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A Mahalanobis distance based Partitioned Path Planning Approach for Performing Coverage Path Planning under Cashew Trees

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AbstractA novel partitioned coverage path planning algorithm for discrete harvesting in cashew orchards is proposed. Collection of fruits and nuts that fall in the floor, is a challenge faced by the farmers in India. The task is highly labour intensive and time consuming process. Earlier research has focused mainly on path planning for continuous crops. A novel distance metric based on Mahalanobis distance is formulated for efficient path planning. The metric takes into about the correlation between various parameters associated with a fruit for computation of paths. A partitioned path planning approach is followed to minimize the computational overhead. Various partition sizes are evaluated for computation of paths and an optimal partition value is proposed based on the computed results. The proposed technique is evaluated against existing techniques for coverage, and also on parameters such as percentage of coverage, standard deviation in the results.

Keywords: Coverage Path Planning, Cashew Orchards, Mahalanobis distance

I. INTRODUCTION

India being the second largest producer of cashew nuts in the world had produced around 82302 metric ton valued at 5168.78 crore rupees in export alone during the year 2016-2017 [1]. The plant relatively being drought resistant, is being planted by farmers in huge scale. The season of flowering is during mid January-February and harvesting happens through the months of March-May. Being a seasonal crop it is relatively difficult to find labour for picking fruits. The nut along with the fruit mature and fall off to the ground in a daily basis. They are to be picked immediately, else the tender fruits tend to decay easily and damage the nut in the process. This is the time when acute labour shortage is also being witnessed in India for agriculture. People tend to migrate to cities for industrial labour and better quality of life. Since the crop is seasonal, there is also the difficulty faced be famers in finding seasonal labour. Manufacturing industries have already moved towards adaptation of robotic platforms, but the automation in agriculture is still lagging behind. Hence the motivation to develop an autonomous system for harvesting in cashew orchards.

II. RELATED WORKS

Path planning is the task of finding a feasible path from starting position to the target position avoiding obstacles in the environment [2]. The environment can be classified as static or dynamic. Frequent re-planning and updates are required for path planning in the dynamic environment. A set of criteria [3] has been defined for autonomous robots to perform coverage path planning which is considered as the back bone for most of the research in the area of coverage path planning. They are:

1. Robot must cover the entire search space.
2. Robot must fill the region without overlapping paths
3. Continuous and sequential operation without any repetition of paths is required.
4. Robot must avoid all obstacles.
5. Simple motion trajectories (e.g., straight lines or circles) should be used (for simplicity in control).
6. An ‘‘optimal’’ path is desired under available conditions.

For complex environments it would not be possible to satisfy all the above mentioned constraints [4]. In literature, the first step in solving coverage problems is to decompose the target environment into sub regions to perform coverage. They are classified as approximate, semi-approximate and exact cellular decompositions techniques [5, 6].Prioritization of constraints is followed for implementation in the field of agriculture. To overcome seasonal labour shortage, a cherry harvesting robot [7] was developed in Japan. A tree pruning device was developed in [8] with the help of wheels to climb and prune the branches of interest. The task of spreading seeds was implemented in [9] for tractors in farmlands.

Elevation models were used to identify the subregions in the terrain. Sub regions were divided and individually optimized for coverage, instead of considering the whole search space. Application of fertilizers in farmland was addressed in [10]. A field elevation model extended to 3-Dimensional terrain was used for estimating field elevation data. An optimization in driving angle was achieved for parallel paths using an energy consumption model. However, these approaches were designed to address the issue of complete coverage in large farmlands for tractor type of vehicles. The total area to be covered was the only objective considered. The crops considered were also present in a highly structured environment. The route planning for orchard operations was modeled as a graph traversal problem in [11]. This approach was extended in [12] for panning an escape model for wildlife navigation.

The novel contribution in this paper is to solve the harvesting in cashew orchards using a discrete model. Discrete coverage path planning is optimized using a Mahalanobis distance based metric. The proposed method is then benchmarked against existing algorithms and results are analyzed.

III. THE REFERENCE FARM

For a reference model, The research was based on the cashew orchard located at 12°02'29.8"N ,79°51'02.1"E Puducherry, India. Trees in the age of 1 to 70 were present in the farm. Since experimental data on the production of cashew was not available, two trees were chosen to analyze the crop flowering pattern. The picking cycle usually ends at 18:00 hours on any given day. Maximum fruit fall was observed during 11 AM to 3 PM in any tree, irrespective of their age. Figure 1 shows a sample tree aged years.

IV. MAHALANOBIS DISTANCE BASED PATH PLANNING

For harvesting applications, it is sufficient if a node is visited only once and the optimal solution is achieved when all nodes are visited. The non uniform distribution of fruits must be accounted while planning a path to all the objects of interest. The objectives of the path planner are;

1. Collect all the fruits present in the search space.
2. Minimize the F_{time}

Where $F_{time}$is the time spend by fruits lying idle in the ground. It is obtained by calculating the difference between the time of fall and the time when a fruit is picked. Every fruit to be picked would have two data components associated with it. The location of a fall and the time of fall. An efficient harvesting model must minimize the F_{time}. The conventional method would be to deploy a Euclidean distance based measurement model to find a shortest path possible. Since the problem has more than one component associated with the fruit, to take into account the correlation between unrelated variables, a Mahalanobis distance based approach was selected. Mahalanobis distance can be defined as the distance from vector $y_j$to the set X = { x_1,…..,xnx} as the distance from the centroid of x, $y_j$to x́, weighted to the variance matrix of the set X.

Where $$d_j^2 = (y_j - \acute{x})' C_x^{-1}(y_j - \acute{x}) \quad (1)$$

The formula for calculating Mahalanobis distance is given by equation 1. Mahalanobis distance for a given fruit distribution is calculated by combining the two data associated with each fruit. i.e. the distance to nearest group and also the amount of time the fruit spent in the ground. The returned number is unitless and is used to correctly classify a fruit as to in which partition set it has to be placed. A matrix is used to store all the routes. If all the routes are stores including the partial routes, the matrix would be of size (n!,n). for an example, if the number of nodes is 20, the memory required to store all the partial routes from a node to every other node would be around 5 Gigabytes. Therefore it is required to partition the dataset such that not more than Ψ fruits are present in any single set. A recursive partition strategy is developed to reduce the memory requirement. The path within subsets is planned first and then a path connecting every subset is planned appending it to the global path.

Initialize the initial, final position
fruits = locations to visit
If (length (routes) > Ψ)

Table 1 Coverage obtained by various algorithms

Coverage obtained by various algorithms				
Number of nodes	DFS [13]	BFS [13]	TSP_NN	Proposed
150	57.00	39.00	100	73.56
300	47.50	27.50	100	68.00
350	51.27	15.33	100	51.70
450	38.62	12.25	100	53.20
550	17.60	13.00	100	37.00
700	12.85	7.00	100	21.70

Table 2 Data analysis for Table 1

	DFS [13]	BFS [13]	TSP_NN	Proposed
Maximum coverage (%)	57.00	39.00	100.00	73.56
Minimum coverage (%)	12.85	7.00	100.00	21.70
Mean coverage (%)	37.47	19.01	100.00	50.86

Table 3 Percentage of coverage for different Ψ values

Number of nodes	Ψ value	Coverage percentage
150	8	67.89
150	9	71.26
150	10	73.56
150	11	70.26
150	12	69.58

Table 4 Percentage of coverage for different Ψ values

Number of nodes	Ψ value	Coverage percentage
300	17	67.53
300	18	68.00
300	19	66.57
300	20	62.17
300	21	57.61

Partition subsets by partitioning nodes based on Mahalanobis distance
Plan a path through the subsets
For each subset in path
Recurse with nodes set to data from subset
End
Else
Plan path through nodes
End

Algorithm 1 Partition strategy

The path planning partition strategy is depicted in algorithm 1. Initially the fruits are randomly grouped into one of the Ψ groups. The calculated Mahalanobis distance metric is used as the cost function. The adjacency matrix is used to store the route information present in the graph. Datasets containing nodes from 100 to 700 were considered for simulation. To benchmark the proposed algorithm, existing graph traversal techniques such as Breadth First Search, Depth First Search and TSP nearest neighbour TSP_NN were considered. Table 1 depicts the coverage obtained by various algorithms.

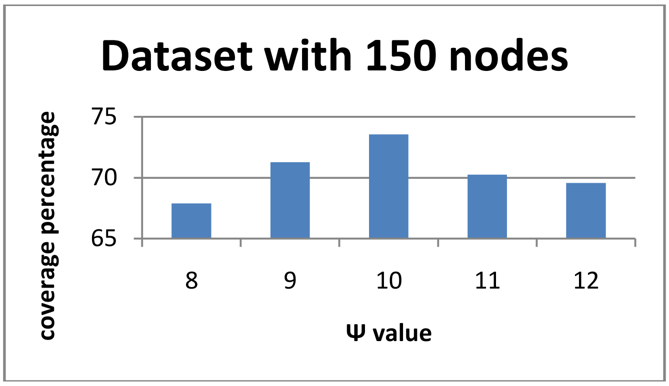

Figure 1 Coverage percentage by varying Ψ value for dataset with 150 nodes

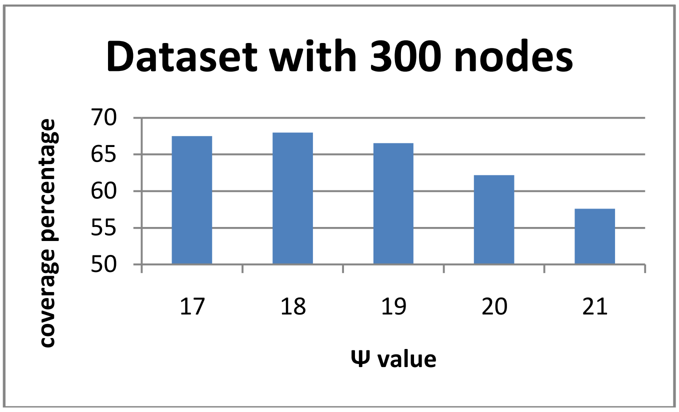

Figure 2 Coverage percentage by varying Ψ value for dataset with 300 nodes

V. RESULTS

Breadth first search works by traversing a graph in short and fast manner. Hence it can be observed that it performed the lowest coverage among the algorithms considered. TSP_NN proceeds by implementing an exhaustive search technique for any given dataset. Hence it was able to achieve maximum coverage but the time taken was very high, in the order of hours. Depth First Search was able to find reliable routes for over a varied range of datasets. The problem is that it does not consider the end point in a given dataset while initializing the computation for path planning. Hence the paths returned would be shorter, ignoring a few nodes in the process. Since the proposed partition methodology was able to consider the starting and end point while initializing the path planning operation, it was able to produce more complete traversable paths when compared to other methodologies. Table 1 represents the coverage percentage obtained by various algorithms. Table 2 presents a data analysis for Table 1. Table 3 represents the coverage obtained by the proposed method by a dataset with node number of 100, by varying the Ψ value. Table 4 represents the coverage obtained by the proposed method by a dataset with node number of 200, by varying the

Ψ value. It can be seen that Ψ value plays an important role in determining the coverage obtained by the proposed method.

VI. CONCLUSION

A discrete coverage path planning algorithm was proposed to solve the problem of picking fruits in a cashew orchard. A Mahalanobis distance based partition strategy was implemented to optimize the coverage routes. The optimal partition value was also evaluated by varying different size of datasets with different Ψ values. The proposed algorithm was benchmarked against existing techniques adopted for coverage. Future works include developing a working model to demonstrate the efficiency of the proposed algorithm.

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