23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

THE INFLUENCE OF THE LENGTH OF TRAJECTORY OF SCARA MANIPULATOR DUTY CYCLE ON ELECTRICITY CONSUMPTION

D. Cekus[*], D. Skrobek[**]

Abstract: *The paper presents the using of Particle Swarm Optimization (PSO) method to determine the shortest trajectory of the end-effector of SCARA manipulator. It has been assumed that the obstacles occur in the workspace, but the transfer above them is impossible, therefore the problem is considered in two-dimensional space. In the PSO algorithm the impact of the inertia weight of the length of the searched minimal trajectory has been shown. For found out trajectory the electricity consumption required to execute a duty cycle of SCARA manipulator has been determined. Only theoretical considerations were conducted.*

Keywords: PSO, SCARA, Manipulator, Optimization, Electricity consumption.

1. Introduction

Lots of engineering problems have the form of optimization tasks. So-called heuristic methods are helpful for complex optimization problems. In this paper, using the Particle Swarm Optimization (PSO) method (Kennedy el al., 1995), the optimal trajectory between two defined points for the SCARA manipulator (Fig. 1a) has been determined. In the analyzed problem, the manipulator has to perform a duty cycle consisting in the movement of the end-effector between two points, but obstacles appear on the path (Fig. 1b). It was assumed that the height of the obstacles prevents the transfer of the elements above them which the problem reduced to the two-dimensional space.

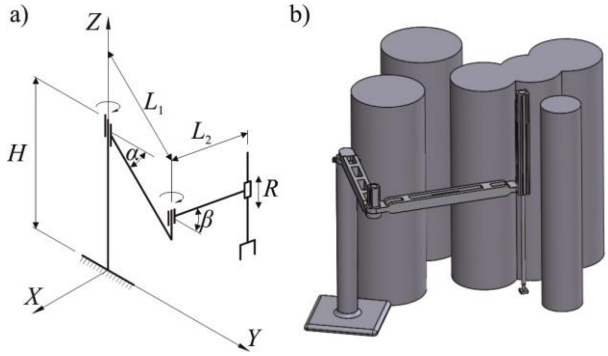

Fig. 1: SCARA manipulator: a) kinematic diagram; b) exemplary working environment.

Determination of the minimal path allows for shortening the time of working cycle, but not to minimize energy consumption, as shown in subsequent chapters of this paper.

2. Formulation and solution of the problem

The first stage of the work is to determine the shortest trajectory of the duty cycle. For this purpose, the PSO method has been used. The following parameters of the PSO algorithm have been adopted: the number of iterations (It) = 200, the population size = 150, the number of points creating the path (without the start and end point) = 10. Using the PSO method, the results also depend on the so-called

[*] Assoc. Prof. Dawid Cekus Phd. Eng., Institute of Mechanics and Machine Design Foundations, Czestochowa University of Tehnology, Street Dąbrowskiego 73; 42-201, Częstochowa; PL, cekus@imipkm.pcz.pl

[**] M.Sc. Eng. Dorian Skrobek., Institute of Mechanics and Machine Design Foundations, Czestochowa University of Tehnology, Street Dąbrowskiego 73; 42-201, Częstochowa; PL, skrobek@imipkm.pcz.pl

"the inertia weight". In this work, the inertia weight was calculated according to the equation (Ao et al., 2010, Ting et al., 2012, Lin et al., 2003, Storn et al., 1997):

$$w = w_0 \exp\left(-a\left(\frac{It}{MaxIt}\right)^b\right), \tag{1}$$

where: w_0 = 0.9; *It* - the current iteration, *MaxIt* - the maximum number of iterations, *a* - local search attractor, *b* - global search attractor. In the present study, the optimal trajectory has been determined for three different values of the parameter *a* and *b* (Fig. 2).

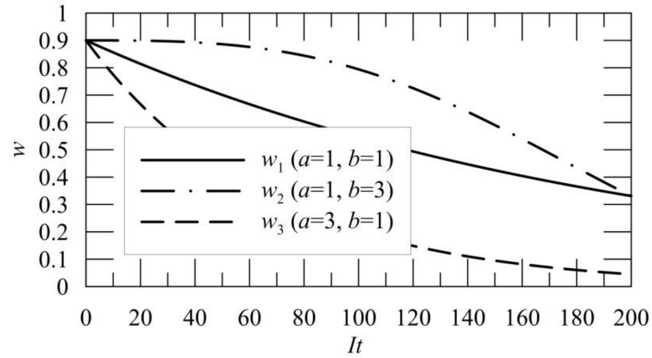

Fig. 2: The value of the inertia weight during subsequent iterations of the PSO algorithm.

For the accepted value of parameters of inertia weight, the following lengths of trajectory have been obtained: 1407.0379 mm (for w_1), 1407.0066 mm (for w_2) and 1406.8273 mm (for w_3). The shortest trajectory (for w_3) with the selected positions of arms L_1 and L_2 is shown in Fig. 3. The position of manipulator arms has been calculated on the basis of inverse kinematics (Cekus et al., 2015).

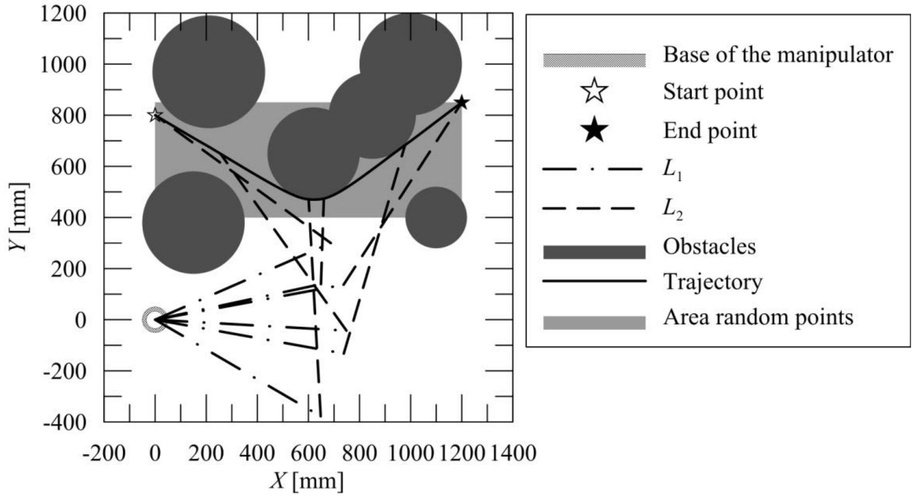

Fig. 3: The determined shortest trajectory with the selected positions of arms L_1 and L_2.

The next stage of the research was to determine the electricity consumption of manipulator drives for the calculated trajectories. It was assumed that for the initial time t = 0 s, the electricity consumption is equal to zero (E_c = 0 J). Total electricity consumption (Kucuk, 2013, Posiadała et al., 2015, Ur-Rehman et al., 2010) is integral of function of total instantaneous power (P_T) within the limits of the considered time <0, t_k>:

$$E_C = \int_o^{t_k} P_T dt\,. \tag{2}$$

It is accepted that the execution time (t_k) each operating cycle is equal to 100 s, despite the different lengths of trajectories.

The total instantaneous power is the sum of the momentary power of individual drives:

$$P_T = \sum_{i=1}^{2} P_i\,. \tag{3}$$

When the drive is in motion, i.e. the angular velocity exists, the momentary power of a single drive is defined as follows:

$$P_i = P_i^{(R)} + P_i^{(L)} + P_i^{(EM)}. \tag{4}$$

Otherwise, the instantaneous power is constant.

The first component of the sum (4) is responsible for losses arising from the winding resistance of the drive. The second component of the sum (4) defines the losses caused by self-induction. The third component of the sum (4) determines the power used to generation of electromotive force.

$$P_i^{(R)} = R_i I_i^2, \; P_i^{(L)} = \left| L_i I_i \dot{I}_i \right|, \; P_i^{(EM)} = \left| I_i U_i \right|, \tag{5}$$

where: R - resistance, L – inductance, U - electromotive force.

Values occurring in equations (5) characterizing the electric current are functions of time and depend linearly on the instantaneous angular velocity of the drive (Fig. 4b) and the instantaneous torque on the motor shaft (Fig. 4b):

$$I_i = k_i^{(I)} \frac{M_i}{u_i}, \; U_i = k_i^{(U)} \dot{\varphi}_i u_i, \tag{6}$$

where: u_i - axle ratio, $k_i^{(I)}$ - torque sensitivity factor, $k_i^{(U)}$ – back emf. constant, $\dot{\varphi}_i$ - the angular velocity, M_i - moment of motor.

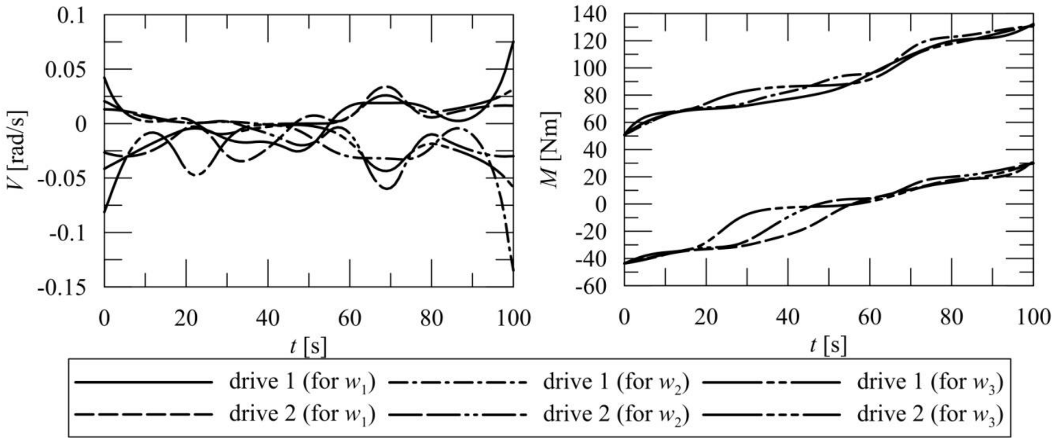

Fig. 4: The angular velocity (on the left), torque on the motor shaft (on the right).

The electric energy consumption of manipulator for adopted the inertia weights is presented in Fig. 5. Aside from drive parameters, the center of gravity position of each arm has the influence on the electricity consumption of manipulator. The change of center of gravity of manipulator arms causes the change of angular position, angular velocity and angular acceleration, which has the impact on the change of torque on individual drive (Fig. 4).

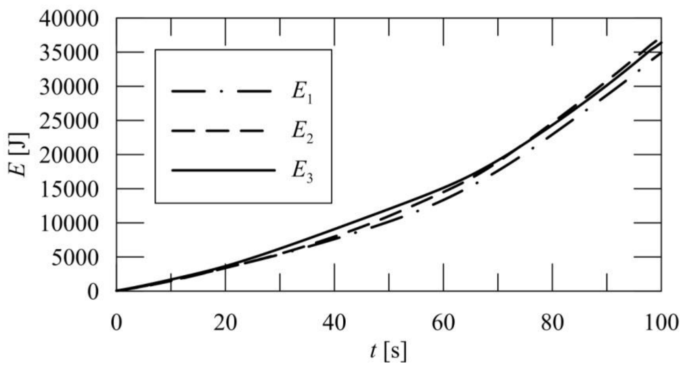

Fig. 5: Electricity consumption.

Total electricity consumption in the examined time (100 s) is equal to: 34915.78 J (for w1), 37222.13 J (for w2), and 36400.73 J (for w3). Based on these results, it can be stated that the minimum energy consumption is not the smallest for the shortest trajectory. It is associated with the change of the center of gravity of manipulator members during of the duty cycles. Therefore, for minimizing the consumption of electricity apart from seeking the optimal trajectory should pay attention to the value of moments of motors.

3. Conclusions

The use of one of the heuristic algorithms - the Particle Swarm Optimization method - to determine the optimal trajectory of SCARA manipulator end-effector has been presented in the work. The task was to calculate the shortest path connecting two defined points avoiding obstacles.

In the calculations the influence of changes of the inertia weight parameters adopted in PSO algorithm on the length of the determined trajectory has been presented. For the obtained trajectories the electricity consumption has been computed. The demonstrated results allowed to conclude that the inertia weight does not significantly impact on the length of the trajectory, while the length of the trajectory has the influence on the energy consumption. However, the lowest electricity consumptions does not occur when the trajectory is minimal. Therefore, the minimization of length of the trajectory to cover by the end-effector of manipulator cannot be the sole determinant during the optimization of the electricity consumption. In this case, first of all, pay attention on the displacement of the center of gravity of arms manipulator during the working cycle.

This work contains only theoretical considerations, but the results of subsequent works will be verified experimentally on four degrees of freedom manipulator that is mounted on a Mars rover (Pierzgalski et al., 2017). Optimization problems will concern a duty cycle in three-dimensional space and will analyze the solutions obtained by other heuristic methods, e.g. the genetic algorithm (Cekus et al., 2015).

References

Ao, Y. and Chi, H. (2010) An adaptive Differential Evolution to Solve Constrained Optimization Problem in Engineering Design, Scientific research 2, pp. 65-77.

Cekus, D., Skalik, A., Skrobek, D. and Waryś, P. (2015) Kinematic analysis of four degrees of freedom manipulator, Solid State Phenomena, Volume: Mechatronic Systems and Materials VI, pp. 277-282.

Cekus, D. and Waryś, P. (2015), Identification of parameters of discrete-continuous models, AIP Conf. Proc. 1648, 850055, http://dx.doi.org/10.1063/1.4913110.

Kennedy, J. and Eberhart, R.C. (1995) Particle Swarm Optimization, Proceedings of the. IEEE International Conference on Neutral Networks, Volume 4, pp. 1942-1948.

Kucuk, S. (2013) Energy minimization for 3-RRR fully planar parallel manipulator using particle swarm optimization, Mechanism and Machine Theory, 62, pp. 129-149.

Lin, W., Lee, W. and Hong, T. (2003) Adapting crossover and mutation rates in genetic algorithms, Journal of information science and Engineering, 19, pp. 889-903.

Posiadała, B., Tomala, M., Cekus, D. and Waryś, P. (2015) Work cycle optimization problem of manipulator with revolute joints, International Journal of Dynamics and Control, March 2015, Volume 3, Issue 1, pp. 94-99.

Pierzgalski, M., Ptak, P., Cekus, D. and Sokół, K. (2017) Modeling and stress analysis of a manipulator mounted on a Mars rover, Procedia Engineering, Volume 177, pp. 121-126, http://dx.doi.org/10.1016/j.proeng.2017.02.199

Storn, R. and Price, K. (1997) Differential evolution - a simple and efficient heuristic for global optimization over continuous spaces, Journal of Global Optimization. 11, pp. 341-359. DOI:10.1023/A:1008202821328.

Ting, T.O., Shi, Y., Cheng, S. and Lee, S. (2012) Exponential Inertia Weight for Particle swarm Optimization, Advances in Swarm Intelligence, vol. 7331, Springer, Berlin, Heidelberg, DOI: 10.1007/978-3-642-30976-2_10.

Ur-Rehman, R., Caro, S., Chablat, D. and Wegner, P. (2010) Multi-objective path placement optimization of parallel kinematics machines based on energy consumption, shaking forces and maximum actuator torques, Application to the Orthoglide, Mechanism and Machine Theory, 45, pp. 1135-1141.