DEPARTMENT OF MECHANICAL AND MATERIALS ENGINEERING

Parallel-Populations Genetic Algorithm for the Optimization of Cubic Polynomial Joint Trajectories for Industrial Robots

Fares J. Abu-Dakka, Iyad F. Assad, Francisco Valero, and Vicente Mata

Centro de Investigación de Tecnología de Vehículos (CITV)
Departamento de Ingeniería Mecánica y de Materiales (DIMM)
Universitat Politècnica de València

1.- Objective

- The main objective of this paper is to obtain minimum-time trajectories for industrial robots using parallel populations genetic algorithms. Subjected to:
  - Physical constraints: joint velocities, accelerations, and jerks.
  - Dynamic constraints.

2.- Modeling

Tow parallel populations genetic algorithms has been implemented.

- PGA1: will resolve the cubic polynomial joint trajectory formulated by Lin, et. all. [1]. where only kinematic constrains are considered. Zero velocities and accelerations at the ends are considered.

$$A \begin{bmatrix} Q_2''(t_2) \\ Q_3''(t_3) \\ \vdots \\ Q_{n-1}''(t_{n-1}) \end{bmatrix} = Y$$

$$A = \begin{bmatrix} a_{11} & a_{12} & & & & & \\ a_{21} & a_{22} & a_{23} & & & & \\ & a_{32} & a_{33} & a_{34} & & & \\ & & & \vdots & & & \\ & & & & a_{n-3,n-4} & a_{n-3,n-3} & a_{n-3,n-2} \\ & & & & & a_{n-2,n-3} & a_{n-2,n-2} \end{bmatrix}, Y = \begin{bmatrix} y_1 \\ y_2 \\ y_i \\ \vdots \\ y_{n-3} \\ y_{n-2} \end{bmatrix}$$

[1] Lin, C.-S., Chang, P.R., Luh, J.y.S.: Formulation and optimization of cubic polynomial joint trajectories for industrial manipulators. IEEE Trans. Automat. Contr. AC-28(12), 1066–1074 (1983)

2.- Modeling

Tow parallel populations genetic algorithms has been implemented.

- PGA1: will resolve the cubic polynomial joint trajectory formulated by Lin, et. all. [1]. where only kinematic constrains are considered. Zero velocities and accelerations at the ends are considered.
- PGA2: will resolve the clamped cubic spline algorithm. where kinematic and dynamic constrains are considered. Zero velocities at the ends are considered.

$$A \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_{n-1} \end{bmatrix} = Y$$

$$A = \begin{bmatrix} 3h_1 & h_1 & & & & \\ h_1 & 2(h_1+h_2) & h_1 & & 0 & \\ & h_2 & 2(h_2+h_3) & h_3 & & \\ & & & \vdots & & \\ & 0 & & h_{n-2} & 2(h_{n-2}+hn-1) & h_{n-1} \\ & & & & h_{n-1} & 2h_{n-1} \end{bmatrix}$$

$$Y = \begin{bmatrix} \frac{3}{h_1}(a_2-a_1) - 3\dot{q}_1 \\ \frac{3}{h_2}(a_3-a_2) - \frac{3}{h_1}(a_2-a_1) \\ \vdots \\ \frac{3}{h_{n-2}}(a_{n-1}-a_{n-2}) - \frac{3}{h_{n-3}}(a_{n-2}-a_{n-3}) \\ 3\dot{q}_{n-1} - \frac{3}{h_{n-1}}(a_n-a_{n-1}) \end{bmatrix}$$

[1] Lin, C.-S., Chang, P.R., Luh, J.y.S.: Formulation and optimization of cubic polynomial joint trajectories for industrial manipulators. IEEE Trans. Automat. Contr. AC-28(12), 1066–1074 (1983)

3.- Genetic Algorithm

Genetic Algorithm :

- Parallel Genetic Algorithm
- Chromosome
- Selection
- Objective Function
- Crossover
- Mutation

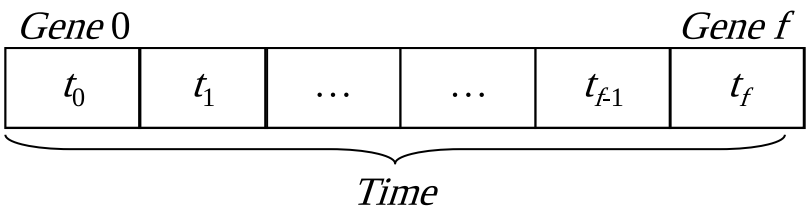
- Parallel population used with migration technique.
- Has multiple independent populations.
- Each population is developed using SSGA.
- In every generation, some individuals migrate from one population to another.
- Each population migrates a fixed number of their best individuals to its neighbor.
- The main population is updated every generation with the best individual in each population.

- Restrictions:
  - Physical: Velocity, Acceleration, Jerk.
  - Dynamical: Torque, Power, energy.

3.- Genetic Algorithm

Genetic Algorithm :

- Parallel Genetic Algorithm
- Chromosome
- Selection
- Objective Function
- Crossover
- Mutation

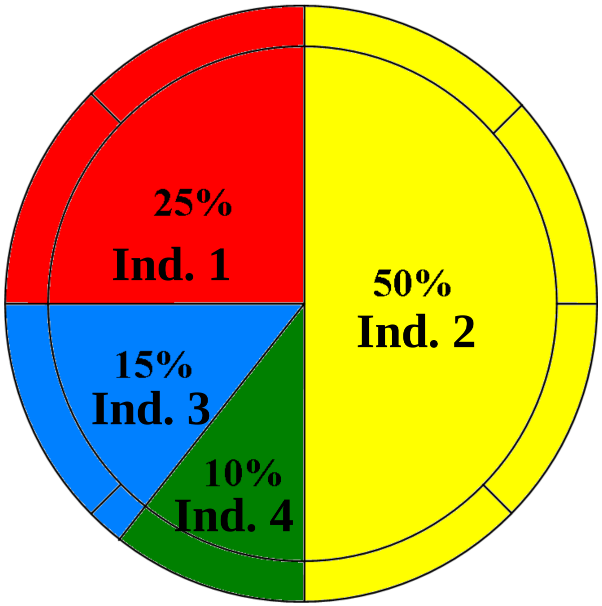


$$gene(i) = RV(t_{j,\min},\ t_{j,\max});$$

3.- Genetic Algorithm

Genetic Algorithm :

- Parallel Genetic Algorithm
- Chromosome
- Selection: roulette wheel
- Objective Function
- Crossover
- Mutation



Roulette wheel selection assign probabilities according to the degree of adaptation of the chromosomes. The roulette wheel selection allows the best individuals to be chosen with a higher probability.

3.- Genetic Algorithm

Genetic Algorithm :

- Parallel Genetic Algorithm
- Chromosome
- Selection
- Objective Function $$t = \sum_{i=1}^{f} t_{pk,i}$$
- Crossover
- Mutation

3.- Genetic Algorithm

Genetic Algorithm :

- Parallel Genetic Algorithm
- Chromosome
- Selection
- Objective Function
- Crossover
- Mutation

$$a_i = (mom_j + dad_j)/2$$

$$gene_j^{Bro} = a_j \times gene_j^{Dad} + (1 - a_j) \times gene_j^{Mom}$$

$$gene_j^{Sis} = a_j \times gene_j^{Mom} + (1 - a_j) \times gene_j^{Dad}$$

3.- Genetic Algorithm

Genetic Algorithm :

- Parallel Genetic Algorithm
- Chromosome
- Selection
- Objective Function
- Crossover
- Mutation $gene_j = gene_j + RV(t_{j,\min}, t_{j,\max}) \times [RV(t_{j,\min}, t_{j,\max}) - RV(t_{j,\min}, t_{j,\max})]$

4.- Results

Example 1: Comparison of Results with [1] & [2].

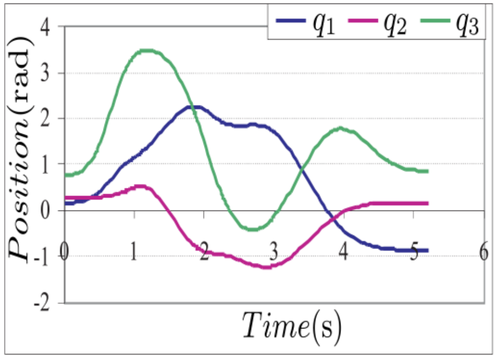
- Path with 10 configurations includes the initial and final.
- The restrictions are the velocity, acceleration, and jerk.

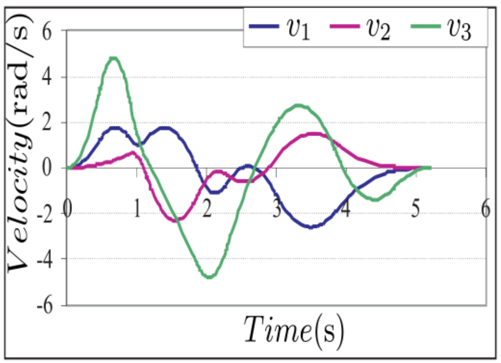
Crossover Probability = 0.95	Mutation Probability						
	0.001	**0.01**	**0.05**	**0.1**	**0.2**	**0.3**	**0.4**
Tse and Wang 1998	20.156	19.880	18.211	18.226	18.929	18.957	19.062
PGA1	19.159	19.578	18.010	18.205	18.121	18.039	18.162
PGA2	18.091	17.726	17.706	17.971	17.896	17.897	17.931
Avg. Comp. Time	1128	1714	6339	9857	19267	29625	45192

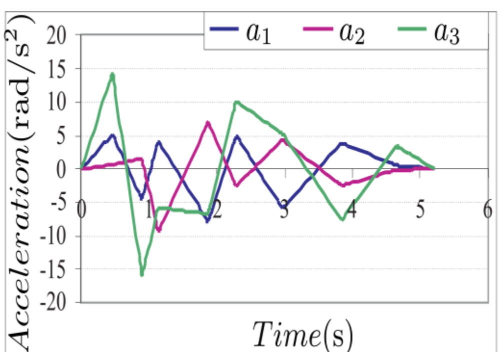
[1] Lin, C.-S., Chang, P.R., Luh, J.y.S.: Formulation and optimization of cubic polynomial joint trajectories for industrial manipulators. IEEE Trans. Automat. Contr. AC-28(12), 1066–1074 (1983)

[2] Tse, K.-M., Wang, C.-H.: Evolutionary Optimization of Cubic Polynomial Joint Trajectories for Industrial Robots. In: IEEE International Conference on Systems, Man, and Cybernetics, San Diego, CA, USA. 4, pp.3272–3276 (1998)

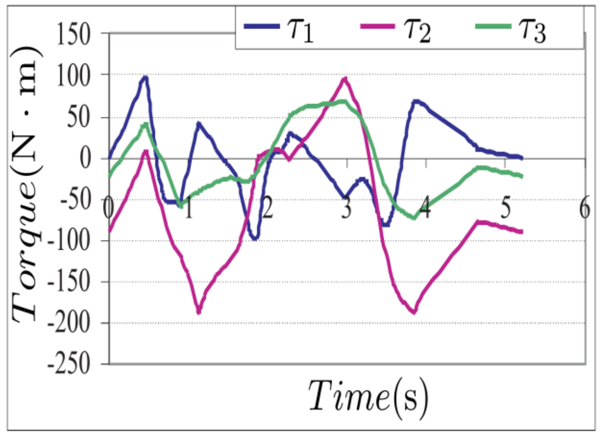
4.- Results

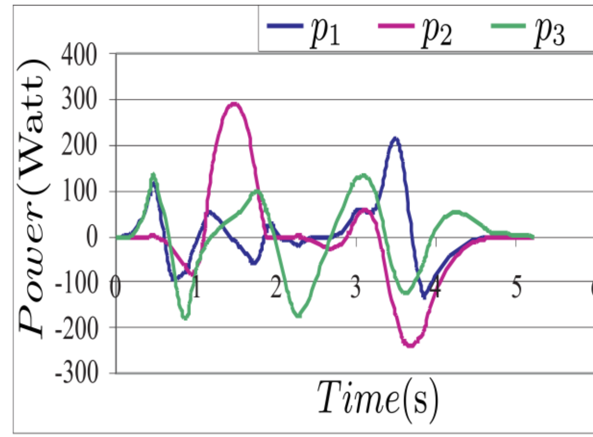






Example: Indirect Method.





- The limitations of torque (in *N.m*) are: $\tau_1 \le |140|$, $\tau_2 \le |180|$, $\tau_3 \le |140|$, $\tau_4 \le |80|$, $\tau_5 \le |80|$, $\tau_6 \le |40|$.
- The limitations of power (in *Watt*) are: $Pot_1 \le |275|$, $Pot_2 \le |350|$, $Pot_3 \le |275|$, $Pot_4 \le |150|$, $Pot_5 \le |150|$, $Pot_6 \le |75|$.

5.- Conclusions

- In this paper a parallel-populations genetic algorithm procedure with migration technique has been implemented to find the minimum time trajectories for industrial robots using cubic spline with different end conditions.
- The algorithm has been validated and evaluated by comparing the results with the results of the other works of other authors.
- The presented algorithm is capable to solve the minimum time trajectory problems with dynamic constraints as shown in example 2.
- In further work, it will be interesting to apply the presenting parallel-populations genetic algorithm procedure to trajectories with different interpolation functions, such as 5^{th}-order B-splines, harmonic, etc.

DEPARTMENT OF MECHANICAL AND MATERIALS ENGINEERING

Parallel-Populations Genetic Algorithm for the Optimization of Cubic Polynomial Joint Trajectories for Industrial Robots

Fares J. Abu-Dakka, Iyad F. Assad, Francisco Valero,
and Vicente Mata

Centro de Investigación de Tecnología de Vehículos (CITV)
Departamento de Ingeniería Mecánica y de Materiales (DIMM)
Universitat Politècnica de València