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Heuristic Rule-Base Controller for Path Planning of Wheel Drive Mobile Robot

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Abstract: This research is concerned with path analysis and planning of a wheeled drive mobile robot, which still requires improvement. Many authors have used different techniques to resolve these problems, but the stability and optimisation of path and time using intelligent decision-making is still an open area of research for the entire research community. This paper presents the optimisation of path and time using heuristic rule-based technique for a dynamic environment filled with structured and unstructured obstacles. The shapes and positions of the static and moving obstacles in the environment are not known prior to execution for the desired goal. The robot has sensory recognition of specific objects in the environment, and this sensory information provides local information to the robot's controller according to its immediate surroundings. The robot intelligently deals with this information using the proposed and developed heuristic rule-based techniques to achieve the desired objective by avoiding obstacles present in the environment. The perception-based heuristic rules are developed and embedded in the MATLAB software to obtain the simulation results. The simulation results show that the proposed methodology is simple, effective and efficient for wheeled drive robot navigation in a real dynamic environment.

Keywords: Heuristic rule-based**,** Path planning, Mobile robot, .

I. INTRODUCTION

The current research and development of mobile robots have attracted the attention of researchers in various fields, including engineering, computer science, biology, mining, and others. With the advancements in robotics and control technologies, many tasks can now be performed with higher efficiency than ever before. Robotic systems are capable of executing operations with extremely high precision. Wheeled drive mobile robots (WDMRs) hold great potential in several applications such as automatic freeway driving, guidance for the blind and disabled, exploration of dangerous regions, and mechanical parts transfer in flexible assembly systems. However, the progress in the field of WDMR robot path analysis and planning has been slower than expected, considering the initial excitement and relatively rapid advances during the early stages of research[1]. Systems where a robot acts independently in complex environments have often been proven only in limited trials or have not produced actions that can be considered significant. Over the past three decades, wheeled mobile robots have been a focal point of research and development. This sustained interest has been primarily driven by the numerous practical applications that can be uniquely addressed by mobile robots, particularly their ability to operate in large, potentially unstructured, and hazardous domains [2]. WDMRs have found applications in various domains such as industry, hospitals, education, rescue operations, mine detection, monitoring nuclear facilities and warehouses for material inspection and security purposes, planetary exploration, military tasks like munitions handling and materials transportation, vacuum cleaners, automatic guided vehicles, and entertainment. Given the wide range of applications described above, it is evident that WDMR research is inherently multidisciplinary in nature.

Autonomous WMR is a challenging research topic for several reasons. Firstly, a WMR should be able to identify features, detect obstacles, patterns, and targets, learn from experience, find a path, build maps, and navigate. These abilities of WMR require the simultaneous application of multiple research disciplines, such as engineering and computer science. Secondly, autonomous WMRs are the closest approximation of intelligent agents. For centuries people have been interested in building machines that can think and make decisions based on the environment around them. To satisfy this goal mobile robotics research has increasingly incorporated artificial intelligence enabling the machines to mimic living beings. Other commercial robots operate not where humans cannot go, but rather share space with humans in human environments[3]. These robots are compelling not for reasons of mobility but because of their autonomy, and so their ability to maintain a sense of position and to navigate without human intervention is paramount. When this occurs, it is necessary to find an alternative route. This implies a process of adaptation to the environment. In addition to avoiding

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collision, the other requirements are smoother motion, shorter travelling time, or more clearance from the obstacle [4]. Therefore, the path analysis and planning involves optimization with respect to certain performance measures. The goal of autonomous WDMR research is to build and control physical systems which can move purposefully and without human intervention in real-world environments which have not been specifically engineered for the robot. The development of techniques for autonomous WDMR operation constitutes one of the major trends in the current research and practice in modern robotics. When we visit an unfamiliar place, like a new building, shopping mall or theme park, we look for guiding information to guide us to our destinations in mind [5].

Path analysis and planning is another exciting challenge in building autonomous WDMR. An autonomous robot must be able to learn its environment and programming itself without assistance. It consists on finding a route from the initial position of the robot to its target destination. Path analysis and planning becomes more difficult when some static as well as dynamic obstacles are added to the environment, shown in Fig.1.

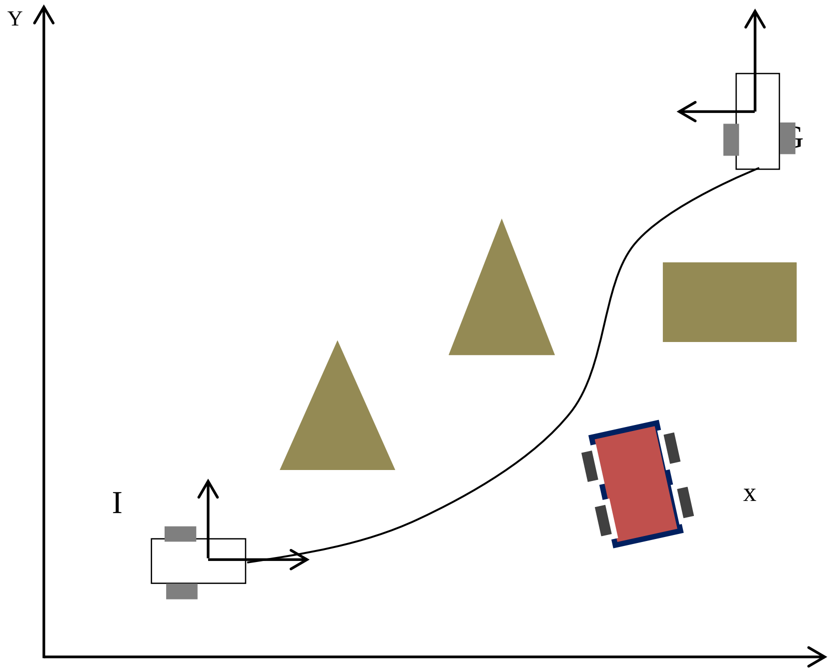

Fig. 1 Path planning problem with static as well as moving obstacles

Another objective is to determine the shortest path from the initial position of the robot to its target destination. This paper purposes alternative ways for determining the best route a WDMR can follow in any environment from its initial position to its target destination with the aim to reach a specified target. The objective of a kinematic controller is to follow a trajectory described by its position and velocity profiles as function of time. Many researchers have studied kinematic behaviour and provided some adequate solutions for (kinematic) motion control of WDMR system[6]. Most of controllers of mobile robot are not considering the dynamics of the system. If the robot is kinematical stable then another challenge is to design an intelligent controller which may provide a general, robust, safe and optimized path so that WDMR navigate in dynamic environment.

This paper contributes for solving the path analysis and planning problem to design and development of control techniques those enables the robot to navigate in a real world environment, avoiding static and dynamic obstacles especially in crowded and unpredictably changing environment. The WDMR explores in the environments and identifies human understandable guiding clues to find a way to the assigned destination. MATLAB software has been used to obtain the simulation results of the proposed algorithm. A series of simulation results show the effectiveness of the proposed control scheme and the robustness of the heuristic rule base controller for path analysis and planning of WDMR. This research is devoted for design of intelligent controller to find the optimal path of WDMR for static as well as dynamic environment. To design an intelligent controller a perception based heuristic rules are developed by the experiential knowledge which is simple, efficient and effective.

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II. HEURISTIC RULE BASE NETWORK

The heuristic rules are based on human perception (i.e. the working environment provides a fixed referential frame for the rules). In the current research work path analysis and planning of the WDMR uses the environmental information to adjust itself according to it. The goal of the research is to develop an algorithm that execute on a man-made visual system, result in the acquisition of perceptual capabilities that robot can be used to perform specific commands [7]. The sensors devices allow to measure the normal ambient distances, which is strongly influenced by the robot's environment. Based on these sensors a human perception based heuristic rules are formulated. This is general, robust and safer methodology which provides fast path planning framework for WDMR. If the target is located right side then the robot will steer clockwise direction i.e. positive steering angle but if the target is located left side then the robot will steer counter clock direction i.e. negative steering angle. Human perception based some of the heuristic rules based on Fig.2 depicts the environment to avoid the obstacles and motion control by the WDMR. The heuristic rules from Table 1 are listed below based on the left obstacle and target both are situated in left side of the robot.

Rule 1: If LOD = 300 mm, ROD ≤ 400 mm, FOD =900 mm and TA = 47˚ Then Change in steering angle = 0˚

Rule 2: If LOD = 200 mm, ROD ≤ 250 mm, FOD =700 mm and TA = 56˚ Then Change in steering angle = -46˚

Rule 3: If LOD ≤ 200 mm, ROD = 150 mm, FOD =1000 mm and TA = 56˚ Then Change in steering angle = -32˚

Rule 4: If LOD ≤ 200 mm, ROD =250 mm, FOD ≤300 mm and TA = 68˚ Then Change in steering angle = 68˚

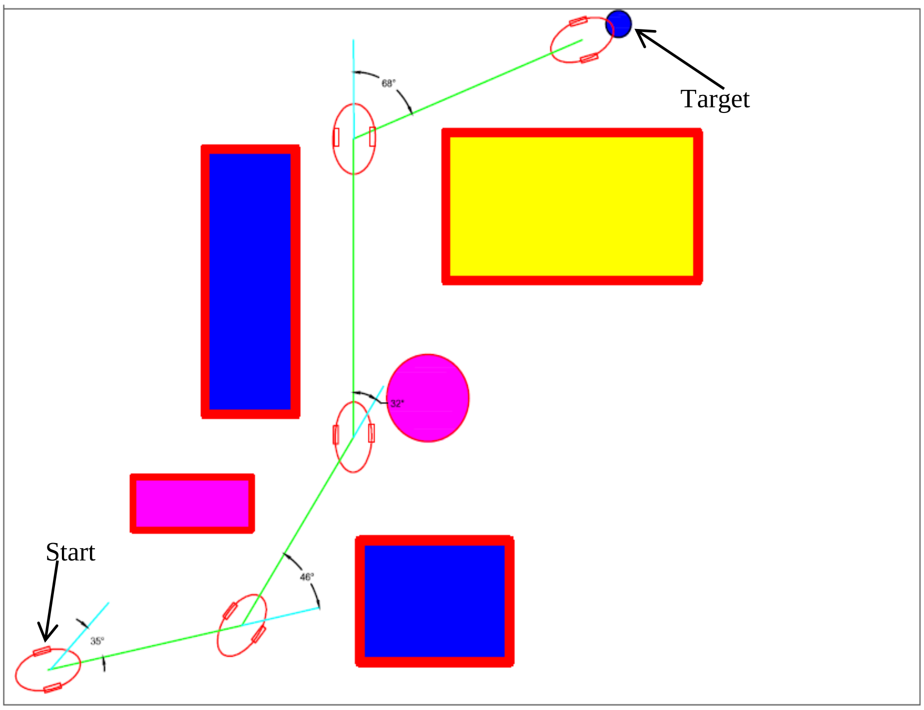

Fig. 2 Human perception based rule formation for obstacle avoidance of WDMR

TABLE 1 Heuristic rules when target located on left side of robot based on Fig. 2

Rule No.	Left Obstacle Distance (LOD) in mm	Right Obstacle Distance (ROD) in mm	Front Obstacle Distance (FOD) in mm	Target Angle (TA) in Degree	Steering Angle (SA) in Degree
1	300	400	900	47	0
2	200	250	700	56	-46
3	200	150	1000	56	-32
4	200	250	300	68	68

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Human perception based some of the heuristic rules in other environment have presented which shows the obstacles avoidance and motion control by the WMR shown in the Fig.3. The heuristic rules from Table 2 are listed below based on the right obstacle and target both are situated in right side of the robot.

Rule 5: If LOD = 500 mm, ROD ≤ 400 mm, FOD =1200 mm and TA = 17˚ Then Change in steering angle = 0˚

Rule 6: If LOD = 300 mm, ROD ≤ 400 mm, FOD =200 mm and TA = 11˚ Then Change in steering angle = 77˚

Rule 7: If LOD ≤ 320 mm, ROD = 400 mm, FOD =No obstacle and TA = 34˚ Then Change in steering angle = -41˚

Rule 8: If LOD ≤ 200 mm, ROD =600 mm, FOD ≤800 mm and TA = 77˚ Then Change in steering angle = -77˚

The above rules are used to design an intelligent controller for solving the path planning and obstacles avoidance problems of WMR. Approximately four hundred rules are fed into the induction program, within the MATLAB software package. The examples present the situations encountered by a robot while moving highly cluttered environment, and the actions that the WMR has to take for avoiding colliding with static obstacles as well as moving obstacles.

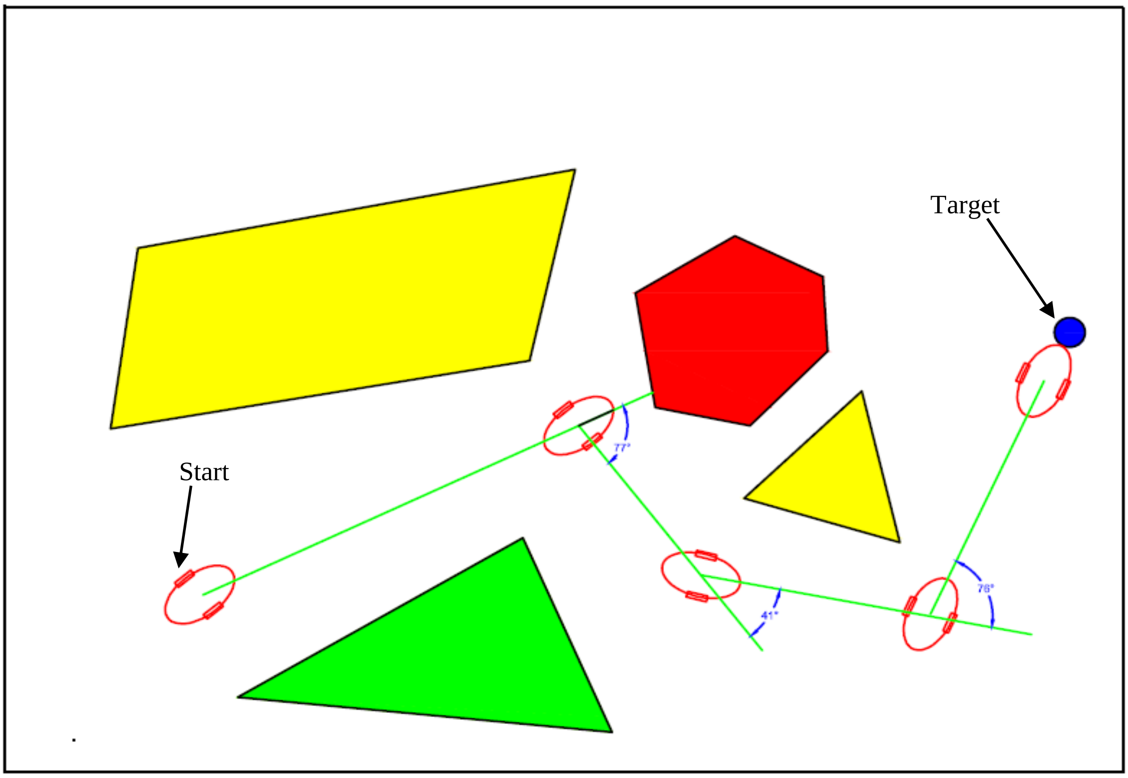

Fig. 3 Human perception based rule formation for obstacle avoidance of WDMR

TABLE 2 Heuristic Rules when target located on left side of robot based on Fig. 3

Rule No.	LOD (mm)	ROD (mm)	FOD (mm)	TA (Degree)	SA (Degree)
5	500	400	1200	17	0
6	300	400	200	11	77
7	320	400	No obstacle	34	-41
8	200	600	800	76	-76

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A. Obstacles Avoidance Behaviour

A mobile robot has to move from an initial position to a final position by avoiding collisions with a set of obstacles in optimal path. To generate a collision-free path, the WDMR has to move along a straight path or take a turn depending on the situations. The obstacle avoidance algorithm for a wheeled mobile robotic system is considered in a medium dense environment (e.g. warehouses and offices). The field of wheeled mobile robotic system has introduced some specific strategies for obstacle avoidance. These strategies can be separated into three categories; classical motion planners, heuristic planners and complete and correct" sensor-based path planning which are used to avoid obstacles. HRBN path planning approach requires no prior knowledge of the environment, using only sensor inputs and robot states [8]. The main advantage of this class is that not requiring complete prior knowledge of the environment, but in practice these methods resolve mainly in very long paths, because no (global) optimization of what so ever can be conducted. The obstacle avoidance technique described in this work that provides a convenient means to determine path whether any static as well as moving obstacles are present in the robot's environment.

The present research work for obstacles avoidance behaviour, an algorithm has been proposed using MATLAB software which uses the very simple mathematical function to get target destination.

The mobile robot has a starting point and a target point, it approaches as good as possible. The target function reads as follows.

$$f(\vec{P},\vec{G}) = \sqrt{(\mathrm{Tarx}-x)^2 + (\mathrm{Tary}-y)^2} \tag{1}$$

Here,$\vec{P} = [x\ \ y]$ is the current position of the mobile robot and $\vec{G} = [\mathrm{Tarx}\ \ \mathrm{Tary}\ ]$ is the target position where robot has to reach. The minimum of the function is reached when P = G. The target angle for WMR is given as

$$\theta = \tan^{-1}\frac{(\mathrm{Tary}-y)}{(\mathrm{Tarx}-x)} \tag{2}$$

If target position and obstacles positions are known from sensors then these data are used to execute the robot movement for obstacle avoidance and target reaching in an algorithm.

Two-dimensional navigation problem have considered as shown in Fig. 4, where the position and velocity of a robot are represented by the Cartesian coordinates x(t), y(t)) and v(t), where 't' is time.

The starting and goal positions of the robot are, respectively, (x; y) and (Tarx; Tary). Its steering angle is $\theta(t)$; $(0<\theta(t) <2\pi)$, which is measured from the x-axis, and has the initial value 'θ_0'. There may be different obstacles of different shape and size in the plane of robot path and the objective is to navigate the robot to the goal without hitting them.

Considering the two assumptions here for obstacles of WDMR; Robot moves only in the forward direction and the Robot turns to the right or left with the minimum rotation radius r_{min}.

For this the equations of motion of the robot are then

$$\begin{cases}\dot{x}(t) = v(t)\cos\theta\,(t)\\ \dot{y}(t) = v(t)\sin\theta\,(t)\end{cases} \tag{3}$$

For assumption (b) is represented here as;

$$|\dot{\theta}(t)| \leq \frac{v(t)}{r_{min}} \tag{4}$$

Consider a quadratic index

$$E(t) = \frac{1}{2}[\theta(t) - \theta^*(t)]^2 \tag{5}$$

Where, $\theta^*(t)$ is a desirable steering angle for avoiding obstacles and for navigation.

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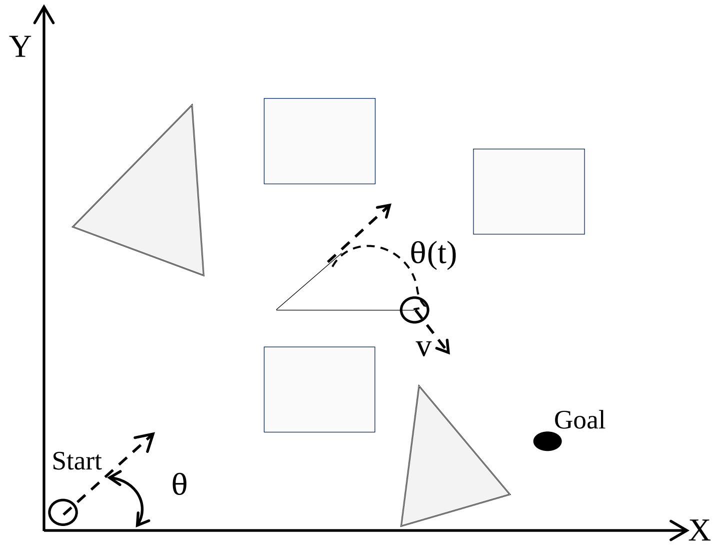

Fig. 4 Robot navigation in the presence of obstacles

If there are no obstacles and assumption (b) is not taken into account then the robot would instantly turn toward the goal at the start of its motion and then move directly toward it. For this reason, the following navigation law is given by [9];

$$\dot{\theta}(t) = -\eta[\theta(t) - \theta^{*}(t)] \tag{6}$$

Where, η is a positive constant.

Since this process can be used not only to navigate the robot to its goal, but also to avoid obstacles by switching $\theta^{*}(t)$ based on the information available from the three distance sensors, $\theta^{*}(t)$ is called the steering angle command.

For considering the obstacles avoidance behaviour of WDMR, the information about the obstacle's distance from the robot, the distance sensors are taken for calculation the distances of the obstacles from the robot position. Let D_c, D_r and D_l be the distances in the center, right and left directions, as shown in Fig.5, where D_r and D_l are inclined from the center by an angle α. Assuming the maximum measurable range of the distance sensors is D_{max}. When the sensor does not detect an obstacle or the distance is greater than D_{max} , the sensor produces a negative output -1.

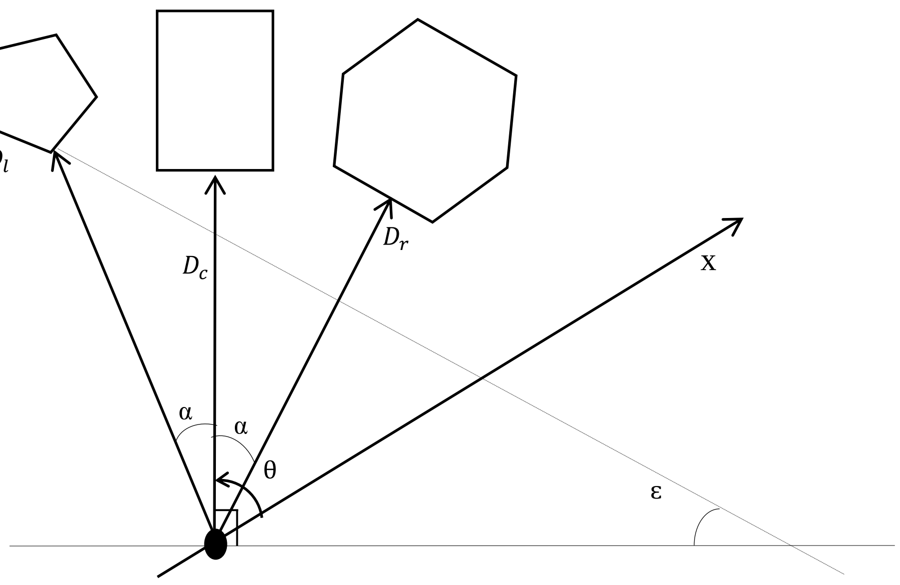

Fig. 5 Obstacles avoidance behaviour

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When the obstacles are detected in the three directions, and $D_l \geq D_r$ as shown in Fig.5 the distance in the left direction is greater than in the right direction and the robot should steer to the left. Letting ε be the angle shown in Fig. 5, the robot should turn to the left by $\frac{\pi}{2} - \varepsilon$ to avoid the obstacle, and when$D_l < D_r$, the robot should turn to the right by $\frac{\pi}{2} - \varepsilon$. Embedding this avoidance behaviour into the navigation control law (6), the desirable steering angle for avoiding the obstacle$\theta^*(t)$ is given by

$$\theta^*(t) = \theta(t) + \mathrm{sgn}(D_l - D_r)\left(\frac{\pi}{2} - \varepsilon\right) \quad (7)$$

Where;

$$\varepsilon = \tan^{-1}\left(\frac{(D\cos\alpha - D_{c,})}{D\sin\alpha}\right) \qquad \left(|\varepsilon| < \frac{\pi}{2}\right) \quad (8)$$

$$D \triangleq \max(D_r, D_l) \quad (9)$$

$$\mathrm{sgn}(x) = \begin{cases} +1 & (x \geq 0) \\ -1 & (x < 0) \end{cases} \quad (10)$$

The above equations are used in conjunction with the heuristic rules that have been formulated based on the human perception are embedded in the algorithm to design the control software.

III. RESULTS AND DISCUSSION

A series of simulations tests have been conducted using MATLAB software package. To demonstrate the effectiveness and the robustness of the proposed method, simulation results on mobile robot navigation in various environments are exhibited. The simulation result obtained with the proposed algorithm without obstacles present in the environment is shown in Fig. 6. It shows that target seeking behaviour is activated by using perception base heuristic rules introduced into the MATLAB software for WMR.

The obstacle avoidance behaviour is activated by using perception based heuristic rules (Table 4.1) introduced into the control software. When arrays of sensors receive the information about the object which is too close to the robot, it avoids a collision by moving away from it in the opposite direction. In this case, the obstacle avoidance behaviour is activated when the readings from any sensor is less than the minimum threshold value. The simulation result for obstacle avoidance has been shown in Fig. 7.

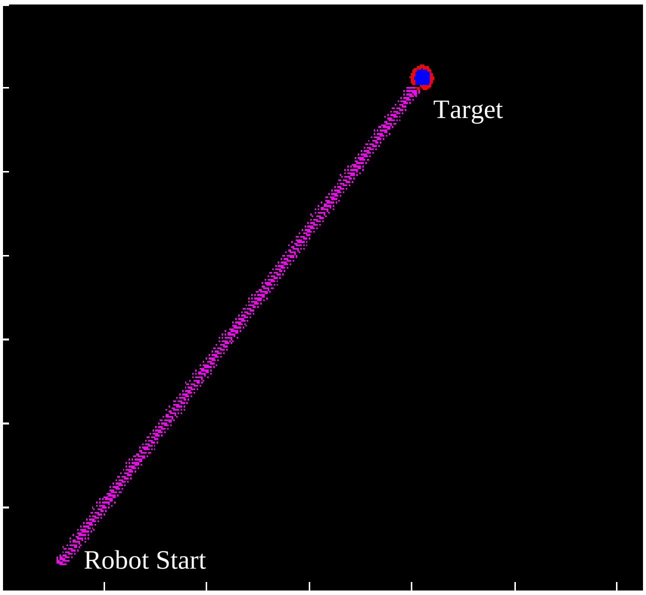

Fig. 6 Simulation result for target seeking

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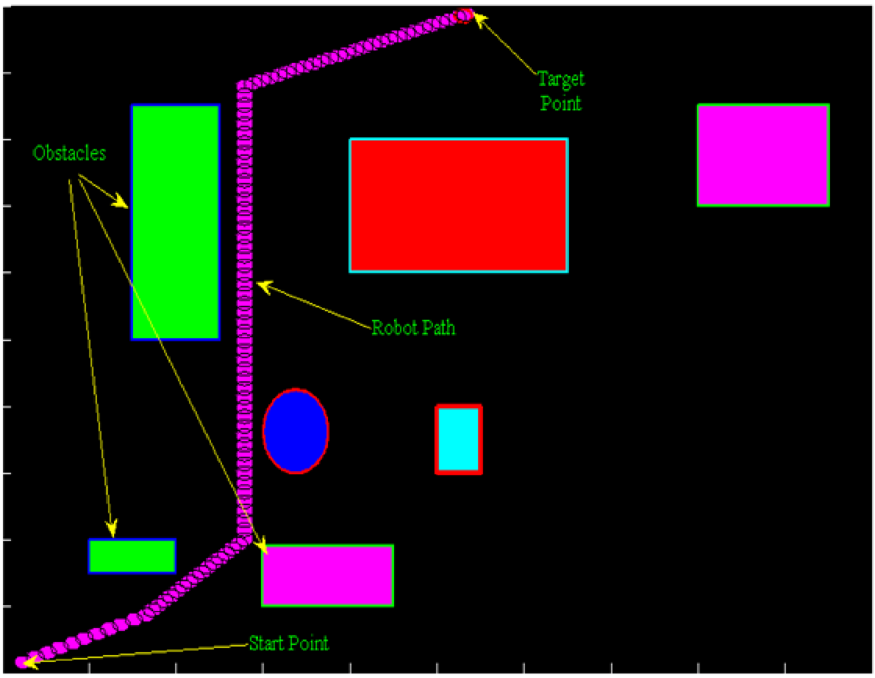

Fig. 7 Simulation result for obstacle avoidance

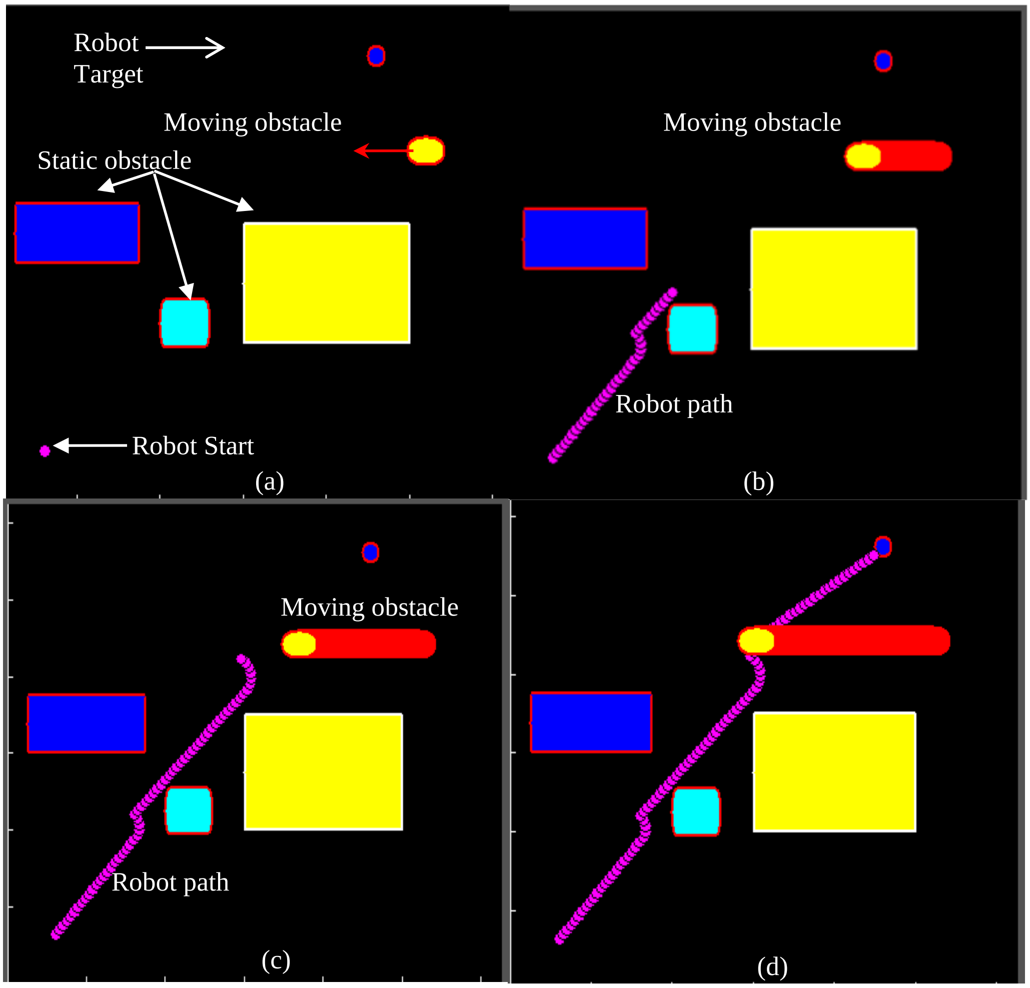

Fig. 8 Simulation result of perception based heuristic rule network in dynamic environment

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Figure 8 (a) shows that three static and one moving obstacles are present in the environment. The robot velocity has been taken 0.38m/s and the moving obstacle velocity has been adjusted at 0.2m/s for the simulation result. Fig. 8 (b) shows the simulation result obtained at time intervals of 3 seconds where the robot starts from its initial position and moves towards the target. It avoids the static obstacles with minimum clearance.

When the robot detects moving obstacles present in the environment, it calculates the speed of the moving obstacle and adjusts its own speed accordingly to avoid the moving obstacle [Fig.8 (c)] & (d) shows the traced optimized path followed by the WDMR avoiding static as well as moving obstacles. Simulation result shows that the feasibility of the proposed methodology.

The result of proposed HRBC for path analysis and planning of WDMR has been compared with the simulation result published in the previous research for path planning of autonomous mobile robot navigation in the same environment as shown in Fig. 9. The comparison of result shows that the proposed method is effective and working efficiently and is better than the algorithm developed by Porta et al. [10]. In fact Porta et al. [78] have given the algorithm for static environment (no moving obstacles are present) only, the proposed algorithm is however applicable for static as well as moving obstacles present in the environment. By comparing of the simulation result it is found that the percentage of improvement in path optimization from the proposed algorithm which is 14.21 less than the result obtained by Porta et al. [10] in the same environment which is in good agreement. Hence the algorithm developed in paper has much wide application as it takes care of many obstacles also in its path.

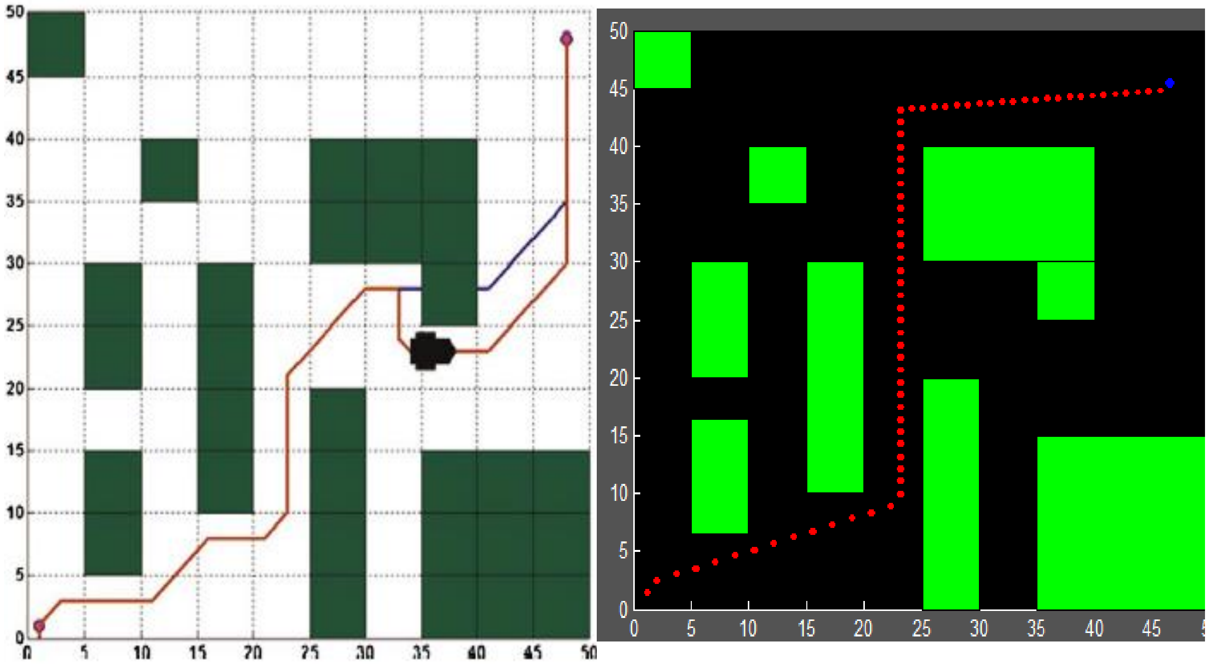

Fig. 9 Simulation result of Porta et al. [78] for path planning of an autonomous mobile robot (b)Simulation result of proposed method for path analysis and planning of WDMR

IV. CONCLUSIONS

In this research proposal, attempt has been made to solve the problem related to path analysis and planning of WDMRs in various environments. The above investigation has been carried out in several stages.

1. From the kinematic analysis of WMR, left wheel and right wheel velocities of the mobile robot has been calculated. On the basis of left wheel and right wheel velocities, steering angle can be calculated by proposed mathematical modeling of WMR.
2. Human perception based heuristic rules have been formed. A human perception based heuristic rule base controller has been proposed for path analysis and planning problem of WMR which provides safe, robust and optimized path. From the demonstrated results of path optimization of WMR, avoiding the static as well as moving obstacles, the algorithm effectiveness is proven.
3. The proposed algorithm may be used to design an intelligent driverless vehicle for public as well as for goods transport.

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