CHAPTER 9

CONCLUSIONS AND SCOPE FOR FUTURE WORK

The main objective of this research work is to develop a novel general methodology based on evolutionary technique for the off-line tri-dimensional optimal trajectory planning of industrial robot manipulators in the presence of fixed, moving and oscillating obstacles with payload constraints.

The following robot manipulators are considered in this work:

1. 2-link planar robot
2. 3-link planar robot
3. PUMA560 robot
4. STANFORD robot
5. MTAB ARISTO 6XT robot
6. ADEPTONE XL robot

The procedure developed in this work to generate an optimal trajectory plan is a better one in all aspects. It has the following advantages:

1. It can generate a global optimal solution.
2. It considers all important decision criteria for trajectory planning of industrial robot manipulators.
3. It is easier to program and implement efficiently when compared to the methods available in the literature.
4. It ensures that the resulting trajectory is a smoother, faster, safer, non-singular one and requires minimum actuators effort and power.

5. It considers both kinematic and dynamic aspects of the robot.

6. It is computationally superior and faster than the methods available in the literature.

7. It gives Pareto optimal fronts that offer more number of optimal solutions for user’s choice.

8. It can also be extended to get optimised trajectory of other types of robots.

Special features of the methodology used in this work are as follows:

- Cubic polynomial, B-spline and NURBS curves are used to define the trajectory.

- Obstacle avoidance is obtained by adding penalty functions to the multicriterion objective function. When dealing with fixed and moving obstacles all the objective functions and the constraint functions have to be up-dated simultaneously at each time instant.

- Evolutionary Algorithms such as GA, NSGA-II, DE and MODE are used.

- Both normalised weighting objective functions approach and average fitness factor method are used to select the best optimal solution from Pareto optimal fronts.
Two multi-objective performance measures viz., solution spread measure and ratio of non-dominated individuals, are used to evaluate the strength of Pareto optimal fronts.

Two multi-objective performance measures namely optimiser overhead and algorithm effort are used to find the computational effort of NSGA-II and MODE algorithms.

The Pareto optimal fronts (optimal solution trade-offs) and results obtained from various techniques are compared and analysed. The results indicate that:

1. Cubic NURBS curve is better than cubic polynomial and cubic B-spline curves in representing robot trajectories.

2. The proposed evolutionary techniques are superior to conventional techniques in all the problems.

3. In majority of cases, MODE technique is better than GA and NSGA-II.

4. MODE technique gives minimum optimiser overhead (OO) and minimum algorithm effort than those of NSGA-II. Also the computational time to find optimum solutions in MODE is 1/3rd of that of NSGA-II. So it is faster than NSGA-II technique. So MODE technique is better, if the user wants the better optimal solution quickly.

5. But NSGA-II technique gives maximum average fitness factor ($F_{avg}$), minimum solution spread measure (SSM), maximum ratio of non-dominated individuals (RNI) than those of MODE. Also NSGA-II gives the better Pareto optimal front with more number of non-dominated solutions for user’s
choice than MODE. So NSGA-II technique is better, if the user wants more choices for the selection of best optimal solution.

6. In all stages except in stage 8, the trajectory has number of intermediate points. The robot joints should pass through them. So obtained optimal trajectory is a practical one.

This work opens the door for further investigations on how the evolutionary optimisation techniques can be used to solve complex problems.

SCOPE FOR FUTURE WORK

- Higher order NURBS curve could be used to represent the trajectory.
- Shape changing obstacles during motion could be considered.
- Online multi-objective trajectory planning for industrial robots in the presence of obstacles could be considered.
- Multi-objective trajectory planning for mobile robots in the presence of obstacles could be considered.
- Multi-objective trajectory planning for cooperative robots in the presence of moving obstacles could be considered.