1. LITERATURE REVIEW

2.1 MOBILE ROBOT NAVIGATION

Successful mobile robot navigation requires control algorithms that are capable of navigating in complex unstructured environments. These control algorithms must have capability to navigate in cluttered environment. Fuzzy kohonen clustering network (FKCN) is adopted for mobile robot navigation [40]. This logic provides navigation engine using simple fuzzy logic controller and behavior-based robotics [45]. While controlling the robot in different kinds of uncertainties, novel concepts of direction weights are used. A preference-based behavior control system for robot navigation in cluttered environment has been presented [46]. Multi-valued concept is used to develop control system [47]. In preference-based behavior control without neglecting any behavior, the robot is able to navigate towards goal without distracting by the presence of cluttered environment [46].

The path planning for mobile robot navigation in ware house environment is implemented [42]. This technique is adopted in ware house for material handling. The FLC based technique can be used either offline or online. The AGV in manufacturing environment is subjected to attractive force to the goal and repulsive force to the obstacle. The multi-valued fuzzy behavior system has been applied for the robot navigation to improve its performance [47]. This method provides a reliable method of behavior fusion; this method ensures that no behavior is neglected during the process so that smooth navigation takes place in cluttered environment. This approach allows all behavior to express their part in the available commands and fuse them by fuzzy fusion method.

2.2 FLC BASED AUTONOMOUS ROBOT

Fuzzy logic approach for mobile robot navigation has been done using differential drive mechanism [11]. The fuzzy logic-based approach for wall following robot uses the information obtained by the concept of general perception to guide the robot on the wall of arbitrary shape and obstacles (which is treated as part of wall) [71]. Complete membership function and fuzzy rule base has been provided for
successful navigation of robot. The ways to improve fuzzy logic controller based on different factors are considered for mobile robot navigation [12]. The navigation has been improved either by modifying hardware (adding more sensors). The other method is purely by developing linguistic-based software. The system can be improved by using more time steps in the fuzzy inference process.

The fuzzy logic controller receives input from sensors which determine the steering angle and velocity of vehicle for both local and global-based navigation [19]. The minimum risk approach using fuzzy logic system has been used for autonomous robot navigation [49]. This has achieved local path planning to escape from local minima and global-based robot navigation in unknown environment. This has proved to be successful through long wall, unstructured, cluttered maze like and modified environment. The approach adapts a strategy of multi-behavior coordination in which novel path searching behavior is developed to recommend the regional direction with minimum risk.

The self-tuning of PD + I fuzzy logic controller is applied to non-linear problems [25]. The controller consists of three separate fuzzy logic controller assigned with minimum rules [5], [7], [6]. Output is automatically corrected depending on the error of perceiving dynamic condition. This has achieved good results at low and medium speed. Programming a sensor-based navigation of a maze has been done by using fuzzy logic controller [33]. This paper gives complete solution to the problem of navigation using fuzzy logic controller to create linguistic rules.

The fuzzy discrete event system (FDES) technique is implemented for behavior based robotics. This technique extracts the multi-valued feature of fuzzy logic property of event system to generate action using fuzzy state vectors. This method combines the advantages of arbitration and fusion behavior aspects [67]. The proposed approach has ability to handle uncertainties of sensors and also indicate the undesirable state within the observed environment. Vector summation scheme is used for command fusion where force vector represents command [7]. Fuzzy logic concept is used to blend the output of different behaviors into collective result. Navigation algorithm based on fuzzy logic algorithm is considered. The constructed mobile robot controller is first checked using mat lab, then it has been translated to VHDL model, and then synthesized into logic gate level of mobile
robot controller architecture for VLSI implementation [77]. Finally, these codes are down loaded into FPGA board for validating the navigation functionality.

The improvement in fuzzy logic algorithm by combining simple fusion of robot behavior by combining simple fusion of robot behavior and self-tuning membership function is done to reduce the degree of complexity of FLC in exploration vehicle [35]. Unsupervised fuzzy logic algorithm gives trajectory for exploration vehicle in unknown environment. The implementation of position and the orientation of robot using combination of kalman filter and fuzzy logic technique has been used to fuse the information from internal and external sensors to have successful navigation in unknown environment [72].

Land mark detection is an important event in mobile robot navigation. The fuzzy temporal rules are used to identify doors using ultrasonic sensors [95]. This concept is used for modelling the necessary knowledge for detection and to consider the variation of sensors signals. The problems of goal not reachable with large obstacles (GUWLO) for fuzzy-based navigation systems are discussed [93]. This problem has been solved by temporary target angle modification, computed with respect to the corresponding surface of the obstacle facing the robot. Resulting algorithm is implemented and effectiveness of improved algorithm is executed.

2.2.1 Type 2 and Interval Type 2 FLC

Type -1 FLC cannot handle all kinds of uncertainties in challenging and dynamic environment, but type-2 fuzzy logic controller using type-2 fuzzy sets can handle all kinds of uncertainties related to sensor and environment. The success of type-2 fuzzy control system is observed for real time navigation in indoor, outdoor unstructured and challenging environment [29]. To minimize the effect of uncertainties, new type fuzzy logic system is introduced that is type-2 FLS. This will overcome the uncertainties in dynamic and non-linear conditions. The interval type 2 fuzzy logic controllers are also introduced, and this gives better performance compared to the other two. All the results of three FLC’s are compared and considering unknown and uncertainty environment, type 2 performed Outstandingly [59].
The interval analysis is the new approach used to implement the Type 2 fuzzy behavior navigation system [31]. Interval analysis is applied along with multiple sensor fusion using kalman filter and other stochastic filter. Interval analysis with multi-sets of sensors has been applied to obtain the estimation of multiple interval robots positions. The output is fused using fuzzy logic to get the desired position. The 2-stage-based fuzzy controller for a sonar-based autonomous robot is experimented in unknown environment [53]. The two-stage FLC outputs both angular and linear velocity. The first stage FLC outputs angular velocity by taking inputs from side sensors, whereas, second stage FLC outputs linear velocity with two important variables. i.e., angular velocity and free space. The two-stage FLC is able to react both quickly and correctly to perceived sensor data.

2.2.2 Alpha Level FLC

Problem of mobile robot navigation when more number of behaviors is active at a time is resolved by using behavior rule selection by considering alpha fuzzy level. The alpha level in linguistic sets [81] helped in decision making to take appropriate action. The main advantage of this alpha level linguistic set is that the navigation controller gets the ability of heuristic type of rule to mimic the human behavior. Same has been shown with mathematical model. The new methodology has been designed to control system that optimizes the behavior rules using fuzzy associative memory. Compared to existing methods the FAM maps the entire inputs space to the outputs instead of certain portion of input space [82]. This approach reduces the number of fuzzy rules required. Experimental investigation of robot navigation using alpha level fuzzy system is evaluated. This gives formal heuristic method of solving problems instead of analytical solution.

2.3 FUZZY-LAYERED APPROACH FOR NAVIGATION

The layer control architecture to autonomous robot is introduced instead of sense/model/plan/act strategy [66] [56], as the layered architecture has direct effect on action. The behaviors are represented as layers and multiple behaviors are considered in parallel to take desired action. Brooks sub assumption [66] was
implemented on wide variety of autonomous robot. The schema theory based on sub assumption was developed for fuzzy-based navigation [69].

Fuzzy-layered mobile robot navigation system in unknown environment is used in different stages for execution [92]. Information from global data and long range perceived data is used by first layer to identify way points as well as trapping. The second layer is useful for local information or short range sensors data. Experimental results are tested for different environments.

The fuzzy logic system is used to perceive the reactive behavior for navigation robot. The two-layered approach implements the inhibition in the first layer and suppression among the selected behavior by weighing the behaviors [58]. COG defuzzification method is adopted to get the crisp output. Effectiveness of this algorithm is confirmed by simulation results. The development of a layered goal oriented fuzzy navigation planning strategy was discussed [92]. Conventional motion planning algorithms face many problems when subjected to real world environment. The information about long range data is used as first layer, and the second layer takes care of local or short range data to avoid all kinds of obstacles to reach the goal point.

2.4 MULTI SENSOR INTEGRATION

Mobile robot navigation by multi-sensor integration performs better coordination and competition among multiple behavior such as, avoiding obstacles, decelerating at curved roads and narrow roads, escaping from U-shaped object and moving towards target in an uncertain environment using ultrasonic sensors [89]. The new technique has been adopted for real time navigation on building floor by using wireless sensor [17]. The surrounding environment information is perceived from the set of sensors and is fed to the micro controller to get proper navigation. The all terrain vehicle made of hybrid method (both legs and wheels) has been used.

The fuzzy logic control of mobile robot has been done using sonar sensors. The behavior-based robot for helpmate behaviors was designed; the FLC gets the information from various sonar sensors to perceive the environment. The behavior grouping has been done in three levels-first high level includes task-oriented
behavior (two sub task- wall following and goal seeking), middle level includes obstacle avoidance and lowest level includes emergency behavior. Each behavior is built on the technology of Intelligent Machine Architecture [83]. Fuzzy logic-based linguistic data perception has been used to avoid the vagueness. In order to receive reliable information the multi-sensor must be used. The multi-agent and multi-target correlation has been used [68] in order to increase the robustness in the navigation of mobile robot; the data fusion is required for this task. Fuzzy-based multi sensor and multi-target concept gives better results in navigation.

2.5 BEHAVIOR BASED ROBOTICS

The new strategy for behavior-based robotics on challenging terrain has been done using both FLC and terrain traversability index [41]. In this real time assessment of surface, characteristics and implementation of these features to the mobile robot controller has been done for successful navigation. The combined terrain feature and navigation feature are considered together and coordination is done by weighing the behavior. The dynamic weighed voting technique is adopted for behavior-based mobile robot navigation [79]. Four different behavior combinations are used to check the functionality of dynamic weighed voting technique. This technique has proved that this method has the ability to handle the problems of action selection [63], [32].

The utility-based control architecture is used for behavior-based robot navigation [77]. The utility distribution decomposes the overall control variables in to simple task-oriented mechanism. The architecture of this approach contains superposition characteristics and thus provides the flexibility to the system, while keeping the designed mechanism unchanged. The most popular approach of superposition, the potential field is used for context-based behavior coordination [95], [43]. Different variety of potential functions is introduced in the navigation based context which discusses on motor schema of behavior-based robotics [8]. Superposition concept is applied using range sensors [88]. Dynamic system approach of superposition-based fusion is executed [75], [76].

The comparison of uni-valued fuzzy behavior system with multi-behavior system is discussed [4]. The multi-valued system performs better in guiding the robot and
the structure of multi-valued system is more computationally intensive. Multi-valued fuzzy logic control system has many advantages compared to uni-valued fuzzy behavior control system. Multi-valued robot navigation overcomes all kinds of sensor and environment uncertainties. The major problem in implementing multi-valued fuzzy inference system is computation burden associated with FIS.

The multi-valued fuzzy behavior control system with singleton approach is used instead of fuzzy set consequence [50]. The singleton-based fuzzy multi-behavior system reduces data storage and increases computation speed. It provides simple way of fusing behavioral outputs to get the desired task. The multi-objective concept was discussed for executing cluttered environment with more number of behaviors. Individual behavior is analyzed with objective function and then it’s assigned its level. Multiple behaviors are combined in to a single behavior that simultaneously satisfies the entire objective as closely as possible.

The utility- based control architecture using distribution behavior [74] is applied on multi-behavior robot. In this method, multiple tasks are divided in to simple and independent tasks. This type of architecture supports superposition characteristics and provides option to extend the functionality. This algorithm is tested on global navigation tasks in cluttered real environment. The real time navigation of mobile robot in unknown environment has been conducted using type 1 and type 2 FLC [28]. Fuzzy logic tool is used with type1 and type2 fuzzy extension for better reliability. Fuzzy rules are defined for successful navigation in a complex environment. Multi-agent optimal path planning needed extra level of intelligence for a better results in group robots.

The overview of learning aspects related to behavior-based control architecture for autonomous robot navigation is discussed [51]. This approach contains modularized architecture with learning ability. The learning algorithm itself is independent of actual sensors by incorporating relevant functions with sensor or actuator libraries.

### 2.6 FUZZY LOGIC BASED BEHAVIOR COORDINATION

FLC can be used for different types of architecture of mobile robot navigation. This has applied to behavior-based robotics to recommend behavior by using
multiple and independent module. The desirability and undesirability measurement is used for formulating the behavior navigation to manage the conflicts between the modules. This module can also be used for different type of mechanisms to avoid causing problem of selection process. Fuzzy exploitation is to understand the agent part in the activated behaviors. Fuzzy-based blending actions for multiple behavior coordination are done in [26]. The design and development of coordination architecture for quadruped walking robot is discussed [15]. Hybrid architecture [21], [24], [49], which is combination of reactive [74] and deliberative [68] is adopted. In order to achieve real time and robust control performance, two stages learning scheme is adopted. This makes the FLC system adaptive to complex situations. Temporal constraints play an important role in coordinating multiple reactive behaviors. Fuzzy state machine is implemented to simplify the design feature.

A hierarchical fuzzy control methodology has been presented for autonomous robots. The behavior coordination and conflict resolution are the main focus [18] [48]. In this concept, the behaviors are subjected to degree of applicability to judge the output. The hierarchy of distributed architecture provides control system with fuzzy-based rules. This architecture is subjected for different types of environment to validate the algorithm. The new concept of distributed architecture for mobile robot navigation is adopted for coordination [37]. The DAMN expresses the degree of relative interest of each behavior by assigning numerical value/command alternative. DAMN concept has been applied, to get successful navigation by resolving many conflicts [50].

The behavior coordination in mobile robot navigation has been done using intelligent voting technique [84]. Voting technique adopted here tolerates the uncertainties and is able to coordinate multiple behavior to achieve goal. Command fusion of output result depends on the inputs of obstacle avoidance and goal seeking. The novel behavior fusion method for mobile robot navigation has been presented considering various behaviors like, obstacle avoidance, goal seeking and navigation supervisor [10]. The fuzzy inference engine for obstacle avoidance and goal seeking is weighed by the navigation supervisor and the output data is fused for desired action required in different context. The behavior-
based control architecture proposed here is able to tackle unknown and dynamic environment.

The fuzzy logic-based behavior coordination is done by action selection method [32]. Two important behaviors are considered—the first is how to divide which behavior should be activated at different context and second is how to combine the results from various behaviors into one action. This method adapts alpha levels to measure behavioral weight and final fusion is by using action selection. Main problem in multiple objective behavior navigation is coordination of different behaviors in complex environment. Multiple objective behavior coordination provides successful technique to coordinate in multi-behavior situation. The proposed approach combines the advantages of approximation reasoning and ease of behavior specification of FLS [62].

The use of fuzzy logic in mobile robot controller provides robustness in unpredictable environment [3]. In order to combine concurrent activities for robot coordination context-depending-blending was used. The CDB gives better approach to behavior combination scheme. The behavior-based robotics can be accomplished using fuzzy logic in different ways. CDB is one of the methods for behavior combination. Initially, fuzzy meta rules are used to express arbitration policy and fuzzy combination to perform command fusion [20]. The context dependent blending was used on the basis of behavior-based robotics [20] [86] [5]. CDB is used before defuzzification step to assign context rules to each behavior. This is more suitable for distributed architecture.

A distributed architecture for mobile robot navigation is presented [38]. In this architecture, different behavior effects are considered with voting, then arbiter performs command fusion and selects best action to reach the goal or to avoid obstacles. Command fusion concept in this architecture helps in overcome multi-behavioral context. In FLC-based robot navigation the attention is mainly focused on design, coordination and fusion of elementary behaviors [23]. The design is based on fuzzy logic control system which follows human reasoning method. The coordination is done by using fuzzy meta rules which depend on fuzzy context applicability and fusion of elementary behaviors is done by weighing each behavior and combining them depending on degree of levels.
The fuzzy cognitive model has been presented; Integration of deliberative and reactive components of multi-agent behavior is done [39]. The cognitive model developed implements the coordination of behavior providing a common cognitive substratum for behavior modules of robots. The fuzzy logic-based behavior blending is done with fixed priorities on the movement analysis [1]. The article [27] is focused on fuzzy logic-based blending, selection, exploitation and recommendation of behavior in new control architecture. The application of fuzzy logic deal with vagueness, the behavior controller to the external context helps the agent to adapt to the environment. The introspection created by the fuzzy behavior logic helps in interacting with the environment.

A novel error mathematical model for laser range finder is developed by considering detection angle and range distance. New concept of virtual angular point is introduced for positioning the robot [90]. A position of the robot is recognized by pair of feature points and is fused together by weighted technique. The research contribution of the paper [14] is the concept of state-based system to maintain context, and combining it with a fuzzy logic controller to mimic the human behavior. The use of fuzzy logic led to the easy operation and algorithm generation. This concept has been implemented on real robot for searching and identifying objects in corridor.

2.7 ARTIFICIAL POTENTIAL FIELD

The traditional path planning algorithm using artificial potential field and fuzzy logic has been analyzed and same is developed using neural network [97]. This new approach realizes real time environment and this has increased the performance of traditional method of artificial potential field. This successfully avoids all kinds of obstacles without any trapping. Artificial potential field is an efficient method to find path of navigation in an unknown environment. But it suffers from local minima problem, and in order to overcome this problem, an ant colony optimization technique is used [16]. ACO solves local minima problems and by this optimal path solution was determined.

The vision based-control system for mobile robot navigation is done using CCD camera and ultrasonic sensors. The algorithm for color detection, detection of
target and obstacle avoidance has been developed. The multi-behaviors are combined using the potential field theory. The robot succeeds by guiding the robot reliably in both tracking of target and following it. Fuzzy vision-based navigation control system provides smooth and reliable navigation [55].

2.8 NEURO-FUZZY APPROACH

The difficulties of constructing correct fuzzy rule base are overcome by using neural network-based approaches [36]. Online learning method has been adopted and dynamic rule generation is developed using neural fuzzy. The optimization of rule construction is done in this paper. This has been found to be good when applied to wall following control of omni directional robot. The neuro-fuzzy algorithm for reactive robot is proposed and developed [13]. This technique can effectively deal with imprecise coordinate conflicts among multi-behavior contexts. RAM-based neural network is used to supervise the FLC. The benefit in using RAM based neural network approach is that it requires very less memory and less computation time maintaining the ability to handle imprecise and complex data.

The new approach for robot navigation on challenging terrain using linguistic fuzzy logic approach has been discussed [78]. Heuristic method of reasoning is adopted instead of analytical solution. The proposed behavior-based navigation strategy using fuzzy rules has major benefits compared to the mathematical model. Even though the fuzzy-based reasoning is easy to implement but for multi-behavior coordination, it’s difficult to find out optimized rules to overcome all sorts of destructions. Artificial neural network is combined along with fuzzy logic reasoning method, and this maps the inputs and outputs in optimized way.

The fuzzy logic and back propagation neural network been used for road traffic signs detection and classification [80]. Fuzzy logic has been used for the sign detection and classification, for back propagation neural network technique is used to display the right task. The purpose of the paper is to make walking safer and easier. The system is divided in to three different stages-first stage detection and improving raw sign image, second is shape analysis with continuous thinning algorithms and the image coding algorithm, finally, image recognition and
decision by fuzzy logic and back propagation neural network technique to display the right task.

The application of mobile robot navigation with obstacle avoidance has been done using polynomial neural network [24]. This polynomial neural network is built from some selected starting location to reach the goal. The efficient technique based on associative retrieval is applied to robot to follow minimal cost polynomial path. This has advantage of interpolating capability with moderate size of data space. Use of new adaptation block for mobile robot to learn new behavioral actions and scripts based-soft computing techniques [87].

**2.9 FUZZY-GENETIC ALGORITHMS APPROACH**

The fuzzy-genetic algorithm-based approach is used for navigation of autonomous robot in varying terrain conditions [85]. The encoding of chromosomes helps in navigating in dynamic environment. This approach has many benefits compared to many traditional methods. The new fuzzy logic controller designed adopts both genetic algorithm and experts ideas [65]. This method can be used in general under actuated mechanical systems. GA is used for obtaining the optimum fuzzy control rules.

Online learning of fuzzy logic system is presented by making use of evolutionary programming technique [54]. On line learning evolved independently towards its own optimal rule. In comparison with other learning methods, fuzzy rules associated with the current input states are evolved and updated. The proposed approach normally evolves several generations in just one execution of the task. The presented technique is used as optimized method of FLC navigation in less evolution time.

The vision-based evolutionary robotics research was described [34]. Gray scale video used to perform the line following task. The GA was to evolve the behavior. The feasibility of this concept is demonstrated through simple line following robot. The fuzzy inference system and reinforcement learning are integrated [94]; the rules are refined through Q(x) learning. The fuzzy reinforcement used to design controller of robot. The scheme of switching behavior in FLC solved the
problem of navigation in complex environment. The robot is also able to escape from concave traps to reach the goal.

2.10 SOFT COMPUTING-BASED ADAPTIVE NAVIGATION

The uses of adaptive fuzzy control approach for complex cluttered environment is discussed [96]. This technique is based on design and optimization of fuzzy logic control performed in two stages. In the first stage, fuzzy logic control parameters are optimized by using rapid prototypic algorithm. The latter algorithm allows convergence of the cost functions to its global minimum by using a local search algorithm which is randomized hill-climber with an adaptive step size. The structure of Fuzzy logic control is divided in to multi input single out put using weighing technique. The robustness of the proposed approach is shown by stability analysis. The software implementation has been done for adaptive fuzzy control system [52]. This approach learns from user behavior. The main objective of this approach was reduction of the memory and computational time. This has been tested on pioneer robot and wheel chair. This approach is found successful for all static and dynamic type of obstacles.

The neuro fuzzy algorithm for reactive robot is proposed in [13]. This technique can effectively deal with imprecise or noisy data coordinate conflicts among multi- behavior context. RAM-based neural network is used to supervise the FLC. The benefit in using RAM-based neural network approach is that it requires very less memory and less computation time, maintaining the ability to handle imprecise and complex data. The genetic algorithm concept is used along with FLC to control the visual servoing robot [21]. Genetic algorithm used to optimize the output in a complex environment. An experimental result shows that genetic algorithm improves the fuzzy logic controller-based mobile robot navigation. This eliminates the steady error and reduces the mean squared error.

2.11 OVERVIEW OF LITERATURE

The autonomous robots are vehicle type device moving in a known and unknown environment with certain degree of autonomy. Behavior-based robotics attempts to formulate approaches that can overcome all kinds of uncertainty in an unknown
environment [51] [73] [84]. Research on behavior-based robotics gains more importance compared to basic navigation technique because of its ability to percept and react to the environment. Behavior-based control [15] [41] [45] does not need building an environment model and reasoning process, it is more suitable for dynamic environment. The main issue in behavior based robotics is how to coordinate multi-behavior conflicts.

A number of behavior based control strategies [66] [70] have emerged since brooks subsumption architecture using switching type of behavior arbitration [41] [70]. These methods employ a priority scheme where highest priority is selected neglecting lower priorities. This has lead to insufficient performance in some context.

The strategy of competitive behavior coordination such as, [66] motor schema control [71], potential field [43], winner takes all [32], temporal sequence [70], state-based deal etc. The competence-based behavior coordination combines the degree of occurrence of various behaviors. The fusion method applied on multi-behavior coordination improved the mobile robot navigation in uncertain environment [69]. The fusion method employed for each behavior is allowed to provide the final output based on situation context [22] and CDB [7].