

Mobile Robot Localization and Navigation in Artificial Intelligence: Survey

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Abstract

The potential applications for mobile robots are enormous. The mobile robots must quickly and robustly perform useful tasks in a previously unknown, dynamic and challenging environment. Mobile robot navigation plays a key role in all mobile robot activities and tasks such as path planning. Mobile robots are machines which navigate around their environment getting sensory information about that environment and performing actions dependent on this sensory information. Localization is basic to navigation. Various techniques have been described for estimating the orientation and positioning of a mobile robot. Navigation may be defined as the process of guiding the movement of intelligent vehicle systems from one location to another location with the support of various types of sensors to the different environments such as indoor, outdoor and other complex environments by using various navigation methods. This paper reviews the following mobile robot systems which are used in navigation for localization (1) Odometry (2) Magnetic compass (3) Active beacons (4) Global positioning system (5) Landmark navigation (6) Pattern matching.

Keywords: *Mobile Robot, Navigation, Localization.*

1. Introduction

In mobile robotics applications that require an autonomous steering system, localization and navigation are generally regarded as the fundamental problems. The previous existence of a map from the region to be explored by the robot can greatly improve the solutions for this problem, as it can reduce or even suppress, in certain cases – the accumulated localization errors created by dead-reckoning techniques [1].

There are two broad types of systems used in the field of mobile robotics such as indoor or outdoor environments. These two circumstances demand a very divergent set of challenges and needs, and often result in very diverse solutions for both software and hardware environment. However, in many ways this distinction between indoor and outdoor mobile robots is not optimal. For instance, mobile robots that operate indoors must still solve complex perception tasks that are more common in outdoor settings, and some outdoor systems operate in rudimentary or planned environments that are more similar to indoor environments. Therefore, it is more useful to use the following categorization when describing the operating environment of a mobile system. Mobile robot localization usually depends on position landmarks direction in a known environment [2] and dead reckoning. Due to slipping of the wheels and the error accumulation of the odometer measurements, the mobile robot may run off course in a short time if only dead reckoning is used. Landmark guidance depends on a priori knowledge of landmarks to estimate robot positions [3]. Localization is a crucial problem in autonomous mobile robots (AMR). Despite the efforts of many researchers, the problem is not yet solved for mobile robots navigating in complex environments or cluttered environments.

The various types of environments in which a robot can navigate are summarized below:

1.1. Structured Environments

Very strong assumptions can be made about properties of the environment. Environments that can be reliably partitioned purely into navigable free space and obstacles are a classic example. Most environments descend into this category, as would an engineered outdoor environment consisting only of flat ground and positive obstacles. A high level of environmental engineering is implied; that is the environment will be modified to enforce any assumptions made about it.

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1.2. Partially Structured Environments

Some assumptions can be made about pre-mapped terrain that although locally smooth, has potentially large changes in elevation. The classic example is urban environments: it is assumed that there are certain proper places to resolve that are easy to detect but may be occupied by dynamic obstacles. The system has three key capabilities namely – (i) tracking stated paths with high accuracy, (ii) detecting small obstacles reliably, and (iii) planning coverage patterns to completely cover a specified area. It is often the case that the environment was originally exaggeratedly created. However, continuous reformation to enforce strong environmental assumptions does not occur.

1.3. Unstructured Environments:

There are no regular assumptions that can be tracked for navigation about the environment. In these cases, two kinds of circumstances can be found:

i. The robot randomly explores the vicinity, like terrestrial vehicles [4]. The robot achieves a mission with a goal position. In this case, a map of the areas in which the robot moves has to be created and a localization algorithm is also needed. A remarkable example of a mapping and positioning system is “Robotic All-Terrain Lunar Explorer Rover” [5].

ii. Another, the “Mars Pathfinder” consists of two components, a lander and a drifter. The lander is a static component in which a stereo camera is fitted to shoot images of the Mars surface, while the drifter is the mobile component which explores the environment. The drifter mission path is determined by human operators in the earth control station by selecting the goal point in 3D representations of previously captured images of the terrain. The position is determined using dead reckoning techniques; in any case none can be assumed to have taken place.

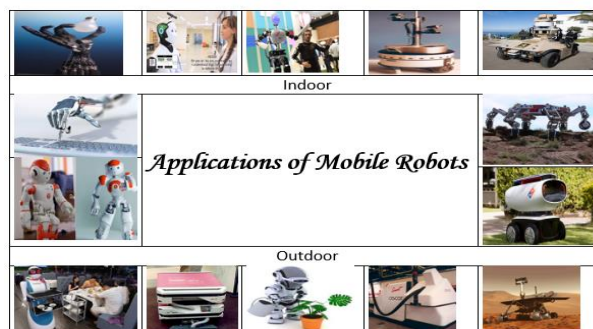


Figure 1: Various applications of Mobile Robots

2. Overview of mobile robot localization and navigation in Artificial Intelligence

Artificial intelligence (AI) is the broad category of mobile robot navigation (MRN) in various environment scenarios and proposes various methods based on navigation to accomplish its implementation. The robot navigation task is not an easy one. According to Leonard [6], the problem of navigation can be framed based on three questions: (i) "Where am I?" and (ii) "Where am I going?", and (iii) "How should I get there?". The first question has been termed the localization problem, the second and third questions are those of specifying a goal and finding an appropriate path to that goal. The navigation is a challenging approach given the high level of concept used to represent the environment, which supports the robot localization and navigation in a structure that also integrates the uncertainty. The various types of robot navigation under each category is summarized as follows:

Table 1. Taxonomy of robot navigation

Taxonomy	Types
Environment representation	Geometric
	Sensor based
	Topological

Localization	Continuous
	Stochastic
Navigation	Grid based
	Two Dimension (2D), Three Dimension (3D)

3. Framework for mobile robot navigation

There are three important components in mobile robot navigation, which are:

- Mapping: the process of memorizing the data acquired by the robot during exploration in a suitable representation
- Localization: the process of deriving the current position of the robot within the map.
- Navigation: the process of choosing a course of action to reach a goal, given the current position

Fig. 2 outlines the general framework of AI-MRN.

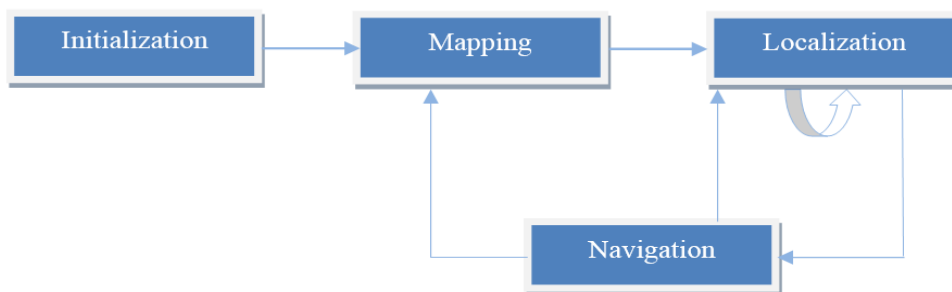


Figure 2: Framework for MRN in AI

4. Taxonomy of Mobile robot environment

Mobile robot navigation can be generally classified into two broad categories based on the environment in which the mobile will explore – (i) Indoor and (ii) Outdoor. Autonomous mobile robots which must be able to acquire and maintain models of the outside environment is said to be in the outdoor environment type. Autonomous mobile robots which must be able to acquire and maintain models of within the environment are said to exist as Indoor environment type. The taxonomy of various navigation strategy is given in Fig. 3.

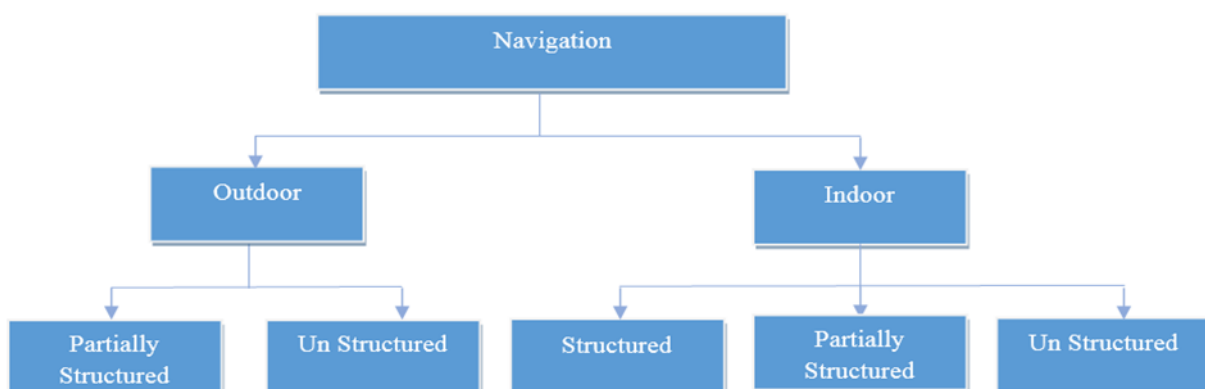


Figure 3: Taxonomy on Classification of MRN in AI

Based on outdoor environment they are classified as “partially structured environment (PSE)” or “un-structured environment (UE)”. Based on indoor environment they are classified as “structured environment (SE)”, “partially structured environment (PSE)” or “un-structured environment (UE)”.

Table 2: Comparison of various MRN in AI based on classification perspectives

S.No.	Technique	Author	Year	Navigation				
				Indoor Environment			Outdoor Environment	
				SE	PSE	UE	PSE	UE
1	Map based [21]	Jiann-Der Lee	1997			√		
2	Localization [11]	E. Stella et. al	2001			√		
3	Localization [10]	Gijeong et. et. al	2002	√				
4	Localization and mapping [12]	D. Lowe et. al	2002			√		
5	Localization [15]	S. Majura et. al	2008	√				
6	Map based[20]	Jean-Arcady Meyer et. al	2003			√		
7	Localization [34]	R. Biswas et. al	2002	√				
8	Localization & Mapping [36]	Happold et. al	2006					√
9	Localization [16]	Huidi Zhang et. al 2006	2006		√			
10	Mapping [25]	M.A. Porta Garcia et. al	2009		√			√
11	Localization [33]	PriscilaTiemi Maeda Saito et. al	2009	√				
12	Adaptive Based [23]	Matt Knudson et. al	2011					√
13	Localization [37]	Jian Kong et. al						√
14	Localization & Mapping[38]	Yoon chang Sung et. al	2016			√		

5. Mobile Robot Navigation in Indoor Environments

In the indoor environments the mobile robots can have disturbances caused by revealing conditions and stationary obstacles. Under these conditions, the lower level functions of robust and real-time landmark processing and trajectory generation must be established in order that the system can be easily applied to autonomous mobile robot. Mobile robots have no external guiding systems [7].

The indoor environment at the center mostly consists of few static obstacles as well as fast fluctuating dynamic areas with many movable obstacles. It provides a typical indoor environment. Therefore, the system developed there can be applied to similar environments without much alteration. The goal of the robot may be reaching a prescribed destination or following as closely as possible finding and mapping an area for a later use [7]. In some indoor environments, it is difficult to detect the movable area because of the complexity of environmental structures. However, when there is a plan to use mobile robots in artificially organized environments, the environmental conditions may be modified according to their complexity [8].

For the mobile robots working in indoor environments, a simple landmark model that is indicated by circle, square, rectangle, and a practical localization algorithm that uses a single landmark in a single image, which runs in real time scenario [9] are usually employed. Navigation in indoor environment can be achieved by goal-oriented technique. In fact, a map of the environment is generally a-priori known and a route to a goal position can be pre-planned. Then, the navigation task of the mobile robot, during the route consists of, continuously, determining its location in the environment in order to verify the vehicle is on the planned path [10]. Generally mobile robot navigation issues are separated from designing the artificial landmarks.

6. Mobile Robot Navigation in Outdoor Environments

Autonomous outdoor navigation ability is necessary for mobile robots employed in many military and civic application areas such as personal assistance, exploration, human robot interaction and transportation of materials [11] [12]. This navigation system that can perceive the environment with matching sensors would improve the mobility of robots and boost the use of them in many daily activities. Autonomous mobile robots can be defined simply as intelligent machines designed to achieve some given objectives by making decisions, managing their resources, and maintaining their integrity in an effective manner [13]. Mobile robots are typically employed in handling tasks that require navigational skills, and they are expected to move smoothly and precisely by utilizing their sensory resources.

The self-localization algorithm for navigation in the outdoor environment has been proposed for solving it. One approach is to construct the environment with identifiable objects with known positions. Another approach is to fix the robot by integrating over its trajectory information and dead-reckoning its position. The last approach is to match active sensor readings to a known model of the outside world or environment [13]. It consists of a very broad topic that has been studied for several years. In the mobile robotics context, navigation can be divided into two problems: static and dynamic obstacle avoidance and path planning. Path planning consists of deciding the most adequate way to achieve a fixed goal. Several path planning techniques have been proposed in the mobile robotics literature and different metrics can be used to evaluate such path planning algorithms. Most path planning approaches are designed to execute in static environment, where information about the environment is fully available.

Obstacle avoidance can be explained for mobile autonomous robots which have widespread applications in several fields like mining, manufacturing, underwater exploration, space missions and as service robots. Mobile robot agents need to move around and interact with different environments. Autonomous robot includes trajectory path planning and obstacle avoidance [14]. In this manner, the robot can avoid unpredicted and dynamic obstacles such as people walking around the robot. This is also a topic extensively addressed by the mobile robotics community.

7. Robot Navigation in Much Complex Environments

One of the key challenges in application of autonomous mobile robot is navigation in environments that are heavily confused with obstacles. The control task becomes more complicated when the configuration of obstacles is not known a priori [15]. The most famous control methods for such systems are based on reactive local navigation schemes that strongly combine the robot actions to the sensory information. Due to the environmental transformation, fuzzy behavior systems have been projected. Regarding intend of predilection based fuzzy behavior system for the obstacle avoidance path planning direct of mobile robot vehicles applications with the help of multivalve judgment network and hence robot travels efficiently even in a very disorderly environment. The hardest problem in applying fuzzy-reactive-behavior-based navigation control systems is that of arbitrating or fusing the reactions of the personal behaviors, which is addressed by the use of preference logic [16] [38].

Safe directional of Autonomous Ground Vehicles (AGVs) in unstructured complex environments, densely cluttered with obstacles is still a major challenge in goal-directed robotic vehicle applications. Navigation through a forest, which attracts special interest from the military community due to the lack of secrecy and destruction found in open environments, is typical for that type of challenges [37].

This navigation problem is a multi-objective control problem that seeks to ensure that the robot not only reaches its goal without hitting obstacles, but also does so at safe speeds that ensures stability. The problem is particularly difficult because some of the navigational objectives may be in opposition to one another.

The navigation problem in cluttered environment is divided into two parts actions: (1) Speed control (2) Heading control. The speed control uses two characteristics: (1) Overtaking avoidance (2) Avoid the obstacles. The heading control executes four characteristics: (1) Avoid the obstacle on front side (2) Avoid the obstacle on right side (3) Avoid the obstacle on left side (4) Target seeking.

The obstacle avoidance behaviors use range finding sensors to determine distances to the nearest obstacle; the goal seeking behavior uses compass measurements to determine the direction of the goal and the overtaking avoidance behavior uses a speedometer reading to determine the robot speed [17].

Local obstacle avoidance is a fundamental problem in autonomous navigation for mobile robot. Most of the navigation approaches in partially known environment combines a global navigation method to find a feasible free path leading to the goal and a local navigation method to follow the path avoiding obstacles [18][19]. Whenever a mobile robot has to deal with an environment that is totally or partially unknown, local navigation strategies are very important for the robot to successfully achieve its goals [30][31].

8. Mobile Robot Navigation Techniques

Mobile robotics is a motivating area for use of artificial intelligence (AI), as it is a domain in which huge bodies of knowledge are needed to enable tasks like intelligent navigation in a large or complex facility while there at the same time is a need for real-time response to external events[32]. Mobile robots can be used as an interesting test-bed for empirical verification of AI techniques and investigation of their applicability and feasibility in real world settings. In several experimental mobile robot systems and almost every commercial system the use of AI techniques has been enormous.

The following section explains some major works that fall under these categories.

- Orientation technique in MRN
- Path planning technique in MRN
- Map based technique in MRN

Landmarks are distinctive features that a robot can recognize from its sensory input. Landmarks can be geometric shapes (e.g., rectangles, lines, circles). In general, landmarks have artificial and known position, relative to which a robot can localize itself[33][34][35]. 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.

8.1. Orientation technique in MRN

The main task in localization is then to identify the landmarks reliably and to calculate the robot's position. 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. Autonomous robotics 'intelligence' is defined as providing robots with some level of intelligence and ability to perform desired tasks without continuous human guidance. The following three properties are foundations of robust robot navigation: (i) the use of landmarks, (ii) the use of pre-determined paths, and (iii) the use of geometrical maps [18] [19].

Path planning of mobile robot performs an adaptive approach in order to always select the better method according to the environment difficulty. Environment characteristics are very variable: there are rather plane areas, cluttered-with or free-of obstacles and others which are uneven with respect to the movement capacities of the robot. Navigation on uneven areas involves fine terrain modelling, complex strategies to tackle robot self-localization and trajectory planning, whereas plane areas can be more easily crossed; motion planning is sometimes not necessary if the area is essentially obstacle free.

8.1.1. Evaluation: Simulation based on the orientation of data gathered from geometric hashing and model-based scene matching.

8.1.2. Advantage: (1) The image features and derivation of the geometric invariants from these features in robot-centered coordinates, (2) finding the best matched candidate and the corresponding transformation using geometric hashing and a weighted distance voting criterion, and (3) the verification of the match by back-projection of model features onto the intensity image of the scene

8.1.3. Disadvantage: Limited to within the range of the uncertainty of the odometry data and the maintaining of the previous location error and to compute the geometric invariants for those scene features located within the range of the uncertainty about the predicted locations.

8.1.4. Outcome: Achieves the comparison with robot centered coordinates with the distance voting criterion.

8.2. Path planning technique in MRN

Movement commands are determined on the basis of (i) a target value (heading or position) and (ii) the information provided by sensors [19] [20]. The capacity to navigate is obviously a major requirement for an animal striving to survive in a given environment, or for an autonomous guided robot trying to fulfill its mission, because it affords the possibility of finding dynamism sources while avoiding rude vulnerabilities [30] [31].

8.2.1. Evaluation: Observation based on 85% strongly agree with that EDU Robot simulation.

8.2.2. Advantage: Helped to understand the functional differences between the three different algorithms.

8.2.3. Disadvantage: Software tool only supports only limited algorithms.

8.2.4. Outcome: Over 90% agreed that the effects of parameter changes can easily be observed and majority of students (89%) agree that the simulator has helped them to understand the functional differences between three different algorithms.

The most primitive navigation strategy that helps the animal or the robot succeed in such tasks consists of relying on mere chance and of moving arbitrarily. Localization and map-learning are interdependent processes since using a map to localize a robot requires that map exists, while building a map requires the position to be estimated relative to the partial map learned so far [20].

An intelligent approach to robot navigation by landmark tracking using computer vision is proposed [21][22]. This approach is founded on the concept that a human can reach the destination by tracking the specific landmark in a previous atmosphere. Only a monocular image of the landmark taken by the mobile robot is required. 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. Methods of pattern matching are integrated to resolve the problems of landmark tracking and understanding.

A great deal of work has recently been executed to address the problem of automated robot navigation in complex workspace using many different sensors. These sensors are composed of active sensors (e.g., optical, ultrasonic) and passive sensors (e.g., camera). A lot of the mobile robot systems using various sensing approaches to indoor mobile robot guidance can be found in [21].

In many robotic exploration missions, robots have to learn specific factors that allow them to: (i) select high level goals (e.g., identify specific destinations), (ii) navigate (reach those destinations), (iii) and adapt to their environment (e.g., modify their behavior based on changing environmental conditions) [22].

The exploration of an unknown environment is an important task for the new generation of mobile robots. These robots are supposed to operate in dynamic and changing environments together with human beings and other static or movable objects. Sensors that are capable of giving the quality of information that is required for the described scenario are optical sensors like digital cameras and laser scanners. Complementary sensory information is transformed into a common representation in order to achieve a cooperating sensor system. This sensor is performed by matching the local perception of a laser scanner and a camera system with a global model that is being built up incrementally environment system [24].

Robot navigation is one of the basic problems in robotics field. In general, the robot navigation algorithms are categorized as global or local path, depending upon surrounding environments. If the environment surrounding the robot is known and the path which avoids the obstacle is selected, then it is called global path planning. In local navigation path planning, the surrounding of robot is unknown environment, and sensors are used to detect the obstacles and avoid collisions.

Designing a robot entails the combination and direction of many sensors and actuators[28]. In general, the robot acquires information about its surrounding through various sensors mounted on the robot. Usually, many sensors, such as infrared sensor, ultrasonic sensor, laser range finder, touch sensor and camera can be used to detect the presence of obstacles [25].

Navigation in mobile robotic ambit is a methodology that allows guiding a mobile robot to accomplish a mission through an environment with obstacles in a good and safe path [27] [28]. The two methods involved in navigation are the environmental perception, and path planning. The concept of mission, mention to the realization of a set of navigation and operation goals; in this sense, the mobile robot should possess an architecture able to coordinate the on-board elements: sensor system, movement and its control, in order to achieve correctly the different objectives specified in the mission with efficiency that can be carried out either in indoor or outdoor environments. Generally global path planning methods complemented with local methods are used for indoor missions since the environments are known or partially known; for outdoor applications local path planning methods are more suitable than the global path planning methods because of the scant information of the environment [26].

Evaluation: Simulation is based on both local and global navigation

Advantage: The path planner application has two operating modes, one is for virtual environments, and the second one works with a real mobile robot using wireless communication. Both operating modes are global planners for plain terrain and support static and dynamic obstacle avoidance

Outcome: This approach allows the detection of unknown obstacles simultaneously with the steering of the mobile robot to avoid collisions and ahead toward the target. The innovations of this approach, entitled the virtual force zone, lies in the combination of two known concepts: (i) certainty grids for obstacle representation, and (ii) potential zones for navigation. This combination is particularly suitable for the accommodation of inaccurate sensor data as well as for sensor fusion, and enables non-stop motion of the robot without stopping in front of obstacles.

8.3. Map based technique in MRN

Odometry is the most widely used method for determining the transient position of a mobile robot. The most practical applications, odometry (monitoring the wheel revolutions to compute the offset from a known primary starting position) provides easily accessible real-time positioning information in-between periodic absolute position measurements [27][28][29].

The authors of [34] aim at developing a method of recovery for the ego-motion and the 3D-structure of a scene, in the case of a virtual moving observer with visual, inertial and odometric sensors. The observer attempts to correct its trajectory and build a 3D depth map of its environment during the execution of a predefined trajectory (a prerecorded list of relative displacements). More precisely, they implemented a reactive visual module utilized on an autonomous mobile robot to automatically correct the predefined trajectory, using inertial and visual cues.

The mobile robot navigation system implementation that uses artificial beacons together with sensors that deliver accurate and consistent measurements of beacon location is a straight forward procedure used by many commercial mobile robots today[35][36].

8.3.1. Evaluation: Simulation provides less energy consumption and supports with high speed of moving targets.

8.3.2. Advantage: The anchor nodes are used to determine the position of a target and to calibrate the optimized value of estimation with help of automatic calibration device.

8.3.3. Outcome: This approach allows the detection of unknown obstacles in indoor applications

The analysis and comparison of various AI based on MRN based on their characteristics are given in Table 3.

S.No	Technique	Author/Year	Odometry	Magnetic compass	Active beacons	GPS	Landmark navigation	Pattern matching
1	Map based [22]	Jiann-Der Lee 1997	NA	NA	NA	Map used	NA	NA
2	Localization [11]	E. Stella et. al 2001	re-calibration position of robot	NA	NA	NA	estimate the camera position	NA
3	Localization [10]	Gijeong et. et. al 2002	NA	NA	NA	NA	to update the artificial landmark points	NA
4	Localization and mapping [12]	D. Lowe et. al 2002	NA	NA	NA	NA	visual landmarks is used for navigation	NA
5	Localization [15]	S. Majura et. al 2008	Range sensor (High)	NA	NA	NA	NA	NA
6	Map based[20]	Jean-Arcady Meyer et. al 2003	NA	NA	NA	NA	land mark points are used	Map based environment & used camera
7	Localization [34]	R. Biswas et. al 2002	NA	NA	NA	NA	NA	Map used for navigation
8	Localization & Mapping [36]	Happold et. al 2006	NA	NA	NA	NA	NA	Stereo camera is used for adaptation to dynamic or unknown scenarios
9	Localization [16]	Huidi Zhang et. al 2006	NA	NA	NA	NA	NA	Stereo camera is used dynamic or unknown scenarios
11	Localization [33]	PriscilaTiemi Maeda Saito et.al 2009	NA	NA	NA	NA	NA	NA
12	Adaptive Based [23]	Matt Knudson et. al 2011	NA (simulation only used)	NA	NA	NA	NA	NA
13	Localization [37]	Jian Kong et. al 2015	NA	NA	beacon nodes used to track the unknown environment	NA	NA	NA
14	Localization & Mapping[38]	Yoon chang Sung et.al 2016	leg positions as well as human positions of mapping	NA	NA	NA	NA	NA

9. Challenges and Open Research Issues

The major problem of path planning in mobile robot lies in the three broad categories - mapping, localization and navigation in different environment. The source in this perception consists of sensors and various techniques like speed, accuracy and time performance. Therefore, any localization mechanism for mobile robot considers any one of the following absolute or relative measurements such as: (1) Odometry (2) Magnetic compass (3) Active beacons (4) Global positioning system (5) Landmark navigation (6) Pattern matching. MRN systems operate around orientation, mapping and path planning techniques. The drawbacks include (i) Uncertain changes

in the environment of mobile robot navigation (ii) Cost increases due to the use of high end sensors. Therefore, many researchers suggest that the distance based sensors is appropriate for mobile robot navigation for the indoor environment and pattern matching is appropriate for outdoor environment.

The following are the open research issues that can be addressed while developing a better mobile robot navigation system using artificial intelligence.

- Developing the real time robot navigation and investigating its applicability in localization with RF-based trilateration systems work reliably indoors.
- Developing hybrid maps, which supports almost all types of environments
- Developing computationally intelligent optimization technique for finding target in cluttered environment.

10. Conclusion

This survey paper introduces existing sensors and techniques for mobile robot positioning in all mobile robot's activities and tasks for Artificial intelligence along with their classifications based on various strategies. Further, different types of techniques in a MRN and respective navigation methods are also discussed. Also, silent features of MRN reformed for navigations with different type of sensor used by the robot are discussed and their significant features are emphasized in a comparable chart, followed by the critics about MRN that would be suitable to environment and localization technique are provided. Finally, as a measure to help out the researchers over the selection of appropriate environments and their path planning strategy, certain open research avenues in this field are also touched upon.

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