# Path Planning for Agricultural Ground Robots – Review

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**Abstract.** The earth's population is expected to increase by a phenomenal 240,000 people every single day, reaching a total of 8.20 billion by the year 2026 and 9.85 billion by the year 2052. In spite of the limited amount of arable land that is now available, it is believed that by the year 2050, an increase in food production of at least 70 per cent will be required to keep the peace across the globe. The practice of precision agriculture, which is widely recognized as an essential method for better crop management, assuring environmental protection, and significantly improving the quality of field products, is regarded as being of the highest significance. The fundamental objective of point-to-point path planning for a mobile robot is to plot a route between the beginning point and the ending point that is free of obstructions and has restrictions placed on the amount of collisions, distance, travel duration, and power consumption. This methodology treats the robot as a single entity traversing a potential field, where the obstacles are attracted to the possible area, and the destination serves as a repulsion point for the robot. The pervasiveness of this research illustrates the wide-ranging themes and applications of route planning techniques in agriculture. This research comprises coverage path planning and point-to-point routing strategies. Navigation is crucial for various agricultural settings, including wheat fields, orchards, vineyards, and greenhouses, for tasks such as precise spraying, monitoring, and harvesting. Some authors have proposed a route planning algorithm suitable for farming machinery and locations. This study provides a comprehensive assessment of route planning techniques for agricultural settings that use ground robots. It scrutinizes the agricultural sector's limitations resulting from robot configuration and terrain characteristics while also considering outdoor conditions, optimization measures, terrain geometry, computational complexity, and real-world testing implementation.

## INTRODUCTION

The world's population is expected to increase by more than 240,000 people every single day, reaching a total of 8.18 billion by the year 2025 and 9.7 billion by the year 2050, according to forecasts. In spite of the diminishing amount of arable land, increasing food production by 70 percent by the year 2050 would be required to maintain global peace. This presents a formidable obstacle for contemporary civilization [1]. In order to accomplish this objective, it is vital to develop environmentally friendly agricultural methods, infrastructure, and technologies that can successfully produce food to meet the ever-increasing requirements of a constantly expanding population. The term "precision agriculture" (PA) refers to an outstanding collection of strategies and procedures that accurately govern the variability of a field in order to grow agricultural output, profitability for the company, and ecological sustainability. The importance of precision agriculture in optimizing crop management, improving product quality, and ensuring environmental safety has obtained a lot of awareness in current years [2]. The use of automated instruments is very necessary for crop monitoring and management [3] when dealing with big fields and/or difficult terrain. As the number of people working in agriculture falls across the world, large-scale farms are increasingly turning to multi-robot systems to perform agricultural chores [4]. Unmanned ground vehicles, also known as UGVs, must be used for the PA mission in order for it to be successful and productive. Since many agricultural products have a limited shelf life, the distribution network must always maintain a high degree of care to prevent the products from being spoiled. The point-to-point path planning of mobile robots' main goal is to determine an unimpeded path between the beginning and terminating sites that reduces collisions, travel time, distance, and energy consumption [5]. The creation of UGVs requires careful planning of their routes, which is one of the most important aspects of this kind of vehicle's design. The usage of UGVs in agriculture may help to stop the deterioration of agricultural goods that occur on farms.

UGVs play a vital role in increasing agricultural output by performing things such as reducing the quantity of fertilizer that is required and achieving precision weed control. This helps minimize the environmental impact of agricultural production. The productivity of farming households as well as the outcome produced by each acre of land is going up as a direct effect of the section of labour and cooperation that takes place across numerous different robot systems (MRS). The potential for utilization has expanded as a result of developments in related research, and as a result, it is now feasible to do tasks with a higher degree of both speed and accuracy [6]. UGVs are being used in the agricultural industry for a variety of tasks, including sowing, sensing, and mapping, among others. In order to do the tasks mentioned above in the agricultural field without being stopped, UGVs must be highly automated with the least amount of human involvement possible [7]. Autonomous agricultural robots should have detection, navigation, action, and mapping capabilities. These are the four characteristics of automation that are the most important to have. It is vital to have strong navigational skills, and detection and mapping are used rather often. When it comes to traveling with UGVs, one of the most important and vital components is the planning of the routes. In order for the vehicle or robot to be able to drive on its own, it must first plan out a path that will take it to a series of specified target locations without coming into contact with any obstacles [8]. Following that, the robot will go along the course that was predetermined by the algorithm that is responsible for path planning. In addition to this, the robot has to have the ability to respond appropriately to unexpected and unforeseen events that may occur in real time. They may include challenges that were not expected, duties that were not planned, and other circumstances that are analogous. Global positioning systems (GPS), in spite of their ubiquitous usage, have several restrictions and downsides in situations that need very accurate navigation or when the satellite signal is poor. Other situations that fit this description include being in a covered space, such as a greenhouse, or in an unique hilly region. Because of wheel slippage on sloping terrains, which happens often in a wide range of crops, including vineyards, UGV motion prediction that is based on wheel odometry has major hurdles in agricultural applications [9].

According to the robotics strategic study schedule, using robotic platforms will boost agricultural output in Europe. In spite of the fact that this area of research is gaining in popularity [10], there are currently only a limited number of solutions that are practical from a business perspective [11]. A large number of agricultural assignments, such as harvesting, spraying, monitoring, planting, and pruning, to name just a few, have been made more efficient via the use of automated systems. Every one of these tasks requires independent navigation from the robots. Localization, motion control, mapping, and route planning are the four essential components that must be present at this critical phase of autonomous robot navigation. Robot path planning is a sequence of measures for the robot's translational and rotational movements to sidestep obstacles from one location to another while the robot operates in its environment. These calculations are performed in order to keep the robot safe as it moves through its environment. In regions where there is a strong concentration of agricultural, it is possible that robot navigation may become much more challenging. In contrast to the internal environment, the agrarian areas are disorganized, chaotic, and difficult to forecast. Methods for route planning that are effective in indoor settings but not necessarily suited to use in outdoor settings might be problematic. Thus, in order to fulfill these requirements, better agricultural route planning strategies will need to be developed. As a consequence of the changes brought about by Industry 4.0 and the exponential expansion of machine learning, path planning for autonomous ground vehicles has attracted a lot of attention in recent years (UGVs). There are a number of publications on this subject, the first of which was established in 1989 by Palmer et al. [12], who presented an issue involving effective field routes that avoided a blockage caused by concerns in the agricultural industry. There are a number of publications on this subject. Research conducted by Bochtis and colleagues [13] on ways in which agricultural equipment may be improved includes a discussion of the use of route planning algorithms to promote farm output. To ensure (1) strategy effectiveness, (2) more suitable product quality, (3) lower expenses, (4) enhanced product safeness and environmental sustainability, (5) shortened customer delivery periods, (6) grew market allocation and profitability while stabilizing the labor force, and (v) all of the advantages mentioned above, Asmart Farm should depend on autonomous decision-making. For Asmart Farm to confirm (1) method effectiveness, (2) enhanced product rate, and (3) decreased expenses; autonomous decision-making should be used. In the case that the robot encounters an unforeseen obstruction, it must change its course. Either the robot has to calculate a new route and then follow it on its own, or it needs to construct a temporary time-dependent trajectory and then eventually retrace its steps back to the initial path. Either way, the robot needs to do one of two things. Both of these options must be used by the robot in order for it to successfully navigate around the obstruction. Planning your route is essential for unmanned ground vehicle (UGV) navigation since it helps you to choose the path that is the shortest and most direct between two places while avoiding obstructions. Local trajectory planning and Global route planning are the two separate features that may be used to divide this issue into two distinct categories. Both of these aspects are affected by the environmental data that is required in order to determine the most effective route. The use of a global geographic map to establish the most efficient way is the purpose of the process known as "global path planning." On the other hand, local trajectory planning creates a route that is clear of potential collisions in real-time by using sensor information that has been obtained from the immediate vicinity. So, in order to successfully execute a variety of operations while minimizing the impact of any barriers, it is necessary to engage in both online local trajectory planning and global route planning [14].

The remaining sections of this paper are structured as follows: Section 2 presents the search methodology for the articles in the study. In Section 3, we describe the optimal path search categories. In Section 4, we explain the use of techniques in robot navigation in precision agriculture. Finally, in Section 5, we summarize the implications of our study.

## METHODOLOGY

This paper added fresh information to the existing body of knowledge on the path/route planning capabilities of robots on the ground used in farming by using the "systematic literature review" approach developed by Fabbri et al. [15]. This was done in order to add fresh information to the current body of knowledge that was already available. It is necessary to conduct a comprehensive literature review in order to appropriately organize and evaluate the material that is currently accessible in a certain field [16]. An approach that is not only accurate but also clearly outlined is required for this assessment. The major strategy that was used in the process of locating original research was searching through a total of five different indexed databases (IEEE Xplore, Elsevier Scopus, Springer Link, ACM Library and Google Scholar). The databases were chosen because they provide access to the highest possible amount of influential research publications and conferences and cover the subject of route planning for agricultural UGVs in a comprehensive manner. This was a significant consideration that led us to decide to make use of the databases. The following search keyword was entered into each database in order to get results: "agricultural ground robotics," "agricultural unmanned ground vehicles," "agricultural UGVs", or "path planning", or "route planning."

Motion planning is the procedure of creating functional trajectories for mobile robot strategies. This is of the utmost importance if additional aspects are present such as kinematic limits, dynamic conditions, object cooperation, etc. The term "motion planning" is used to describe this specific method. In addition, from a topological point of view, the term "route planning" directs to the calculation of the best sequence for accessing the nodes in a network. This may be seen as an extension of the concept of "travel planning." This computation is exactly the same as the issue involving the whole traversal of a graph. On the other hand, "path planning" directs to the problem of finding a without collision route connecting an established starting point and a final destination end [17]. This term may be construed either topologically, geometrically, or in the sense of a trajectory. We looked at all of the many ways that route planning may be done for ground robots to utilize in agricultural settings, and articles that were chosen to be analyzed were from a wide range of agricultural situations.

This evaluation of relevant study is being done with the intention of providing answers to the following questions:

1. What kind of agricultural work does it participate in?
2. Which method of route planning is being implemented?
3. On-line qualifications?
4. Should it be static or dynamic?
5. What is the ideal route?
6. What are the features of geometry?
7. Optimization criteria?
8. What are the limitations of the robot?
9. Limitations?
10. The difficulty of the computation and the amount of time it takes?

11. What were the circumstances of the field tests?

## PATH PLANNING FOR AN AUTONOMOUS GROUND VEHICLE

Automatic ground vehicle guiding may now be established via the use of either local positioning systems or global positioning systems. This was not achievable in the past (GPSs). The Global Positioning System has grown as a result of recent advancements in satellite technology, which led to this (GPS). The driver of an agricultural vehicle that is fitted with a GPS is freed of the heavy responsibility of precisely steering the vehicle, the precision of trajectory tracking is enhanced, and the vehicle is able to work throughout the night or in situations that are cloudy. These are just three of the numerous perks that come along with having a GPS system installed in agricultural vehicles.

### Point-to-Point Routing

Establishing a without collision path from a starting location to a terminus point while reducing space, travel period, and power consumption is the goal of mobile robot point-to-point route planning. This is accomplished by starting at one location and finishing there. With this strategy, the barriers operate as a point of attraction for the robot, while the destination acts as a point of repulsion in a potential field. This kind of route design, also known as the cell-by-cell breakdown approach, divides the agricultural open space into manageable parts so that it may be more efficiently used. In [18], a method for estimating the locational limits that are placed on an item as a result of the existence of different entities is presented. Their approach is predicated on the idea that the position and orientation of an item are each represented by a single point in a composition area. In this space, individual coordinate conveys a different phase of flexibility, and the point that represents each position and orientation is known as a configuration point. When the algebraic total of all the potentials is equal to zero, as is often the case in this approach, the production of local minima takes place. As was noted in passage [19], the circumstances may make it impossible for the robot to do the task it has been given. Results from an experiment employing research prototype rovers detailed in [20] showed that the planner provides real-time efficiency while also permitting the use of the whole vehicle mobility envelope in rugged regions.

When a mobile robot's voyage does not use the obstacle area's external edge, the total duration it takes to complete the journey is cut down. Goto et al. [21] came up with the idea of using an A* algorithm-based strategy to cut down on processing time. Castillo et al. multi-objective .'s genetic algorithm approach employ the travel distance of the route and complexity as the target functions [22]. The Rapidly Exploring Random Tree, abbreviated as RRT for short, is a well-known sampling-oriented strategy used to explore pathways aimlessly. RRT enjoys venturing into unknown regions. The RRT has a distribution of vertices that is consistent across the board. The procedure is not too complicated, there are not a great deal of edges, and RRTs are continuously connected to one another. These planners are simple yet inefficient, and they have a preference for planning routes with a lot of curves [23]. RRTConnect, sometimes referred to as bi-directional RRTs, is a technique that links two RRTs, one at the starting point and the other at the destination position, using a heuristic. There are no differential restrictions in situations when this approach performs well. One of the trees is extended with each iteration, and each newly generated vertex is connected to a nearby vertex on the other tree. The functions are then reversed, and both trees begin to explore the arrangement area that is now open. This method may be used to simulate the motions of a robotic arm with a large number of degrees of freedom. A street map of the area under investigation and an accompanying Safe Region (SR) are created using Sensor-based Random Trees, or SRTs [24]. The sensors can determine the boundaries of the Local Safe Area (LSR). Separately SRT node consists of a Local Safe Area and a free configuration that may be configured in whatever the user chooses. The whole of the Local Safe Regions come together to form the Safe Region. It is a promontory of the free space surrounding the robot laid out in a specific format. For instance, the form of the LSR is decided by the angular resolution of the sensor that is mounted on the robot. The ball and the star are the two possible forms of an LSR structure. According to the results of experiments, the LSR exploration approach structured like a star achieves a higher degree of precision. Karaman et al. [25] made RRT*, a method that converges to results that are almost as good as ideal, available to the public. The researchers Masehian and Sedighizadeh [26] were successful in achieving their goals of brevity and smoothness thanks to the combination of PSO and a probabilistic route map. On the other hand, multi-objective PSO (MOPSO) algorithms have been designed for over 20 years and have completed essential strides in the handling of multi-scope optimization issues. These algorithms have been used to accomplish great breakthroughs. The usefulness of MOPSO differs significantly, hanging on the dimensionality and complexity of the problems being considered. While planning their courses of action, a few of the researchers used a technique known as multi-scope decision-making or MODM. The analytical scale method, often known as AHP, was applied by Kim and Langari [27] in order to construct the optimal route for a mobile robot. The Point Bug approach was developed by Buniyamin et al. to limit the utilization of an obstacle's exterior boundary (deterrent border). This was accomplished by looking for an actual periodic location on an obstruction's outer frame that may be utilized as a turning place to the mark and then creating a complete route from start to site.

The authors Masehian and Sedighizadeh [28] employed the particle swarm technique in conjunction with a possible road map to reach their shortness and smoothness purposes. Ahmed and Deb made a change to the non-dominated sorting genetic algorithm so that it would concurrently take into account the smoothness of the route, the safety of the journey, and the distance travelled. The non-dominated sorting genetic algorithm was improved by Ahmed and Deb [29] so that it could concurrently take into account the smoothness of the route, the safety of the journey, and the distance travelled. MOPSO was used in the research presented in reference to design robot trajectories and produce Pareto optimal pathways. Fernandes et al. [30] force the robot to rotate at its highest possible speed by applying a cell decomposition technique including A*. In the realm of route planning, there has been a lot of interest in the use of algorithms that are inspired by nature. In the research on robot route planning, GA, PSO, and ACO are three topics that are often explored and have shown positive results. Several algorithms for route planning that are inspired by nature are explored and reported in great detail by Mac et al. [31]. GA is a strategy for optimizing established natural genetics using methods such as natural selection, mutation and sample crossover. This approach is known as the genetic algorithm (GA). It has been claimed that mobile robot motion planning may be improved by using a method that combines the Voronoi diagram (VD) with the altered Ant Colony Optimization (M-ACO) algorithm. The Voronoi chart generates borders and vertices in the region, including obstacles. The M-ACO algorithm selects the nodes so that point-to-point motion planning may be used to design the safest and most efficient shortest path. Elhoseny et al. [32] used an altered generalized algorithm (GA) to create a route planning method in a dynamic environment. In order to determine the fastest, most scrimping, slickest, and securest path in the actuality of barriers and drafts while also regarding collision release, activity limitations, and rate restraints, Ma et al. [33] suggested a dynamic extended multi-scope particle swarm algorithm. This was carried out to determine the best course when currents and barriers were present.

## Coverage Routing

Coverage route planning is the process of creating a path that passes through every point in an area or volume while avoiding obstructions (CPP). Cao et al. [34] definition of a covering operation included the following requirements:

1. The robot has to be capable of encircling the entire area.
2. The robot must serve the space entirely, with no overlap.
3. The procedures must be continuous, sequential, and devoid of redundant paths.
4. The robot has to steer clear of any obstacles.
5. Utilize basic motion trajectories.
6. An optimal course of action is sought underneath the current situation.

In complicated situations, however, it is not always possible to fulfill each of these requirements to the fullest extent possible. Prioritization is necessary as a result. Depending on the level of assurance that they provide, these algorithms may either be classified as heuristic or as comprehensive. This determination is made regardless of whether or not they are considered to be online or offline. Coverage strategies often make advantage of cellular breakdown, either implicitly or explicitly, in order to guarantee coverage. There are methods that are close, almost close, and precise [35].

Another possible coverage strategy is the usage of cell grids. Using this approach, the map is divided into a cell grid, and a route is then constructed that passes through each cell in the grid. Zelinsky et al. [36] used the time-tested wavefront technique to identify a coverage route. The algorithm wavefront will generate a wavefront from the destination cell back to the beginning cell after you have specified both the starting cell and the target cell. Before traveling closer to the target, the wave fronts first visit the cells located in the level groups that are equally far from it. Randomization is a low-cost option that may be useful for tiny robots working in constrained environments. Nevertheless, this method is not optimum. According to Choset et al. [37], the most significant benefit of using a random method is that it eliminates the need for using specific route planning algorithms or localization sensors. This is not possible when it comes to the needs of the agricultural sector since some agricultural activities require specific procedures that cannot be given by random operations. Hence, this cannot be achieved. The costs associated with maintaining the platform would likewise be much higher. According to Huang [32], the sweep line or cells need to be rotated in order to get the finest possible boustrophedon patterns. Methods that are used in the precise dissection of cells partition open space into discrete areas (cells). In order to cover the free cells, you only need to make a few simple movements. One example of this would be a pattern that uses zigzags to fill all of the available space. A popular method of cell disintegration known as boustrophedon cell breakdown involves moving freshly created cells in a straightforward back-and-forth motion to accomplish the task of destroying cell membranes. The cellular disintegration in the route formation experiment carried out by Acar et al. [38] was flawless.

In their design for an energy-optimized coverage route, Schafle et al. [39] used GA as their main analytical technique. For a cleaning robot, Kouzehgar et al. [40] devised a simple additive weighting (SAW)-based route planning method, taking into account the quantity of area covered and the energy used. According to a method reported by Zoto et al. [41], a coverage route plan for a UGV may be created automatically using high-resolution photographs taken by a UAV. The findings of the experiments indicate that the whole research considerably improves the design of coverage routes for UGVs in hard environments, such as steep vineyards. This might be of assistance to farmers in the management of agricultural operations. Yet, when trading with settings that range widely from grape region to vineyard location, there are a number of difficulties to consider.

Using methods such as the classic accurate cellular decomposition techniques, Morse-based cellular decomposition procedures, and landmark-based cell decomposition algorithms [42], the initial map can be segmented into smaller units that can be traversed using a straightforward movement pattern. Morse-based decompositions are not limited in any way by the polygonal structures and impediments that are necessary for traditional precise cellular decompositions since these decompositions are dependent on them.

## APPLICATION OF ROUTING IN AGRICULTURE

We were able to find a reasonable number of articles on this subject, which shows that there are many different subjects and uses for route planning in agriculture. This collection of articles includes both point-to-point path planning solutions and coverage route design challenges. In addition to its employment in other agricultural contexts, navigation is put to use in settings such as greenhouses, orchards, vineyards, and wheat fields. A wide range of activities, including monitoring, accurate spraying, and harvesting, are all possible with the help of navigation. As opposed to that, some authors recommend a route planning algorithm that does not particularly connect to a goal but is suited for agricultural machinery and/or places [29]. In agricultural applications, there is no universal method for route planning that incorporates a variety of ways for each job, regardless of whether the environment is 2D or 3D.

The first article on point-to-point route planning to be featured is from 1998 and proposes a Method for producing a path for agricultural robots while taking into account the location's constraints. The point-to-point route planning journal published this work. Linker et al. [43] reported on a study that included a modified cell breakdown for orchard navigation in 2008. They considered the environment as well as the vehicle's unique limitations. There was a predilection for forward motion, a limited range of pitch and roll degrees, a reluctance to turn often, and a restricted steering angle among them. Even if the writers claim that the path they selected is optimal, some limitations may force them to choose a less desirable path. Similar to the strategy used by Santos et al. [44], this method considers the location of the robot's centre of gravity and restricts the roll, pitch, and yaw angles to ensure safe navigation in a vineyard with a steep slope. They carried into performance the restrictions that were specific to the vehicle and the circumstance at hand. These limitations included a limited scope of roll degrees and pitch, a selection for onward movement, and a disinclination to perform regular turns. Further elements, including soil compression and automatic recharge methods, are considered in various iterations of this methodology. Another piece of work makes use of the D* cell decomposition method, which is similar to the A* method but also incorporates robot dynamics. This study's objective is to look at a peculiar oil palm field. Although Mai et al. [45] apply ACO to monitor several sites during potato production, an artificial potential field planner is applied in an unstructured 3D terrain for the goal of energy optimization [46]. Although cell decomposition is a somewhat preferable method for point-to-point route routing, the authors disagree on which methodology should be employed.

**TABLE 1.** Applications of routing in the agricultural sector

| Paper | Implementation | Approach to the Path Planning | 2D/3D Terrain Configuration | Robot Restrictions | Limitations |
|---|---|---|---|---|---|
| 46 | We suggest a multi-layered approach to track a vineyard robot's autonomy, guide it to the nearest charging level while off-line, and dock it there while considering visual tags. | | 3D Irregular and curving vine rows that have steep slopes towards the margins of the scene. | Differential robot | During the first execution of the algorithm, it is possible that it will need to run for many hours. |
| 44 | It has been suggested that a field-operated agricultural rover take an improved route rather than a direct route in order to save energy and increase the battery's life span. | Artificial Potential Field | Simulated topography in three dimensions that is devoid of structures and obstructions | | |
| 47 | Avoiding soil compaction when navigating through steeply slope vines | A Modification of Cell Decomposition Using A* | Vine rows that are crooked and bent, having steep inclines at the borders. | Differential robot Tracks robot Tricycle robot | When many pathways are generated from the same site, the processing time will rise so as to prevent compaction. |
| 48 | Navigation through vineyards with steep slopes while being mindful of the vegetation wall distance | | Rows of twisted vines that are irregular in shape and have steep slopes at the margins | data | It is not feasible to guarantee a precise distance during the course of the full journey. |

| | | | | | |
|---|---|---|---|---|---|
| 49 | While navigating through steeply slope vines, the robot's center of mass is aware. | | Rows of crooked, twisted vines that are irregular in shape and have steep slopes at the margins. | Differential Robot:<br>− limited pitch and roll according to center of mass<br>− limited steer angle<br>− limited maximum turn rate | Memory-intensive for large-scale topographies due to the complexity of the computations. |
| 50 | It is recommended to use an online route planning system in greenfield farming in order to enable autonomous tractor steering control. | The model that was suggested by the authors | | Tractor with trailer:<br>− limited steer rating | The distance of the swath from the location of the pickup center is getting close to one meter. |
| 51 | The ideal paddy or wheat harvesting zone for a robot combine harvester | N-polygon method to select the most productive location for harvesting | 2D: Polygon fields that are both convex and concave | Big dimension agricultural tracks machine | |

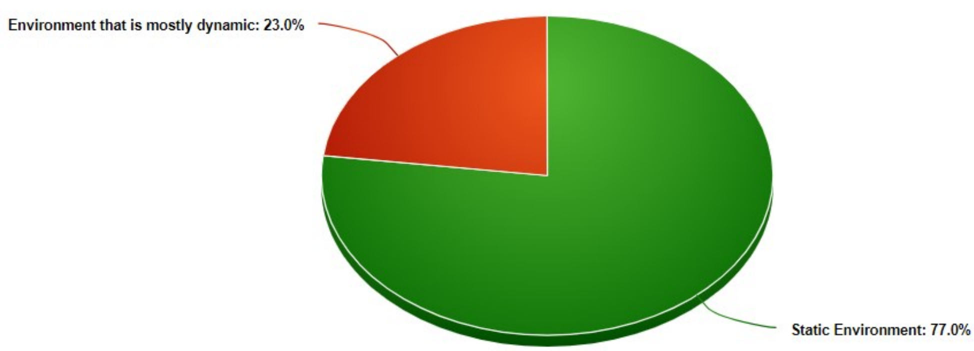


**FIGURE 1:** Environment for the testing of the point-to-point approach routing method

An examination of Table 1 indicates that the point-to-point path routing method is specifically tried in a fixed setting sooner than the applicable area state of the farming ground. The body of research presents a wide range of solutions to the problems associated with route planning. In this area of study, one of the most prevalent goals is to completely cover topographies that have an uneven shape. The work that was picked the longest ago is from 2006, and it is called "95." It is a Hamiltonian Graph exploration that searches irregularly shaped regions for the fewest overlaps and manoeuvres possible. 2009 saw the development of a greedy method for covering curve-shaped fields by Oksanen et al. [52], who used a heuristic approach to the problem. Five years later, in 2011, A GA-based method for forecasting the most suitable path for agricultural equipment to travel in order to save the most fuel was described by Hameed et al. [53]. The authors contend that their strategy either provides a less desirable option, is excellent, or is very close to being ideal. Just 2 point-to-point and 2 coverage path planning analyses offer an answer of online in dynamic environments, suggesting that most strategies are static off-line route planners. [54] More petite than half of the writer's reason to have conducted studies in real-world situations since there aren't many point-to-point methods in this category. This may be because there aren't many point-to-point operations in this region.

No official measurements were taken; however, the computational complexity was investigated since most writers cannot give factual information on this issue, containing computational conditions and material directions in certain circumstances. This was done because of the situation. According to several writers that describe their coverage route planning approach, a measure of difficulty known as nondeterministic polynomial-time complexity is used for the purpose of classifying decision-making situations. [55] According to the findings of this review research, route planning is used often in the industrial sector as well as the interior environment; on the other hand, agricultural settings for ground robots utilize it quite seldom. Because of the frequency with which it happens, farming makes it far more difficult to design a coverage path. On the other hand, point-to-point planners are ideal for precision agricultural operations that need a single activity to be carried out on a certain number of plants. These kinds of activities are sometimes referred to as "counting" operations. For the purpose of, say, trimming plants, the robot must confine its movements to only those specific plants and not the whole surrounding region. In conclusion, agricultural route routing research is necessary if one is interested in "getting on track" with the implementation of agricultural automation. In the future, research should concentrate on verifying and improving the suggested approaches by conducting in-depth evaluations of them in real-world agricultural settings.

## CONCLUSION

A complete analysis of a route routing technique for use in agriculture using ground robots is offered here as part of this body of work. It researched the application in the agricultural sector and discussed the restrictions that were imposed by the robot configuration or the terrain kind in the farming sector. The investigation was conducted in the farm sector. This paper explains the route routing approach, the type of outdoor conditions, the topography geometry features, the optimization measures, the strategy's limitation, the computing complexness, and the testing implementation in a real-world scenario. Specifically, the paper focuses on the terrain geometry features. According to the research findings, there are two distinct route routing strategies point to point and coverage path routing. Based on the results of the study, it seems that point-to-point route routing has advanced farther in agriculture than coverage path routing has. This is because coverage route routing is often needed for agricultural implementation in a more general sense. In contrast, point-to-point path routing is directed at newly developing precision agriculture. This distinction is necessary for understanding why this is the case. The coverage route planning technique has been validated in a static environment 83% of the time, while it has been validated in a dynamic environment 17% of the time. The point-to-point route routing technique has only been evaluated in a somewhat dynamic situation in 18% of the total instances. In contrast, it has been validated in a static environment 82% of the time.

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