After finding the optimal path and direction, the vehicle has to orient itself in the particular direction with the help of used Navigation system, say, GPS. Finally the vehicle is driven with the instructions by the controller node.

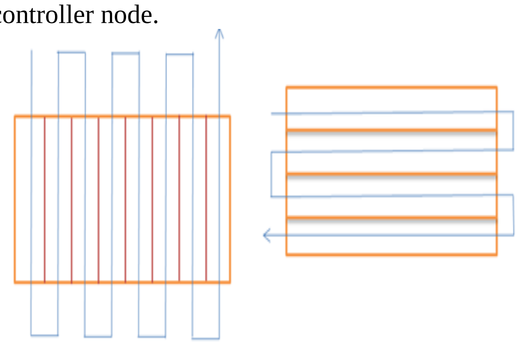

Fig. 3. Routing parallel to shorter edge(a) and longer edge(b)

For regular shaped fields such as square or rectangular fields, the optimization can be achieved in a simpler way. For example, the path of traversal can be planned parallel to the longest edge of its boundary as shown in the following figure.

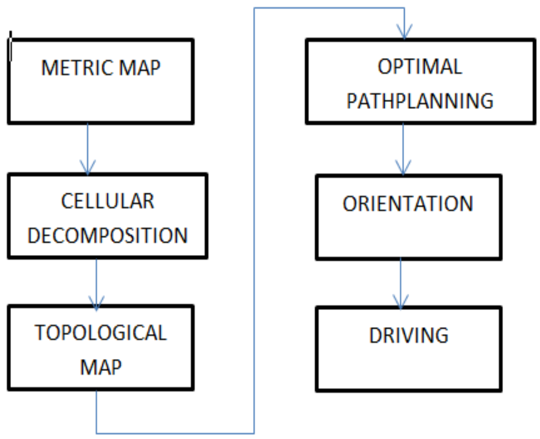

Fig.2. System workflow

For irregular shaped fields some advanced methods should be used. One of such algorithm is the "divide and merge" method. The following are the steps involved in the algorithm execution.

• Division of field in to several cells
• Finding optimal path for each individual cell
• Merging all the cells with a global optimal path.

The cellular decomposition can be done using either exact cellular decomposition or combining it with boustrophedon passes. This is used to decompose the fields into trapezoidal cells using plane sweeping.

The trapezoidal cells are analyzed for the optimal path and start direction. This is similar to the method defined for regular shaped fields.
During the final stage, all the cells are merged with several constraints. One of the conditions for merging is that when two adjacent cells have same path direction and there occurs a chance for smooth transition between those cells, they can be merged into a single cell.

5. Obstacle Avoidance

Obstacle avoidance is of greater complexity for implementation. Normally the obstacles can be detected using a wide range of sensors [5]. For example, the Infrared and ultrasonic sensors can be used to identify static sensors. Image processing can be used. In case of harvesting application still more complex sensory system has to be implemented. This is because the image processing subsystem must be efficient and faster enough to identify obstacles as the vehicle moves towards it, however, the distance between the system and the obstacle cannot be interpreted [2][7].

Ultrasonic sensors can be used in such a case but the obstacles cannot be perceived properly, that is the system will not be able to analyze whether the confronted object is an obstacle or a crop plant. In such a case a complex design must be implemented to differentiate between the field objects. The positioning of sensors also depends upon the height of crop plants, and similar characteristics. The pits or wells are still difficult to identify in a farm field. For simpler implementations these features are not considered in this system definition. A simpler sensory system with 3 or 4 ultrasonic sensors are used in this model.

So far, the considerations were made for static obstacles. During routing of the vehicle, dynamic obstacles such as animals, etc., can also be faced. In case of an obstacle being identified, wall following technique can be undertaken. That is, the vehicle is made to traverse along the contour of the obstacle. When the obstacle is dynamic, the vehicle is instructed to pause for specific time period and then to resume work once the path is free from it [9].

6. Power Optimization

The energy cost of robotic vehicle is highly associated with the number of turns the vehicle takes during its traversal. The controversial characteristic of time and energy considerations is that only either of the two can be achieved at a time. More the number of turns, lesser the routing time but higher the cost incurred with respect to power consumption. Therefore the number of turns can be reduced.

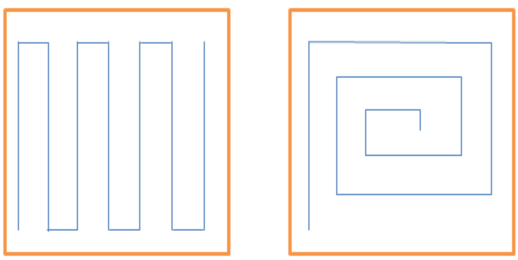

Fig.4. Minimal time traversal (a), minimal energy traversal (b)

For example, the following Figure shows two different path planning strategies with respect to minimal time and minimal energy means. In Fig 4.(a) The path planning suitable for coverage time reduction is depicted. With addition to this, the vehicle can be provided with solar cells, for improving power saving and proper utilization of solar power. The power optimality also depends on the path planning algorithm used. The path with the minimal turning parameters would consume the least energy.

Fig. 4.(b) shows the path planning meant for energy conservation. The main difference between the two is that the amount of turning parameters is reduced in the second method.

7. Conclusion

The autonomous agricultural system model with optimal path planning with obstacle avoidance was proposed. The power optimization was implemented with the help of an efficient path planning methodology. The GPS enabled system with self-navigation and orientation was defined. The power consumption can be minimized to maximum level of possibility.

8. References

[1] S. X. Yang and C. Luo, "A neural network approach to complete coverage path planning," IEEE Trans. Systems, Man, and Cybernetics, vol. 34, no. 1, pp. 718-725, Feb. 2004.

[2] C. Luo, S. X. Yang, D. A. Stacey, and J. C. Jofriet, "A solution to vicinity problem of obstacles in complete coverage path planning," in Proc. IEEE Int. Conf. Robotics and Automation, pp. 612-617, May 2002.

[3] R. N. de Carvalho, H. A. Vidal, P. Vieira, and M. I. Ribeiro, "Complete coverage path planning and guidance for cleaning robots," in Proc. IEEE Int. Sym. Industrial Electronics, pp. 677-682, July 1997.

[4] Ryerson, A. E. F. and Q. Zhang. Vehicle Path Planning for Complete Field Coverage using Genetic Algorithms. Agricultural Engineering International: the CIGR Ejournal. 9: Manuscript ATOE 07 014, July 2007

[5] Sörensen, M. J. Artificial Potential Field Approach to Path Tracking for a Non-Holonomic Mobile Robot. In 11th Mediterranean Conference on Control and Automation, June 2003.

[6] Shah-Hosseini, H. The intelligent water drops algorithm: a nature-inspired swarm-based optimization algorithm. In International Journal of Bio-Inspired Computation, 1(1/2): 71-79, 2009.

[7] Sorensen, C. G., T. Bak, and R. N. Jorgensen. Mission Planner for Agricultural Robotics.

[8] González, E., O. Álvarez, Y. Díaz, C. Parra, and C. Bustacarra. BSA: A Complete Coverage Algorithm. In Proceedings of the 2005 IEEE International Conference on Robotics and Automation, pp. 2040-2044, Barcelona, Spain, April 2005.

[9] Guo, Y and M. Balakrishnan. Complete Coverage Control for Nonholonomic Mobile Robots in Dynamic Environments. In Proceedings of the 2006 IEEE International Conference on Robotics and Automation, pp. 1704-1709, Orlando, Florida, May 2006.

[10] Jin, J. and L. Tang. Optimal Path Planning for Arable Farming. 2006 ASABE Annual International Meeting, Paper No. 0611581-12, Portland, Oregon, 2006.

[11] Kang, J. W., S. J. Kim, M. J. Chung, H. Myung, J. H. Park and S. W. Bang. Path Planning for Complete and Efficient Coverage Operation of Mobile Robots. In Proceedings of the International Conference on Mechatronics and Automation, pp. 2126-2131, Harbin, China, 2007

[12] Zelinsky, A., R.A. Jarvis, J.C. Byrne and S. Yuta. Planning Paths of Complete Coverage of an Unstructured Environment by a Mobile Robot. In Proceedings of International Conference on Advanced Robotics. 1993.

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