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Wheeled Mobile Robot Trajectory Planning Using Evolutionary Techniques

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ABSTRACT: This paper proposes two multi-objective trajectory planning optimization algorithms namely Multi Objective Differential Evolution (MODE) and Elitist Non-dominated Sorting Genetic Algorithm (NSGA-II). They are applied for a differential drive wheels mobile robot (WMR). A cubic NURBS curve is used to constitute the mobile robot's path. The objective functions considered are travel time, traveled length and actuators efforts. All objective functions are to be minimized. The constraints considered are mobile robot's kinematic limits, obstacle avoidance and dynamic limits. Two Stationary and five moving obstacles are present around the robot. Experimental and numerical simulations results are examined and compared.

Keywords: optimal trajectory; differential drive, WMR; MODE; NSGA-II, NURBS.

I INTRODUCTON

For many applications in indoor besides outdoor environments, WMR are used. They are applications in both structured and unstructured environments. Trajectory planning is a crucial issue in planner module of mobile robot design. One of the work of planner module is motion planning. This module prepares trajectory planning. The trajectory planning for WMR's main goals are: robot travel time and travelling distance are to be very minimum. Further, energy spent by WMR during travelling has to be very minimum. During the movement of the mobile robot, WMR has to avoid few obstacles. They may be fixed or moving type. For a smooth besides practical trajectory planning, both constraints of kinematic and dynamic parameters of WMR have to be taken into account. The trajectory planning problem is creating an optimal trajectory by optimizing few objective functions namely travelling time, travelling distance and actuator efforts and also by satisfying few kinematic and dynamic bounds besides obstacle avoidance.

For saving energy many researchers have used many criteria like minimum trajectory length, loss of kinetic energy, kinetic energy, steering actions, potential energy of mobile robot actuators, actuator efforts, motor energy consumption, smoothness of trajectory, etc. In this work, minimum travelling time, minimum travelling distance and minimum actuators efforts are considered to save mobile robot travelling time and energy.

Based on environment's nature present around the mobile robot, trajectory planning is prepared in both off-line besides online. Suppose the environment is already known and structured, off-line mode motion planning is best. Same time, for unstructured as well as unknown environment, the best one is online motion planning. All researchers used lot of implicit and explicit algorithms. Further, more traditional type and intelligent type algorithms are practised by many researchers [1-7]. In general traditional optimization algorithms give sub optimal solutions and intelligent algorithms give optimal solutions. Evolutionary algorithms like Genetic Algorithm (GA), Differential Evolution (DE), NSGA-II and few GA variants are generating optimal solutions. The optimal solutions may be global optimal solutions.

In this research work, two algorithms namely NSGA-II and MODE have been utilized for multi-objective trajectory planning of WMR. A function of cubic NURBS utilized to represent the trajectory of WMR. The objective functions considered are travel time, traveled length and actuators efforts. All objective functions have to be minimized. The considered constraints are obstacle avoidance, kinematic parameters' and dynamic parameters' limits of WMR. Stationary type and moving type hurdles are considered. The robot is a Differential drive WMR (DDWMR) type. Experimental and numerical simulation results arrived were analyzed and compared.

The rest of the paper is arranged as follows: Next section (section 2) outlines the problem formulation. Next following section (Section 3) briefs optimization strategies (NSGA-II and MODE). Section 4 presents an experimental and numerical simulation for a DDWMR with two stationary and five moving obstacles. Problem results are detailed and discussed. The conclusions are noted in section 5.

II PROBLEM FORMULATION

2.1 Optimization model

The goal is WMR has to go from starting location place to target location place by avoiding seven obstacles (two stationary and five moving). WMR's motion is to be accomplished by minimizing traveling time and actuator efforts. Also minimizing trajectory distance has to be considered to get shortest path. To get a feasible, practical and smooth trajectory mobile robot's kinematic and dynamic bounds are to be satisfied.
The problem representation in optimization format is given below:
Performance criteria considered are
Objective function number 1 is minimization of traveling time: $f_{obj1} = \int_0^T dt$ (1)
Objective function number 2 is minimization of actuator efforts: $f_{obj2} = \int_0^T \sum_{i=1}^{2} (\frac{\tau_i(t)}{\tau_i^{max}})^2 \, dt$ (2)
Third objective function is minimization of traveling distance= $f_{obj\,3}=\sum_{i=0}^{t} di$ (3)

Constraints considered are:
1. WMR Geometric constraints:
   Starting and final postures i.e. path end points (starting and finishing)
2. Avoidance of obstacles constrained = distance of WMR from obstacles > 0
3. Kinematic constraints:
   (a) Speed of WMR at starting and finishing location = 0
   (b) WMR velocity < WMR's maximum velocity
   (c) WMR acceleration < WMR's maximum acceleration
   (d) WMR jerk < WMR's maximum jerk
4. Dynamic Constraints
   WMR motors' torque < WMR motors' maximum torque

2.2 Description of the DDWMR

The DDWMR has four wheels (2 independent active type + 2 supporting passive type). DDWMR geometrical details are presented in Fig. 1. Fig. 2 explains mobile robot obstacle avoidance with moving obstacles. The operational configuration WMR in a frame (O,X,Y,Z) is characterized by the following formula. Here (x,y)= centre point of WMR and θ =an angle of rotation with respect to Z axis.

$$\mathbf{q} = [x, y, \theta]^T \tag{4}$$

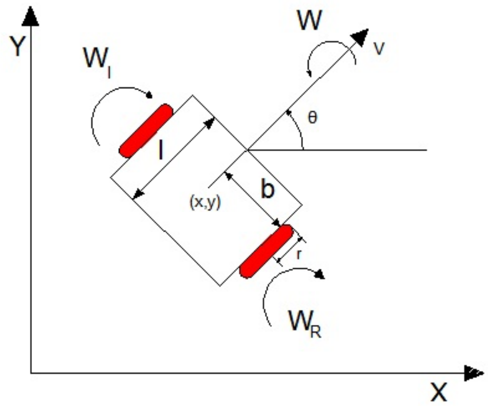

Fig. 1. Geometrical representation of WMR.

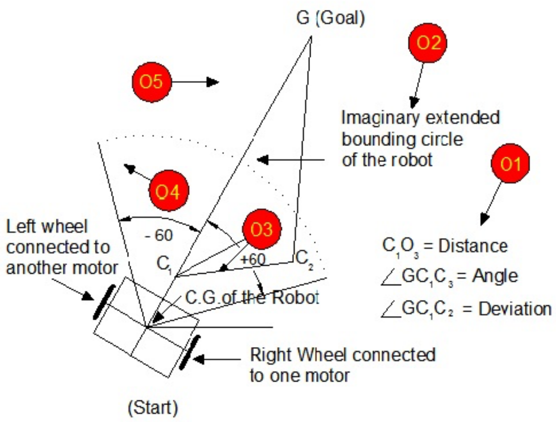

Fig. 2. Robot motion among moving obstacles.

2.3 Trajectory representation

Starting point of WMR's path, its destination point and must pass through intermediate points are received as inputs. Based on these details, robot trajectory is specified. A cubic NURBS curve with 4 control points gives a shape to the trajectory.

NURBS curve has some useful properties viz. smoothness and local modifications possibility, which make possible definition of robot trajectories. Also, these NURBS curves' properties are good for complicated geometry design, promising them a novel tool in computer assisted drawing and design (CADD) and Computer aided manufacturing (CAM) and computer graphics fields.

NURBS is characterized parametrically by the equation mentioned below:

$$P(u) = \frac{\sum_{i=0}^{n} N_{i,k}(u) w_i B_i}{\sum_{i=0}^{n} N_{i,k}(u) w_i} \qquad (5)$$

III PROPOSED APPROACHES

Two evolutionary type optimization techniques such as NSGA-II [8] and MODE [9] are employed for getting an optimal trajectory planning of WMR with fixed and moving obstacles are described. Fig. 3 outlines numerical procedure used to solve this optimal trajectory planning problem. Normalized weighed objective functions (NWOF) method is used to identify which the best solution from all non-dominated solutions available in Pareto optimal front resulted by MODE and NSGA-II. The performance measures of multi-objective optimization such as ratio of non-dominated individuals (ROI) and solution spread measure (SSM) are incorporated in the solution algorithm for evaluating the Pareto optimal fronts' strength. Also, two performance measures of multi-objective optimization - algorithm effort (AE) and optimiser overhead (OO) are used for finding out the NSGA-II and MODE algorithms' computational effort.

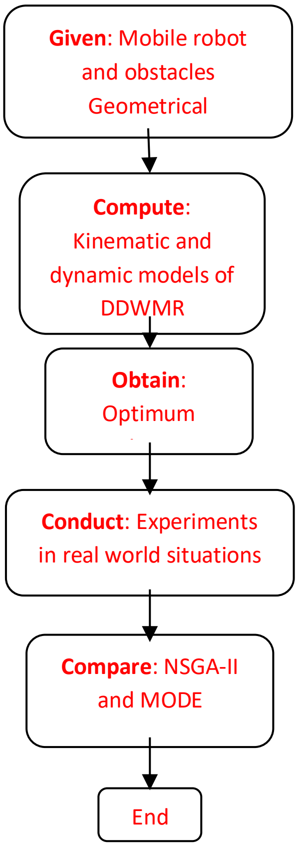

Fig. 3. Numerical procedure available in this optimal trajectory planning.

IV SIMULATION RESULTS

The kinematic model of the DDWMR available in previous work is used. All necessary geometrical details of WMR namely wheel radius, robot mass, moment of inertia are measured for a custom developed and our own WMR. Active wheels have individual DC motor. Passive wheels are not having motors. Other necessary gadgets namely Arduino board and electronics components are incorporated for a better WMR's control and programming.

Table 1. Results of Algorithms.

	$f_{obj\ 1}$	$f_{obj\ 2}$	$f_{obj\ 3}$	Combined Objective Function (COF)
NSGA-II	10.5s	53.5J	53cm	38.961
MODE	9.8s	49.7J	49cm	36.131
	RNI	SSM	AE	OO
NSGA-II	0.018	0.784	0.21	0.153
MODE	0.019	0.752	0.20	0.151

First simulations have been executed using the proposed evolutionary techniques such as NSGA-II and MODE. Next step is that the resultant optimal trajectories are taught to the robot through Arduino programming. Now the mobile robot executes the desired motion. The results namely travelling distance, travelling time and WMR actuator efforts are observed (Table 1). A comparison is made. Simulation results in this problem proved that the NSGA-II and MODE algorithms are best for finding out optimal trajectory planning of DDWMR. The RNI and SSM are used for evaluating the Pareto optimal fronts' strength. The AE and OO are used for finding out the NSGA-II and MODE algorithms' computational effort. Pareto optimal fronts made by NSGA-II and MODE are analyzed and compared. Again, results from NSGA-II and MODE are examined and analyzed.

From the observed results, the information derived: (a) NSGA-II and MODE optimization algorithm gave a best optimal front for the better user choice. So, as per the user choice, the best optimal solution was taken, (b) Also, no. of solutions in optimal fronts was good, (c) NSGA-II and MODE algorithms' computational effort was good, (d) Simulation experiments proved the point - NSGA-II and MODE are best algorithms for doing optimal trajectory planning for DDWMR.

V CONCLUSIONS

The proposed approach finds optimal trajectory planning using two evolutionary optimization approaches such as NSGA-II and MODE for a custom made DDWMR. Cubic NURBS curve used to give a shape for the trajectory. The obstacle avoidance, geometric, kinematic, dynamic parameters' constraints are imposed. Seven obstacles (two stationary and five moving obstacles) have been considered. Minimization of traveling distance and time, actuators efforts are considered as objective functions. The performance measures of multi-objective optimization -RNI and SSM are used for evaluating Pareto optimal fronts' strength. The performance measures of multi-objective optimization such as AE and OO are used for finding out NSGA-II and MODE algorithms' computational effort. Pareto optimal fronts generated by NSGA-II and MODE are analyzed and compared. Also results gave by NSGA-II and MODE are analyzed and compared. Simulation experiments proved the point - NSGA-II and MODE are best algorithms for doing optimal trajectory planning for DDWMR.

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