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Obstacles Avoidance Mobile Robot System in Uncertain and Ever-Changing Surroundings

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Abstract – Robotic navigation has remained an open issue through the last two decades. Mobile robot is required to navigate safely to goal location in presence of obstacles. Recently the use of mobile robot in unknown dynamic environment has significantly increased. The aim of this paper is to offer a comprehensive review over different approaches to mobile robots in dynamic environments, particularly on how they solve many issues that face the researchers recently. This paper also explains the advantages and drawbacks of each reviewed paper. The authors decide to categorize these articles based on the entire content of each paper into ten common challenges which have been discussed in this paper, including: traveling distance, traveling time, safety, motion control, smooth path, future prediction, stabilization, competence, precision, and low computation cost. Finally, some open areas and challenging topics are offered according to the articles mentioned.

Keywords: Dynamic environment, navigation, obstacle avoidance, path planning, robotics

Introduction

Autonomous mobile robots these days accomplish a number of tasks precision with safety (Dash, 2015; Pol & Murugan, 2015). Motion planning and trajectory planning are vital issues in the domain of Robotics and, more commonly, in the domain of Automation (Gasparetto, Boscariol, Lanzutti, & Vidoni, 2015; Wu, Lo, Lin, & Liu, 2014). The motion planning of mobile robot is to discover the route form start position to the goal in an environment with obstacles, so the robot can avoid all the obstacles safely with less processing and least cost (Abbadi & Přenosil, 2015; J. Liang, 2011)

There are two categories of motion planning approaches which are grouped according to the data gained from the environment, namely global motion planning and local motion planning (Xue & Xu, 2011). The global motion planning is path planning under conditions based on environment entirely known, whereas local motion planning is path planning based on the local realized environment of sensors. It is similarly labelled as off-line or stationary and on-line or dynamic path planning in relation to the behaviour of obstacles (Zafar, Baig, Bukhari, & Khan, 2010). If the way is a predefined resolution in the situation of stationary obstacles, then the path planning is titled offline decision making or stationary motion planning. In contrast, if the resolution is prepared by the robots once the obstacles are not stationary (dynamic obstacles), the conditions are familiar as online or dynamic path planning (Peng, Huang, & Luo, 2015; Raja & Pugazhenthi, 2012b)

Motion planning can be generally grouped in two substantial methods, which are classical and heuristic (Morales, Toledo, & Acosta, 2016). The classical techniques have several disadvantages, for instance a long difficulty tune in high dimensions, and inability to escape from local minima, which make them unsuccessful in practice (Masehian & Sedighizadeh, 2007). Subsequently, the use of the heuristic methods spread because of their accomplishment in addressing issues for instance computational difficulty, local minima and exploration (Tang, Khaksar, Ismail, & Ariffin, 2012).

The aim of this paper is to offer a survey of the recent research progress in the field of robotic motion planning approaches for dynamic environments. Conventional and evolutionary algorithms which are commonly used for robotic motion planning in dynamic environments have been addressed. The advantages and drawbacks of each method are also briefly explained. Additional open areas and challenging issues involved in developing computationally effective motion planning procedures are presented according to the articles stated.

Obstacle avoidance Challenges for Dynamic Navigation

It can be easy to establish the globally optimal route through using optimization techniques if the whole information of environments has been given in which a robot is positioned; whereas the local planner uses sensory system, and when earlier unidentified and unexpected obstacles are sensed, on-line re-planning to evade the recently detected obstacles is effectuated (Miao & Tian, 2013). An enormous number of studies on robotics motion planning in dynamic environments have been undertaken (Rantanen, 2014; Strimel, 2014). Subsequently, we introduce a number of these works and indicate the most substantial works of each one. As we outlined about 100 papers, we classified these articles according to their particular issues to recognize what the recent trends of significant issues in the field of robotic path planning are:

First Challenge; Traveling distance issue

As regards shorter travel path, (Goel & Singh, 2013) offered an enhanced method for motion planning via Artificial Bee Colony Procedure to match the concept of shorter travel path in changing environments. This method suffers from ignoring the physical features of mobile robot. An innovative method of choosing and evading collision with the 'closest' or the 'most dangerous' obstacle is given in Savkin & Wang (2014) to determine the 'most dangerous' obstacle, how to cope with obstacles that are unobserved or out of detecting range, how to deal with situations with two or more 'dangerous' obstacles concurrently. However, in Hossain & Ferdous (2015) a new procedure through Bacterial Foraging Optimization (BFO) procedure is developed to calculate the shortest reasonable travel path to navigate from any current place to the goal place in an unrevealed environment with moving obstacles. However this method did not take into consideration the orientation of robot and obstacles.

A novel method for robot tracking in changing environments, indicated as visibility binary tree technique, is presented in Rashid *et al.* (2013), but it does not get the better of the success of VisBug and Tangent Bug procedures. An active on-line robotics motion planning procedure in changed environments has been enhanced in Raja & Pugazhenthi (2012a) which hybridize a mathematical model for avoiding collision and evolutional Particle Swarm Optimization (PSO) technique to find an optimal safety route achieving robotic restrictions (kinematic and dynamic). This procedure does not need any separate recovery mode technique to escape from trap locations. In Narayanan *et al.* (2012) anytime planner is established which constructs a Safe Interval Path Planning (SIPP), which is a fast A*-variant for planning in dynamic surroundings which use intervals as a substitute of time-steps to indicate the time dimension of the matter. Even though it can offer safe routes for the following fifteen seconds of execution within 0.05 seconds, it is not considered a physical robot.

Lin & Yang (2015) enhanced RRT algorithm via an innovative two dimension-span resampling method and a pruning technique through a b-spline function to decrease travel distance and computation time. Nevertheless, when the robot moved between two hindrances, router planning did not take into account the safe boundary, and the proposed technique did not take into account any contradiction between the physical and assumptive obstacle places. In Zafar & Baik, Abdul Rauf Baig Rauf (2013) an optimal method is offered for multiple routes generation via simulated niche based particle swarm optimization for dynamic motion planning it can be an active method for providing short, safe, and feasible routes in dynamic restrictions. To create a reasonable safe path from the initial place to the target place when the robot is stuck in a sharp ‘U’ or ‘V’ formed obstacle or the mobile robot meets dynamic obstacles, Genetic Algorithm (GA) with Dynamic Path Planning Algorithm (DPPA) is proposed in Yun *et al.* (2011) to disregard the unnecessary routes to minimize the whole traveled distance. On the other hand, it did not consider the physical constraint.

A new method is offered in Purian & Sadeghian (2013) through Fuzzy Logic to determine the shortest path in unidentified, dynamic surroundings with various difficulties. In this approach, the robot is assumed as a point. The authors in Lafta & Hassan (2013) create a system capable of doing tasks in autonomous way in chaotic unidentified environments. The major benefit of this controller is it lets robot to escape obstacles and reach destination with less travel distance, but it did not take into account the velocity direction of hindrances. In Arora *et al.* (2014) a motion planning technique based on genetic algorithm is suggested for finding track for mobile robot in changing environment. It determines a shortest track from start to target by avoiding obstacles in the optimal time, but it ignores velocity direction of obstacles

Second Challenge; Traveling time issue
In Zhong *et al.* (2011) velocity obstacles procedures applied for changing collision prevention are improved by keeping in mind distance and epoch before collision. It accomplishes fast navigation towards the destination when robot evades collision with dynamic obstacles. Nevertheless, this algorithm can be applied to evade circular obstacles only. A new approach for resolving mobile robot navigation in dynamic surroundings, through the heuristic features of an improved ant colony with Fuzzy Logic system is presented in Purian & Sadeghian (2013) to improve smoothness, time and distance of the route and lastly develops elements of fuzzy rules schedule, but the schedule which is treated as heuristics data in choosing of ants is set manually to speed up the convergence of the procedure.

A Subgoal-Guided Force Field procedure, which considerably develops the act of the Force Field technique, is suggested in Jin-xue (2011) for actual-time motion planning and collision prevention in partially identified and dynamic surroundings. It provides rapid planning procedures and a big range of executions. Nonetheless the wheel sliding plus additional degrees of freedom as a result of a robot’s inner structure are unnoticed. In Abiyev *et al.* (2012) the proposed procedures are fundamentally based on potential field procedure, vector field histogram and A* methods to lead a robot in any orientation to the target, and to identify its exact location in the surroundings. It has expertly found the preferred and near greatest solutions in short travel time. In contrast it does not take into account the physical constrains of robots.

The authors in Matveev *et al. (*2012) designed a sliding mode-based method for navigating a unicycle-like robot to destination via chaotic changing environments with moving and deforming hindrances. This approach offers fast navigation and it acts better than Velocity Obstacle (VO) technique. In the meantime, due to the reduced speed, the robot goes together with the dynamic obstacle for a long time, thereby resulting in the robot experiencing an extensive side maneuver. A novel moving obstacle avoidance technique for non-holonomic mobile robots in changing surroundings is presented in Hashim *et al.* (2012) to emphasize the ability of mobile robot to acquire the epoch lost through obstacle avoidance and find the destination at the identified time. This algorithm is useful for task-based executions for example patrolling an enormous area and robot soccer, which want the mobile robot to be at the identified position at the identified period with preferred direction. Nevertheless, the dynamic obstacle is assumed to follow its way exactly and does not move away from its first planned route.

A novel technique of global robotic motion planning to navigate in a surrounding chaotic environment with obstacles, that have arbitrary shape, size and location, is designed in Raja & Pugazhenthi (2011). It is valid to static, partially moving as well as dynamic surroundings containing obstacles. The benefit of this technique is reduced travel distance and time of the processor, but the surrounding is global (place and speed of obstacle are identified). A Complete Coverage Path Planning (CCPP) technique in Hsu *et al.* (2014) with the capability of giving minimum working time, minimum energy utilization, mixed method modes and obstacle evading for fixed or dynamic objects. However there it ignores the slipping on the left and right wheel. In Zheng *et al.* (2011) a novel procedure of motion planning process to move robot soccer in changing surroundings based on ant colony technique is offered to design the optimal track. It makes the convergence constancy optimal and makes the speed rapider.

Third Challenge; Precision issue
To achieve precision, a technique for robot navigation that hybridizes a global process strategy with a local reactive obstacle avoidance process is designed in Hacene & Mendil (2013) that directs the robot to reach the destination through "gap vector" technique. It allows the robot to design its track in chaotic surroundings, and to keep its track close to the Desired Path (DP) while evading hindrances. However, the back sensors are absent in planning the robot as the robot infrequently uses the back sensors and always travels ahead. In contrast, the proposed method in (RW.ERROR - Unable to find reference:37) extracts the collision cones of different shapes of obstacles through a laser sensor, where the obstacle size and the epoch to collision are calculated to consider the speeds of the robot. It formed a collision cone very precise and made by the circle fitting method and lets the mobile robot to proceed through a narrow gap although it can avoid obstacles which had varied capability to evade other hindrances.

Montiel *et al.* (2014) planned a Fuzzy System Controllers for a differential mobile robot that improved to steer in outdoors environments over a predetermined track from position A to position B autonomously. It is useful for decreasing the accumulated fault that grows with the interval when using an odometer system, but it did not take into account the velocity direction of obstacles. There is an improved structure in Ferguson *et al. (*2015) for long-term trajectory estimation and strong collision avoidance of walkers and other moving agents in actual-time when these agents show previously unseen performances or variations in intention. It is able to acquire new behavior patterns online and quickly discover and react to change-points and advance estimation precision relative to current approaches.

Fourth Challenge; Stabilization issue
To reach the Stabilization, a Multi-Robot System (MRS) in Benzerrouk *et al.* (2012) should reach and conserve a specific formation in dynamic environments through the limit-cycle principle and a penalty function to acquire angular and linear robots' speeds. It promises the stabilization (by Lyapunov function) and the safety of the MRS, besides the toughness and the competence. However, this technique did not take into account the robot kinematic restrictions while generating the convergence to the control set-points. The authors in Tamilselvi *et al.* (2011) suggested a technique which makes the test bed with Fire Bird V Mobile Robot for future enhancement of a clever wheelchair for elderly people aid in the interior environment for determining the space between obstacles. The procedure's Stabilization, rapidity, and slight storage footmark make it public for actual-time collision finding.

Fifth Challenge; Less calculation cost issue
Masehian & Katebi (2014) introduced a new easy tool for online avoidance of obstacles titled Directive Circle (DC) for producing collision-free tracks for differential-drive wheeled mobile robots toward a moving goal amongst changing and fixed obstacles. It can be implemented simply in real-time with fewer computations than the Velocity Obstacle (VO) procedure and without suffering from large amount of obstacles. On the other hand, the robot does not forecast the obstacles' expected ways, and responds to their actions based on their current velocity and place. In contrast, in (Miao & Tian, 2013), a developed Simulated Annealing (SA) technique is advanced for robotic motion planning in changing surroundings with both fixed and moving obstacles to enhance act in both robot track solution and processing epoch. It offers the best route solution, and made its actual-time and on-line executions possible, but the robot dimension is ignored.

A bio-inspired clever method is proposed in Choi & Zhu (2011) to motion planning for decentralized movable objects in changing surroundings to reserve a safe space between one another, and track to their respective destination. It finds out impending neighbors, reduces the computations overheads and disregards unnecessary robot travels. Instead, the navigation parameters of the proposed technique are practical, identified through trial and error, and there is still a lack of effectual analytic guideline to design the parameters. In Vechet *et al.* (2014) a hybrid technique which joins three methods: potential fields, rule based motion planner and Voronoi diagrams is proposed to take the highest of all stated techniques to produce reliable routing system with extreme importance on safety. The mix of all three techniques decreases the computations cost and advances the strength of routing, but this method is not optimum in its act but in the strong point and with respect to the safety of both the robot and environment moving people.

Sixth Challenge; Motion control issue

To achieve motion control, Mallik & Sinha (2013) presented a control procedure through collision cone technique to eliminate collision with fixed and dynamic irregular obstacles. It can simply perform obstacle avoidance control process in a changing environment. Nevertheless, stability analysis of the proposed control process is under inspection. In contrast, the authors in Franzè & Lucia (2015) enhanced an innovative separate-period Receding Horizon Control (RHC) process via set-theoretic concepts to guarantee control execution and determine load savings under limited contentment. The suggested method handles serious obstacle situations that are hard worked by dynamic motion planning case, but the obstacle locations on the working space are predefined.

The enhancement and execution of neural control schemes in robotic obstacle avoidance in real time via ultrasonic sensors with hard methods of decision-making are considered in *Medina-Santiago et al.* (2014). It shows a great solution to the problem of smart vehicles navigation, their skill to learn nonlinear relations between the input data and sensor data output. In the meantime, in Lopez *et al.* (2011) an online planning process is offered for unidentified changing surroundings that focus on accessibility and using objects motions to reach a specified goal. This procedure is able to find out a route via moving platforms to reach a destination placed on a surface which is not reached directly, but it does not take into account navigation in physical areas with physical objects. A laser simulator search graph approach has been implemented to find a free-collision path in a complicated unknown environment. This algorithm gives the possibility to consider some constraints based on the real world path as in road or factory environments. Ali *et al.* (2013), but it did not consider the relative velocity of the obstacle.

Seventh Challenge; Competence issue

Wu & Feng (2012) created a local track through obstacle-movement guess and a Rolling Window for dynamic motion planning to partly change the global track. It accomplishes together global and local obstacle avoidance via motion, cooperative with a best path, which evidences the feasibility and effectiveness of the method. The drawback of this method is the limited zone which means not crowded area. The Fuzzy Logic procedure with four modules in (Faisal, 2013; Al-Mutib *et al.*, 2013) are used to steer an autonomous mobile robot in unstructured, varying and unidentified environment to arrive to the destination and obstacle avoidance acts amongst four modules and exchange the control among modules. The suggested technique is active and robust under dynamic obstacle scenarios. However, because of the use of several sensors to predict the surroundings, we do not have any evidence on the actual time process, and due to the absence of testing and simulation, we cannot judge to what level that this system is efficient.

The algorithm proposed in Bis *et al.* (2012) is dependent upon an occupancy grid which has been used to avoid fixed and dynamic obstacles. A search zone lets the robot to escape moving obstacles and track efficiently the target via uncertain sensor data, but this procedure presumes that the vehicle is holonomic and not appropriate to design extended and complex paths. Fuzzy Logic controller is suggested in Dongshu *et al.* (2011) to resolve the robot routing and priority-based behavior control so as to get the non-collision path of mobile robots in dynamic unidentified surrounding. This system can lead the mobile robot successfully, but it does not take into account the speed of obstacle. A dynamic navigation process for a self-directed vehicle routed without Global Positioning System (GPS) and automatic operation in unknown surroundings is offered in Zhao *et al.* (2011). The Intelligent Pioneer showed worthy acts in dynamic navigation. However, the controller of the vehicle's body came to be unsettled because of the high velocity of vehicle, thus it had to be stopped and fixed.

Vignesh *et al.* (2012) built a 2-D grid based map through the incorporation of wave-front process and A* search algorithm for a given state of the surroundings via effectual navigation approaches to reach destination with evading obstacles. The proposed algorithm operated well with competence of at minimum 80 percent, but the robot as presented is in its plain form and several extensions is feasible.

Eighth Challenge; Smooth path issue

In (Faisal 2013; Hedjar *et al.*, 2013) the obstacle avoidance performance is performed and the Wheeled Mobile Robot (WMR) is directed to its goal through fuzzy logic control technique. It gives smooth paths, cost savings, self-organization, and flexibility. However, it is not precise for quick dynamic move of WMR. A developed obstacle avoidance and road correction mechanism is proposed in (Shih *et al.,* 2012) to evade obstacles and correct the road. It lets the robot to navigate smoothly via three obstacles and correct the walking road in the similar period. In addition, it uses a slight cost device which can have a like act as an expensive device, nonetheless the surroundings do not ensure greatest performance each period, mainly when an obstacle might impede the ultrasonic sensor's detecting capability, and the sliding of the land could also reduce the robot's walking competence. A new framework with coinciding laser-based dynamic obstacle avoidance and outdoor vision-based steering is presented in Cherubini *et al.* (2014). It combines a reactive, visual servoing, with tentacle-based method; to assurance track following and obstacle evading by deceleration. However, the existing configuration (forward-looking lidar) needs to be altered.

The authors in Mohammadi *et al.* (2014) presented an enhanced A* search process procedure, which determines an obstacle-free track, has a best calculation time and smoothness of the latest road. The road is smoother than roads that result in other traditional procedures. In contrast, other navigation methods such as multi-point potential field technique for Autonomous Underwater Vehicle (AUV) which is developed in Subramanian *et al.* (2012) are potentially unqualified to evade the local minima problem in spite of it giving a smooth road. The innovative hierarchical architecture that Group MAGICian developed in Boeing *et al.* (2012) gives clever and active tactical planning, smooth actual-time road modifications and obstacle avoidance. However, it cannot provide the shortest road. A computationally efficient navigation procedure is offered in J. Choi (2014) for self-directed land vehicles performing in semi-structured environments with a job recognized by waypoints, passageway widths and obstacles to decompose the mission road and to smooth the road, but it suffers from inadequate sensor range. The benefit of a self-reconfigurable routing system designed for independent robots working in varied environments (Marques *et al.,* 2013) is to offer extra proof on the benefits of taking into account the Robot Operating System (ROS) as a fundamental of the robot's control scheme. However the road followed by the robot has specific variation from the ideal road caused by varied factors.

Ninth Challenge; Safety issue

Artificial Potential Field (APF) method is utilized with a Bacterial Evolutionary Procedure (BEA) (Montiel *et al.,* 2015) for the purpose of getting a developed flexible route planner method. The direction of obstacles was not considered in it. However, they guarantee an optimal, safe and feasible route. In a new technique called " Follow the Gap Method" (Sezer & Gokasan, 2012), safety is confirmed through conducting the robot in to the maximum gap's center as much as possible while trying to provide the reach of end point. However, this new method suffers from low velocity, the local minimum at dead-end situation and setting.

Zhang *et al.* (2013) proposed a new potential field method for the purpose of eliminating the unneeded obstacle avoidance to a large extent and moving to the end safety and quickly in changing environments. The collision as the velocity of the obstacle enhances can be considered as the disadvantage of this algorithm, because the repulsive force is too small to be capable of escaping the moving obstacle. The algorithm proposed in Savkin & Wang (2013) belongs to the type of biologically inspired or biomimetic path planning methods. In biology, a parallel obstacle avoidance approach is called negotiating obstacles with fixed curvatures which was adopted for a unicycle-like robot's steering towards a target while avoiding collisions with moving obstacles. The simplicity and effective computationally with safe navigation are the characteristics of the proposed algorithm. At the same time, Kalman filter is utilized by a different technique known as Escaping Algorithm (EA) (Yaghmaie *et al.*, 2013) for the purpose of forecasting the movement of dynamic objects and merging them with potential filed technique so as to steer safely in the changing environment. However, the abovementioned paper will not compare its used method with other similar approaches that deal with dynamic obstacles to evaluate their performance.

A 3-D extension of the Bayesian Occupancy Filter was proposed by (Llamazares *et al.*, 2013) for the purpose of resolving the issue of dynamic obstacle avoidance for a mobile platform via the stochastic optimum control structure in order to compute routes that are suitable and best regarding safety together with energy competence under limitations. From the other point of view, this technique suffers from high computation cost of utilizing Approximate Inference Control Method (AICO) in real-time planning execution. Wang *et al.* (2013) proposed a new collision free steering technique for an electric-powered wheelchair in chaotic settings and environments. This new technique aims to prevent collisions with dynamic obstacles including pedestrians or vehicles under the control and guidance of proposed process and reach the target. Flexibility together with applicability for large variety of environments can be considered as the characteristics of this process. Moreover, these procedures can fulfill the navigation mission with restricted information; however, the driving wheel roll is assumed without sliding.

Q-learning process is a new technique proposed by Jaradat *et al.* (2011). This advance technique is used to solve the mobile robot steering in changing environment issue through restricting the situation based quantity on a new definition for the situations extent. This algorithm is a good one in terms of decreasing the size of the Q-table. Moreover, it is good for increasing the speed of the navigation process. However, the robot only considers the current situation of the goal and it does not consider the prior situation in order to predict what the next situation will be. Ohki *et al.* (2012) proposed a collision avoidance method for a mobile robot in changing environment. This technique takes account of the near-team movement and "personal space" of moving obstacles for the purpose of evading evacuees in a 2 dimension plane situation. Nevertheless, the obstruction of the sensors in simulation test at the present moment is not considered in this method. Therefore, it is not easy to predict the movement of the obstacles precisely when it is applied on a real mobile robot. Collision-free path is offered by the adjustments of VFH+ together with VFH* (Vector Field Histogram) method in environments with dynamic obstacle (Babinec, Duchoň, Dekan, Pásztó, & Kelemen, 2014). It is not necessary to re-plan the route or switch between different process for the purpose of accomplishing collision free avoidance of both dynamic and stationary obstacles in this method. It is handled by VFH*TDT (Vector Field Histogram with Time Dependent Tree) method simultaneously. Molinos *et al.* (2014) proposed a new method on the basis of famous Curvature Velocity Method (CVM) and a probabilistic 3 dimensional occupancies and velocity grid developments for safe and strong self-directed navigation. Nevertheless, this method is examined only in indoor environment.

Hsieh & Liu (2012) applied Non-linear Model Predictive Control (NMPC) for the purpose of determining realistic trajectories for the WMR in order to track safely to get to an appointed target in a recognized changing environment. However, the environment captured by dynamic and stationary obstacles is defined in advance. An increased (Rapidly-Exploring Random Trees) RRT∗ is introduced by Shan *et al.* (2014) for the purpose of blending lane data and evading obstacles in order to discuss an application state by which the needed route is not the same as the optimum route. There is still a gap in its paradigm effectiveness in an actual autonomous vehicle in this algorithm. Gori *et al.* (2012) introduced Dynamic Force Field Controller (D for C). This framework is efficient and reliable in humanoid robotics' situation for real time arrival and navigation when obstacles exist. This technique seems to be specifically flexible regarding environmental differences allowing a safe navigation procedure and producing valid routes in almost each state. However, Zhu *et al. (*2011) introduced a process for dynamic unknown environments on the basis of increased ant-based process. The drawback of this process is that the multiple dynamic obstacles happening at the same time in Rob's

VD (Robot's Vision Domain) is not considered in it. However, it has good effect and great real-time performance.

Dong-Shu & Hua-Fang (2011) proposed a method that focuses on safety. A hybrid planning method which includes local planning together with global planning is suggested by choosing the developed Ant Colony Optimization (ACO) for the purpose of designing the global route and rolling window in order to evade local collision. However, it only explains the motion planning, where the obstacles of moving rout is recognized. This test makes use of a Fuzzy Control Procedure for motion planning together with obstacle avoidance. Therefore, it enables the mobile robot search for target, avoiding obstacles and preserving heading (Chang & Jin, 2013). This paper will not examine the obstacle's velocity vector which can be regarded as its disadvantage. The work conducted by (Mohanty & Parhi, 2012) in which an adaptive Neuro-Fuzzy Inference System (ANFIS) is applied to route generation and self-directed mobile robot's obstacle avoidance in an unknown environment and stationary, has the same disadvantage.

Tenth Challenge; Future prediction issue

Abaee Shoushtary *et al.* (2014) proposed a new hybrid method adopted from Honey Bee Mating Optimization (HBMO) method (for the purpose of robot navigating distance reduction) together with tabu list method (for the purpose of avoiding hindrance) for team robot plan. This method behaves better than ACO and PSO methods. However, the velocity of all robots for every run is similar. Du Toit & Burdick (2012) introduced a relatively closed-loop receding horizon control method. In this method, the resolution includes prediction, planning and estimation. This method considers opportunity limitations that happen due to unsure sites of obstacles and robot. It is capable of coping with increasing uncertainty in the expectation elements of the changing, unsure environment solution because the uncertainty is reduced as a result of predicted data that is related to the future belief circumstances.

Liang *et al.* (2011) planned an indoor house work robot coverage route for the purpose of evading obstacles on the basis of performance of Fuzzy Controller under changing environment and setting. Fuzzy control refers to an effective tool that can be used to cope with the systems model that is non-linear, time variable and uncertain. Only indoor surrounding is defined by it. Knepper & Rus (2012) proposed a new multi-agent distributed hitting escaping method for the purpose of drawing stimulus from human walkers to collectively evade collision without liking better one agent over some other. Moreover, this method integrates arbitrary tracks as made by a path planner which runs on every steering robot together with anticipated human tracks. Two supportive attributes are offered by this method. The first one is sampling bias which is decreased as routes' distribution in the free space is just the basic sampling distribution in that area. The second one is the refusal sampling technique which is easy to be used. However, this method can be costly in very chaotic spaces. In Aenugu & Woo (2012) the suggested mathematical method is applied in real-time to produce a 3-D track for the mobile robot to move and reach an arbitrarily moving target while avoiding arbitrarily moving obstacles. The relative velocities of the mobile robot, goal, and obstacles are considered in the generation of the path, but it ignores the physical dimension of robot.

Lee *et al.* (2012) proposed a three dimension vision based local hindrance avoidance method based on fuzzy logic and view image. It is developed on a humanoid robot. Therefore, it is capable of selecting avoidance trend and walking movement effectively. Motion planner that has all the information concerning the route data and obstacle position in advance is not needed by these systems. Nevertheless, the robot is not capable of controlling walking professionally due to slip together with hardware fault because the control process is needed by the robot for steady walking. Mbede *et al.* (2012) connected the advantage of more controllable freedom's degree that Omni directional mobile robot offers with its Type-2 Fuzzy Logic Capability of coping with the high steps uncertainties in unknown and unstructured dynamic surroundings. It is suitable for actual world execution together with on-line stationary and finally moving obstacle avoidance. However, it only functions in indoor surroundings. The wheels have no slipping in the traction force's orientation. Those interaction forces that are not in the traction force's orientation are ignored. The electrical period of the motor is constant.

Li *et al.* (2012) proposed a developed method of potential function. They used Artificial Neural Network (ANN) for the purpose of acquiring data of velocity together with the location of the target and obstacles. How to explain the attractive together with repulsive force is discussed in this method. Also, it discusses how to expect the velocity of the obstacle. Furthermore, the interval between obstacle and the robot is discussed. However, the planned route is not optimal. That is because the size of the robot is restricted. Junratanasiri *et al.* (2011) introduced a tracking system in an uncertain environment that focuses on moving obstacle for a mobile robot through designing the velocity, angular velocity and hindrance's location uncertainties utilizing fuzzy membership function. In order to dominate velocity together with angular velocity of a robot, A Type-2 Fuzzy Logic method is used. However, the robot determines to wait for the obstacle and after that tracks towards the target. As illustrated in Fig.1. This enhances the run time. Tang *et al.* (2013) introduced a new reactive obstacle avoidance method on the basis of a "Divide and conquer" method and "Situated activity paradigm" method which navigate the robot for the purpose of traveling between unknown obstacles and towards a goal without hitting. The tasks complexity is minimized using this method. Moreover, the reactivity is improved. However, the shortest route cannot be gained.

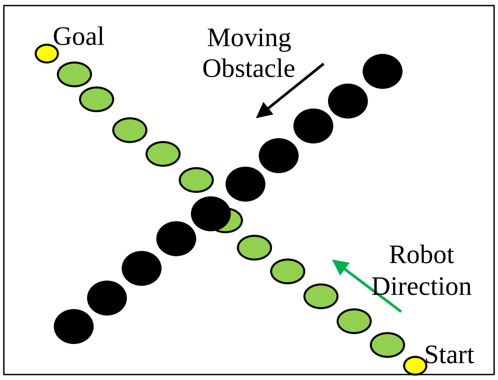

Figure 1: The robot navigates to goal and the obstacle travels from top to bottom, at that time the robot selects to wait for the obstacle to pass, afterward the obstacle passes the robot and lastly the robot reaches to destination

Summary

a. Statistics analysis

This study reviewed a total of 100 articles, which cover sufficient depth of works in the dynamic path planning field from the year 2011 to 2015.Through the reviewed papers, the authors summarized and identified the relationship and importance of each challenge during the recent five years. Figure 2 shows the level of interest for the recent years. As illustrated in Fig.2, the percentage of smooth path issue is increased from 6% in 2011 and 2012 to 22% in 2013 to become 33% in 2014 and 2015. This means the interest in smooth path issue will increase in future. Moreover, about 10% of the articles in 2011 and 2012 are related to precision issue, and then they rose to 20% in 2013 to become 40% in 2014 and decreased to 20% in 2015. Furthermore, 18% of papers in 2011 are on safety issue, and then became 29% in 2012 and 35% in 2013 to decrease into 16% in 2014 and 6% in 2015.

To add to that, about 29% of papers in 2011 and 2012 are devoted to stabilization issue, and then settled at 14% in 2013, 2014, and 2015. In addition, traveling distance issue occupied about 8% in 2011 to become 17% in 2012, while this percentage increased to 41% in 2013 to decrease again to 17% in 2014 and 2015. Besides that, there is fluctuation in percentage for the low computation cost which ranges from 20% in 2011 to 10% in 2012 and again 20% in 2013 to become 40% in 2014 and decrease to 10% in 2015. For traveling time issue, the percentage of concern in 2011 is 42% and minimized to 38% in 2012 to become 10% in 2013, and then 11% in 2014 and 5% in

2015. Additionally, approximately 18% of interest is concentrated in 2011, 2013, and 2015, while about 9% is devoted to 2012 and the highest value is 37% in 2014. Competence issue ranged from 29% in 2011 to 43% in 2012, while in 2013 the percentage was about 14% and decreased to 7% in both 2014 and 2015. Finally, 19% of the papers are related to future prediction issue in 2011, while the greatest percentage of 57% belongs to 2012, and then about 9% in 2013, 10% in 2014, and 5% in 2015.

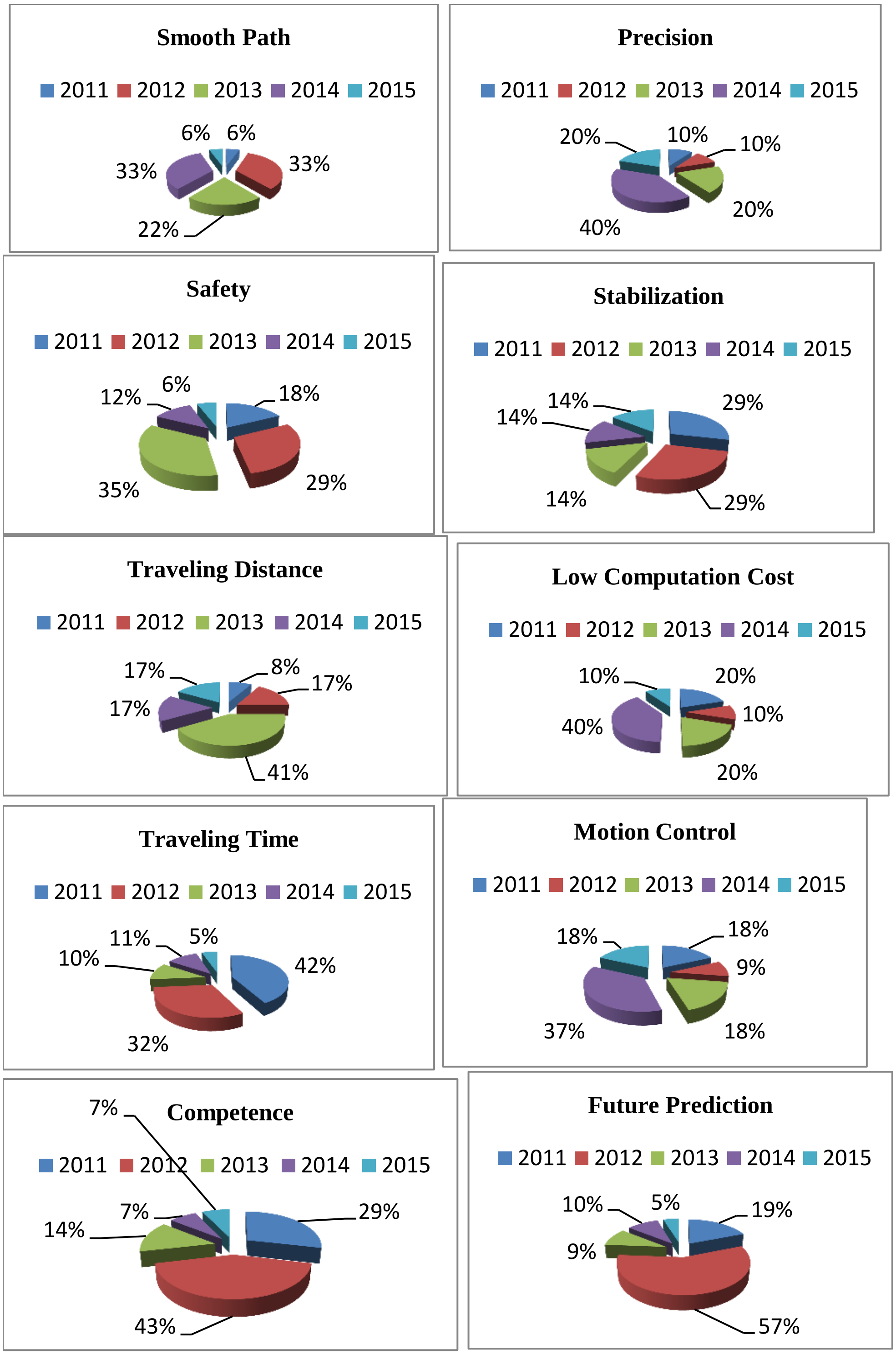

Figure 2: The relationship between type of challenge and related year

Based on the above mentioned results, it can be concluded that the most significant issues are as shown in table 1.

Table 1: Obstacle Avoidance for Dynamic Motion Planning Challenges

Challenges	**Recent Studies%**	**Related year**
Future prediction	57%	2012
Competence	43%	2012
Traveling Time	42%	2011
Traveling Distance	41%	2013
Low Computation Cost	40%	2014
Precision	40%	2014
Motion Control	37%	2014
Safety	35%	2013
Smooth path	33%	2012 & 2014
Stabilization	29%	2011 &2012

Based on the reviewed papers, the overall methods of obstacle avoidance are as summarized in Figure 3:

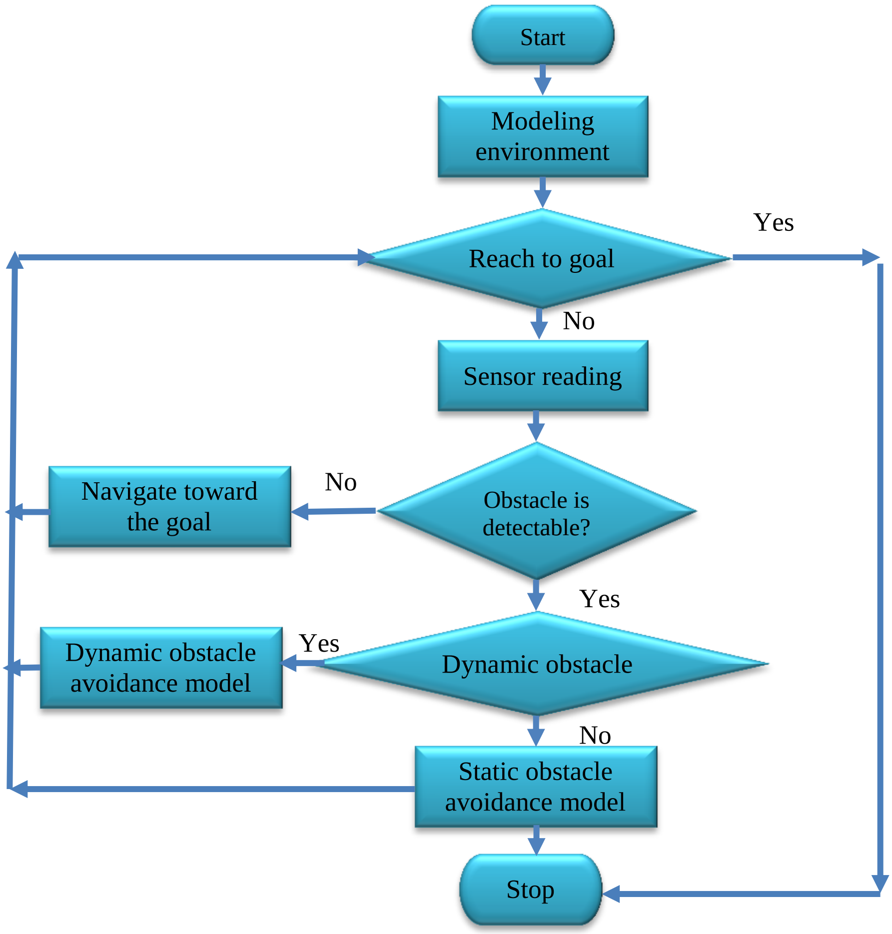

Figure 3: Obstacle Avoidance Procedure

b. Disadvantages and possible improvements for the reviewed papers
In the area of motion planning in dynamic environment, heuristic method has shown to provide better result compared to pure traditional methods (Raja & Pugazhenthi, 2012b). Many algorithms have been proposed to overcome the difficulty of NP-hard path planning issue because better quality of routes affects the efficient use and functioning of mobile routes (Davoodi, Panahi, Mohades, & Hashemi, 2015; Kang *et al.,* 2015). Based on the literature reviewed, there is still scope for the development of more efficient on-line motion planning algorithms with moving obstacles that will lead to overcoming the abovementioned challenging as below:

- Relative velocity is the most significant element that has a strong influence in dynamic motion planning. It refers to the adjacent obstacle forwards of relative velocity vector concerning the robot. This factor was not used as constrain in the mentioned methods by those who proposed it. Therefore, we must put emphasis on this factor in future.
- Two important problems should be addressed and settled in order to have a successful navigation of the mobile robot to the goal in a dynamic environment. The first problem is concerning the real-time identification of the moving obstacles. The second one is regarding the shortest together with safest path produced dynamically. Therefore, there is a need to design a good path which leads to faster travelling time as well as an obstacle avoidance system for mobile navigation in dynamic setting.
- Finding the proper solution is not guaranteed in Heuristic methods. Therefore, one of the best ways to increase the efficiencies of these methods can be to integrate some of them with each other.
- The uncertainty concerning the motion planning problem increases in dynamic environment significantly as all the information of a dynamic environment will change with the obstacles' motion. Therefore, an improved method for a hybrid heuristic planning algorithm in an environment with dynamic obstacles is considered to be essential.
- Failures in crowded complex environments because some specific types of environments which classic algorithms fail to find a feasible path in a reasonable amount of time. Local minima outcomes may occur in some cases. In the complex and crowded environments, the performing and safety requirements for planned path of nonholonomic robots are more difficult.
- In some of the above mentioned methods, the kinematics constrains of a mobile robot were utilized whereas some other ignored these constrains. It can be regarded as an advantage for a particular navigation scheme when some of the actual world elements that influence mobile robot steering schemes' plan is considered. This is due to the fact that it will be easier to transform the plan into practical application.

Moreover, there are many more challenges in mobile robotics due to uncertainty in detecting, path control, multiple optimization goals, forecasting and multiple robot direction.

Conclusion
Today, new applications in various sectors inspired the development of motion planning. In dynamic environment, several methods are presented in the research community to solve the motion planning problem. In this paper, different methods of the motion planning together with obstacle avoidance algorithms including Fuzzy Logic, Velocity Obstacles, Gap Vector, Fitting Circle, Collision Cone, Potential Fields, Follow the Gap, Directive Circle, A*, Neural Network, Biologically Inspired, Escaping Algorithm, Bayesian Occupancy Filter, Artificial Bee Colony, Ant Colony, Bacterial Foraging, Honey Bee Mating, Rolling Window, Q-Learning, Personal Space, Simulated Annealing, Sub goal-Guided Force Field, Vector Field Histogram, RRT*, Particle Swarm Optimization, Voronoi Diagrams, Genetic Algorithms and Generalized Complete Coverage were discussed. Moreover, this paper presented the evolution of the research on the path planning of mobile robots in dynamic surroundings, comprising on-line planning during the recent years. A great number of motion planning issues have been increasing despite the development of many efficient methods. Some of these problems are: determination of collision-free route, modeling of changing environment, multiple

optimal functions, obstacle's dynamic constraints, shortest path, and low run time. These limitations cause motion planning issues to need more efficient algorithm and to be more challenging.

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