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Navigation techniques of mobile robots in greenhouses

Ehsan Kamran[1], Asadullah Mirasi[2*], Mousarreza samadi [3]

[1]Department of farm machinery, Faculty of Agriculture, Islamic Azad University, Ilam Branch, Ilam, Iran.
[2]Department of farm machinery, Faculty of Biosystems Engineering, Islamic Azad University, Lordegan Branch, Shahrecord, Iran.
[3]Ph.D. Candidate in post-harvest, Department of Agricultural Machinery Engineering, University of Tabriz, Iran.
[*]Corresponding author: asadmirasi@yahoo.com

ABSTRACT

With the continuous development of the industrialization process, the countries all over the world gradually appeared lack of agricultural labor force and aging phenomenon, which was especially prominent in developed countries. However the agricultural robot with high operating efficiency, high qualities of work will play an increasingly important role in future agricultural production. Robot navigation is not only the key to automation and also the biggest obstacle constraining their development. This paper provides a review of relevant mobile robot positioning technologies. The paper defines seven categories for positioning systems: 1. Odometry; 2. Inertial Navigation; 3. Magnetic Compasses; 4. Active Beacons; 5. Global Positioning Systems; 6. Landmark Navigation; and 7. Model Matching. Therefore, the research status of agricultural robot navigation was introduced in this paper. Also, this paper discusses the problem of using navigation methods for agricultural mobile robots in greenhouses. Nowadays, many agricultural tasks are dangerous and repetitive for human beings and could be improved employing robots. The autonomous navigation in greenhouses has been solved using both deliberative and pseudo-reactive techniques.

Keywords: autonomous, Magnetic, agricultural, Global Positioning

INTRODUCTION

With the continuous development of the process of industrialization, the phenomenon of agricultural labor shortages gradually appeared in the world, particularly in developed countries. In recent decades, with the rapid development of computers, image processing and mechatronics technology, agricultural machinery development continuously toward the direction of agricultural robots, which can reduce labor intensity, to avoid agricultural chemicals cause environmental pollution, and reduce the manpower and material resources in the agricultural Input costs. In the decades of agricultural robot navigation research, there is a variety of ways, Such as signpost navigation, perception navigation, visual navigation and GPS navigation and So on. Recent developments and advances in robotic field enable to apply mobile robots for greenhouse tasks which will not fatigue and can reduce operator's importance, improving the efficiency and operation safety. In order to make successfully greenhouse tasks through mobile robots, the first approach is to design appropriated vehicles to the structure and to the rough ground of the greenhouses. The second phase is to implement navigation techniques which permit to the mobile robot travel the corridors. In previous works, it is possible to find some examples of mobile robots used in greenhouse tasks. (Mandow, et al., 1996) describes an autonomous vehicle (Aurora) for spraying tasks.

The navigation control of this robot depends on a previous sequence of behaviors established by an operator, thus it does not employ strictly deliberative or reactive navigation techniques. (Sammons, et al., 2005) presents an autonomous spraying robot whose navigation control relies on inductive sensors which detect metallic pipes buried in the ground. An autonomous robot for harvesting cucumbers in greenhouses has been described in (Van Henten, et al., 2002), but unlike the previous reference, it is guided on the heating steel pipes.

This paper surveys the state of the art in sensors, systems, methods, and technologies that aim at finding a mobile robot's position in its environment. In surveying the literature on this subject, it became evident that a benchmark like comparison of different approaches is difficult because of the lack of commonly accepted test standards and procedures. The research platforms used differ greatly and so do the key assumptions used in different approaches.

Perhaps the most important result from surveying the literature on mobile robot positioning is that, to date, there is no truly elegant solution for the problem. The many partial solutions can roughly be categorized into two groups: relative and absolute position measurements. Because of the lack of a single good method, developers of mobile robots usually combine two methods, one from each group. The two groups can be further divided into the following seven categories (Borenstein et al, 2014):

I: Relative Position Measurements (also called Dead-reckoning)

1. Odometry
2. Inertial Navigation

II: Absolute Position Measurements (Reference-based systems)

3. Magnetic Compasses
4. Active Beacons
5. Global Positioning Systems
6. Landmark Navigation
7. Model Matching

Review of techniques

In this Section we will review some of the techniques used in mobile robot positioning. Examples of commercially available systems or well-documented research results will also be given.

1. Odometry

Odometry is the most widely used navigation method for mobile robot positioning; it provides good short-term accuracy, is inexpensive, and allows very high sampling rates. However, the fundamental idea of odometry is the integration of incremental motion information over time, which leads inevitably to the unbounded accumulation of errors. Specifically, orientation errors will cause large lateral position errors, which increase proportionally with the distance traveled by the robot. Despite these limitations, most researchers agree that odometry is an important part of a robot navigation system and that navigation tasks will be simplified if odometric accuracy can be improved. For example Cox [1991], Byrne et al. [1992], and Chenavier and Crowley [1992], propose methods for fusing odometric data with absolute position measurements to obtain more reliable position estimation.

2. Inertial Navigation

Inertial navigation uses gyroscopes and accelerometers to measure rate of rotation and acceleration, respectively. Measurements are integrated once (or twice, for accelerometers) to yield position. Inertial navigation systems have the advantage that they are self-contained, that is, they don't need external references. However, inertial sensor data drift with time because of the need to integrate rate data to yield position; any small constant error increases without bound after integration. Inertial sensors are thus mostly unsuitable for accurate positioning over an extended period of time.

3. Magnetic Compasses

Vehicle heading is the most significant of the navigation parameters (x, y, and Θ) in terms of its influence on accumulated dead-reckoning errors. For this reason, sensors which provide a measure of absolute heading are extremely important in solving the navigation needs of autonomous platforms. The magnetic compass is such a sensor. One disadvantage of any magnetic compass, however, is that the earth's magnetic field is often distorted near power lines or steel structures [Byrne et al., 1992]. This makes the straightforward use of geomagnetic sensors difficult for indoor applications.
Based on a variety of physical effects related to the earth's magnetic field, different sensor systems are available:
Mechanical magnetic compasses.
Fluxgate compasses.
Hall-effect compasses.
Magneto resistive compasses.
Magneto elastic compasses.

4. Active Beacons

Active beacon navigation systems are the most common navigation aids on ships and airplanes, as well as on commercial mobile robot systems. Active beacons can be detected reliably and provide accurate positioning information with minimal processing. As a result, this approach allows high sampling rates and yields high reliability, but it does also incur high cost in installation and maintenance. Accurate mounting of beacons is required for accurate positioning. Two different types of active beacon systems can be distinguished: trilateration and triangulation.

5. Global Positioning Systems

The Global Positioning System (GPS) is a revolutionary technology for outdoor navigation.
GPS was developed as a Joint Services Program by the Department of Defense. The system comprises 24 satellites (including three spares) which transmit encoded RF signals. Using advanced trilateration methods, ground-based receivers can compute their position by measuring the travel time of the satellites' RF signals, which include information about the satellites' momentary location. Knowing the exact distance from the ground receiver to three satellites theoretically allows for calculation of receiver latitude, longitude, and altitude.

6. Landmark Navigation

Landmarks are distinct features that a robot can recognize from its sensory input. Landmarks can be geometric shapes (e.g., rectangles, lines, circles), and they may include additional information (e.g., in the

form of bar-codes). In general, landmarks have a fixed and known position, relative to which a robot can localize itself. Landmarks are carefully chosen to be easy to identify; for example, there must be sufficient contrast relative to the background. Before a robot can use landmarks for navigation, the characteristics of the landmarks must be known and stored in the robot's memory. The main task in localization is then to recognize the landmarks reliably and to calculate the robot's position.
In order to simplify the problem of landmark acquisition it is often assumed that the current robot position and orientation are known approximately, so that the robot only needs to look for landmarks in a limited area. For this reason good odometry accuracy is a prerequisite for successful landmark detection.

7. Map-based Positioning

Map-based positioning, also known as “map matching,” is a technique in which the robot uses its sensors to create a map of its local environment. This local map is then compared to a global map previously stored in memory. If a match is found, then the robot can compute its actual position and orientation in the environment. The pre-stored map can be a CAD model of the environment, or it can be constructed from prior sensor data. Map-based positioning is advantageous because it uses the naturally occurring structure of typical indoor environments to derive position information without modifying the environment. Also, with some of the algorithms being developed, map-based positioning allows a robot to learn a new environment and to improve positioning accuracy through exploration. Disadvantages of map-based positioning are the stringent requirements for accuracy of the sensor map, and the requirement that there be enough stationary, easily distinguishable features that can be used for matching. Because of the challenging requirements currently most work in map-based positioning is limited to laboratory settings and to relatively simple environments.

7.1 Map- building algorithm

One of the main problems working in greenhouses is that the layout changes over production periods. Furthermore, farmers rarely have updated digital maps of their greenhouses. For this reason, an algorithm to build a sensorial map was implemented. This algorithm is based on combining sensor readings with the localization of the robot (Dudek and Jenkin, 2000; Fujimori et al., 2002). In the future, this sensorial map should be manipulated in order to be used by the deliberative approach. Furthermore, this work can be a start toward implementing SLAM (Simultaneous Localization and Mapping) techniques in greenhouses (Leonard and Durrant-Whyte, 1991; Durrant-Whyte and Bailey, 2006).
To build the sensorial map, the sonars are employed to determine the distance to the objects in the environment. First, sonar readings should be translated to distance (this has been determined experimentally). Next, the location of the robot is calculated using the dead-reckoning method. Finally, sonar readings are expressed in the global reference system.

7.2 Map matching algorithm

One of the most important and challenging aspects of map-based navigation is map matching, i.e., establishing the correspondence between a current local map and a stored global map [Kak et al., 1990]. Work on map matching in the computer vision community is often focused on the general problem of matching an image of arbitrary position and orientation relative to a model (e.g., [Talluri and Aggarwal, 1993]). In general, matching is achieved by first extracting features, followed by determination of the correct correspondence between image and model features, usually by some form of constrained search [Cox, 1991]. A discussion of two different classes of matching algorithms, “icon-based” and “feature-based,” are given in [Schaffer et al., 1992].

Navigation mobile robot in greenhouse techniques

Greenhouses are structured environments where the distribution of plants is at least partially known. As seen in figure 1, plants are usually arranged in parallel straight rows with narrow corridors for the operation of humans and machines. The main obstacle to the movement of mobile robotics in greenhouses is related to the fact that navigation algorithms should take into account unexpected events (humans working in the greenhouse). Furthermore, appropriate filters for the sensor readings, and robust navigation strategies should be examined. All the previous requisites are described in this article.

In mobile robotics, the most dominant paradigms for robot control are deliberative and reactive control. Deliberative techniques use a world model (map) to calculate a safe path between an initial point and a goal point. Models are typically either metric or topological maps. Metric maps explicitly reproduce the metric structure of the environment.

Topological maps try to represent the environment as a graph (Siegwart and Nourbakhsh, 2004). On the other hand, reactive techniques do not require a previous environment model. These approaches rely on a sensorial system to determine the states of the vehicle and to execute an action (Dudek and Jenkin, 2000).

The navigation challenge for a robot operating in a greenhouse involves planning a reference trajectory and reacting to unforeseen events (workers, boxes, tools, etc). For this reason, the objective of this project is to develop a hybrid solution (figure 2). The first time that the robot navigates the greenhouse if a map exists, it is employed by a deliberative method. On the other hand, when there is no map, a pseudo-reactive method is used. Moreover, along the path a sensorial map is built, to be employed by the deliberative module in later runs. These layers are discussed in the following section. The two previous approaches utilize a security layer to avoid collisions. This layer uses on/off sensors. Finally, it has a low-level control or servo control layer. This layer is composed of two PID controllers that regulate the speed of the tracks. This article discusses each method separately, but the combination of both techniques is relatively easy.

Deliberative technique

Deliberative techniques are based on planning a course of actions that enable the robot to reach a goal position. The main drawback of this solution is that the planned actions are considered off-line, and events in real time are not taken into account. For this reason, deliberative techniques are useful only when the mobile robot is in a structured environment and when the application demands extreme reliability (Siegwart and Nourbakhsh, 2004). Typically, the navigation architecture used in these solutions is composed of three layers (figure 3). The upper layer is the path planning that involves identifying a free-of-obstacles trajectory that will cause the robot to reach the goal location. This reference trajectory is determined off-line. Secondly, the executive layer or controller determines the set points to the low level actuators. Generally, it uses the error between the current location and the reference trajectory. The selected algorithm has been Pure Pursuit (Amidi, 1990). Finally, for the location of the robot a relative location approach has been selected. This is based on the well-known dead-reckoning method using odometry (Borenstein et al., 1996; Siegwart and Nourbakhsh, 2004). Additional to this navigation architecture, a security routine and servo controllers are at the lowest level (as explained in the previous section).

Accuracy Deliberative navigation

After the previous experiments were completed, the deliberative algorithm was tested by using a map of the greenhouse. As in the previous experiments, two types of trajectories were tried: a straight line and an S-shaped trajectory. The look-ahead distance used in the Pure Pursuit controller was two sampling positions. The error between the reference and the tracked path can be considered negligible, with a maximum deviation of 15 cm. The mobile robot has a small oscillatory behavior. This behavior is due to the look-ahead distance of the Pure Pursuit. The main disturbances are irregular soil and noisy data from odometers (Sánchez, et al., 2006).

Path-planning algorithm

The selected path-planning algorithm is a modified Voronoi Diagram. This is defined as the locus of points equidistant from the closest two or more obstacle boundaries, including the workspace boundary. The set of points in the Generalized Voronoi Diagram has the useful property of maximizing the clearance between points and obstacles (Choset, 1997). Once the Voronoi algorithm is applied to a greenhouse map, the edges inside of rows of plants must be eliminated to provide an obstaclefree path (figure 4).

Search algorithm

The result of applying the Voronoi technique is a graph. This graph represents all possible paths in the greenhouse without obstacles. The mobile robot Fitorobot has to spray all the plants in the greenhouse, as was explained in the introduction. For this reason, the robot could achieve this goal by passing only through appropriate corridors. For example, in the distribution presented in figure 5, only the corridors marked with the red bold line must be visited.

To solve this issue, a traversal algorithm should be implemented. The objective of this algorithm is to determine the reference path that the mobile robot should follow. The solution proposed here is a technique based on the so-called depth-first search (O'Rourke, 1998; Sedgwick, 2002). The procedure is as follows: first, to visit a vertex, mark it, then (recursively) visit the next vertex that is adjacent to it and has not yet been marked and has the maximum distance. This process determines an ordered vector with the vertices that traverse the graph. The edges between vertices represent the greenhouse corridors. Finally, these points should be interpolated to define the reference path.

Figure 6 shows an example of the previous solution. It shows a typical distribution of plants (rectangles), and the graph determined using Voronoi. The distance between vertices in the longitudinal direction is 30 m and in the lateral direction 2 m. Figure 6 shows the ordered vector with the vertices that traverse the graph.

Pseudo-reactive technique

Reactive navigation strategies focus on control of the robot's trajectory using information provided by its sensors during robot motion. Classical reactive navigation algorithms such as Bug, Tangent Bug and Potential Fields are not well suited to solve navigation in greenhouses. The main drawback of previous algorithms is that they become unstable easily, for example, with a narrow corridor, with noisy sensor readings, etc. (Siegwart and Nourbakhsh, 2004). Thus, a new pseudo-reactive algorithm has been developed to avoid this problem. The architecture of control is composed of four layers (figure 7). The first one (build map) corresponds to the module that builds a sensorial map. The following layer (navigation) is responsible for filtering the sensor readings, determining the location of the mobile robot using the dead-reckoning method, and generating the set points to the low-level servo controllers. Finally, the bottom layer (avoid obstacles) is responsible for detecting and solving special events in the greenhouse, such as: centering the robot and curved corridors. Additionally, for this navigation architecture, a security routine and servo controllers are at the lowest level (as explained in previous section). Faults in sonar readings are detected comparing the three sonars on each side. When one of them presents data different from the next sonar, the navigation algorithm does not take this sensor into account.

Accuracy Pseudo-reactive navigation and mapping

The sensorial map fits quite appropriately the line of plants. As is reflected in this figure, the average error between the tracked path and the center of the corridor is small (lesser than 0.15 m).

Wireless sensor network (WSN) for robot navigation system

The emergence of wireless sensor networks to provide new ideas and methods for robot localization and navigation. A mobile robot location and navigation system were designed and implemented based on WSN by Yan and ping (2007), which estimates the distance between the robot and beacon node by using the RSSI (Received Signal Strength Indicator) between them. The mobile robot's status information such as position, speed and acceleration could be available by using adaptive Kalman Filter algorithm.

Agricultural mobile robot navigation scheme based on WSN and multi-sensor information fusion

Therefore, based on WSN application in robot navigation system is feasible, our research group is studying a combination of the electronic compass, gyroscope, and machine vision, multisensory information fusion, and WSN for positioning and navigation of agricultural mobile robot. We expect to develop an agriculture robot navigation system with low-cost and high precision.

The problems of agricultural robot research

Navigation research based on machine vision and GPS is relatively deep in recently, and it had made some progress. But its research is mostly in the single-phase research and the experimental stage, so there is a large gap in practical applications. (1) Machine vision is sensitive to changes in the external environment, real-time image and poor stability, and the speed of image processing algorithms is relatively slow and so difficult to meet the requirements of real-time operation of the agricultural robot navigation system. (2) GPS navigation is susceptible to environmental factors, so its accuracy and reliability should to be improved. At the same time due to the high cost of GPS applications, which created major obstacles to the promotion and application of agricultural robots.

There by increasing the ability of the GPS anti-environment factors and reducing application costs, the development of fast image processing algorithms, designing and selecting the sensor with strong anti-interference ability and effective information fusion, the rational combination of a variety of automatic navigation technology. These are conducive to solve the current problems in the automatic navigation.

Conclusion

This paper presented an overview over existing sensors and techniques for mobile robot positioning. We defined seven categories for these sensors and techniques, but obviously other ways for organizing the subject are possible. The foremost conclusion we could draw from reviewing the vast body of literature was that for indoor mobile robot navigation no single, elegant solution exists. For outdoor navigation GPS is promising to become the universal navigation solution for almost all automated vehicle systems.

There is a lot of random noise due to the complexity of the agricultural production environment.

And the source of sensor information is complex, a variety of navigation sensors didn't suite to agricultural unstructured characteristics. Therefore, future studies need to consider the agricultural production environment and the mobile robot's own characteristics, combined with a variety of sensor information fusion technologies, to get the best agricultural mobile robot navigation systems through improved and perfected. So that to meet the increasingly high requirements of modern agriculture such as navigation accuracy, stability and security.

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Figure 1. real image of a greenhouse

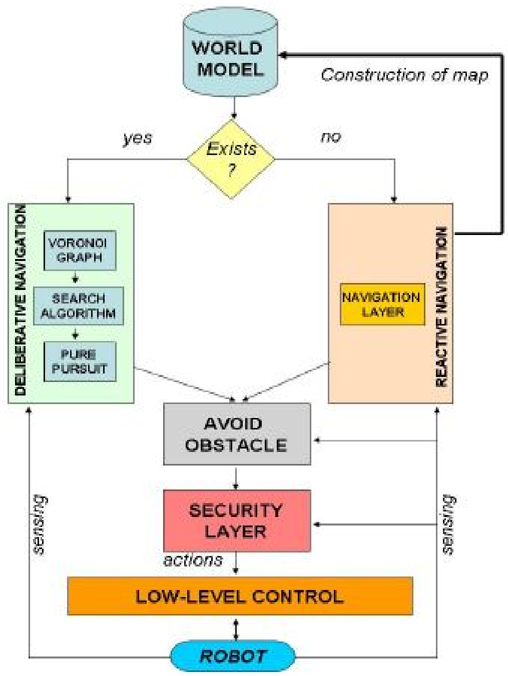

Figure 2. Proposed navigation strategy for the mobile robot.

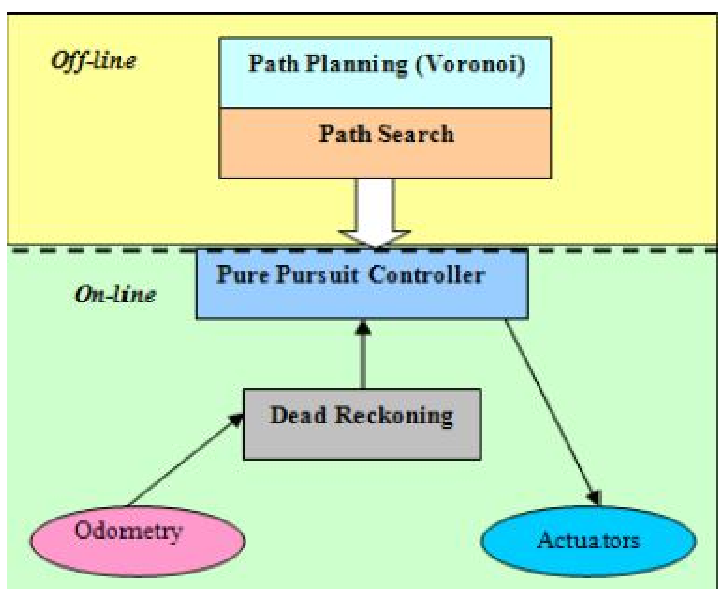

Figure 3. Deliberative control architecture.

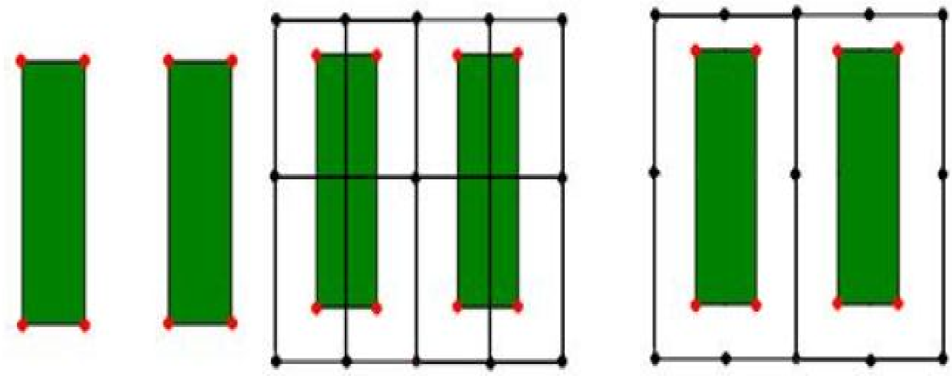

Figure 4. Voronoi's algorithm applied to a greenhouse.

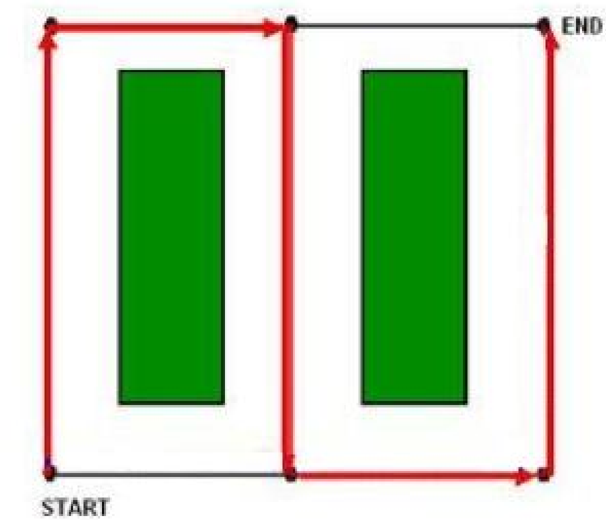

Figure 5. Rows of plants in a greenhouse and tracked trajectory to traverse them.

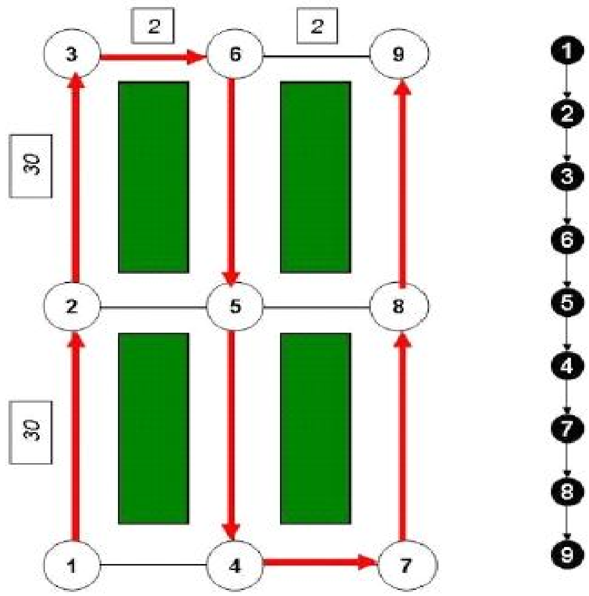

Figure 6. Traverse algorithm to obtain the reference trajectory.

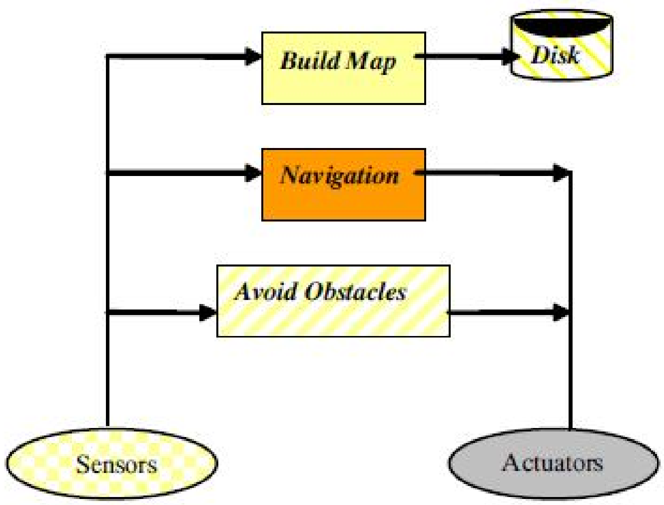

Figure 7. Pseudo-reactive control architecture.