Liet. mat. rink. LMD darbai, **50**, 2009, 172–177

Trajectory planning method of mobile piezorobot

Ramutis BANSEVIČIUS[1], Asta DRUKTEINIENĖ[2], Genadijus KULVIETIS[2]
[1] Kaunas University of Technology
Kęstučio 27, LT-44312 Kaunas, Lithuania
[2] Vilnius Gediminas Technical University
Saulėtekio 11, LT-10223, Vilnius, Lithuania
e-mail: bansevicius@cr.ktu.lt; astad@it.su.lt; genadijus_kulvietis@gama.vtu.lt

Abstract. This paper presents analysis of trajectory planning methods for mobile robots and new trajectory planning method research for mobile piezorobots. Here are deduced motional simultaneous equations for this kind of robots that describe point-to-point motion by given function. Preliminary experimental results prove the feasibility of proposed mathematical model.

Keywords: mobile piezorobot, piezoelectric actuator, trajectory planning method.

Introduction

Trajectory planning in two-dimensional space of mobile piezorobot with three power actuators was analyzed. Mobile piezorobots – devices capable of manipulating objects small mass in a limited space but with very high accuracy [5].

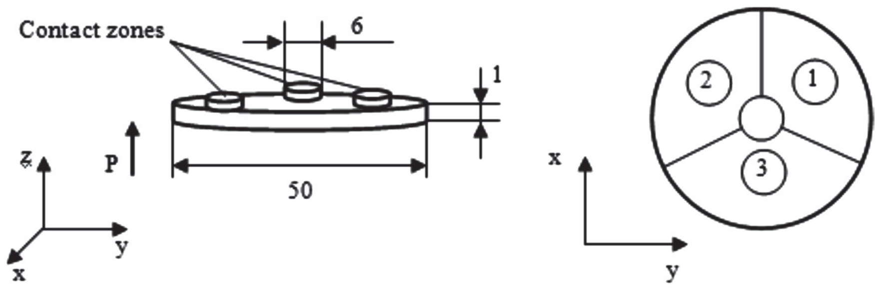
Trajectory planning (also called kinodynamic motion planning) is one of principal elements of robot motion planning. Base components of planning are [4]: state – position and orientation, velocity, structure of robot; time – all planning problems involve a sequence of decisions that must be applied over time; actions – generate actions that manipulate the state; goal state – during the actions, robot must reach a final set position; a criterion – action selection depends on desired criteria: feasibility, optimality, speed.

Different trajectory planning methods are used for autonomous robots. Generally are used splines [1–3,6]: cubic, trigonometric, exponential and β-splines. Clothoids curves [7,8] for smoothing trajectory are used too.

However, none of these planning methods inadequate to describe the movement of mobile piezorobot according to the given continuous function. Problem, when piezorobot is not rotating around its central axis and is active only one power actuator at a time, was researched.

1. Mobile piezorobot model

Mobile piezorobot model is design from piezoceramic plate with three magnetized metallic cylinders, which are attached to piezoceramic plate (Fig. 1). Converter's contact zone is top surface of three cylinders, which at the time of excited are moving in elliptical trajectory.



a) b)

Fig. 1. Construction of mobile piezorobot.

Electrodes are covered all bottom space of the ring and are divided in three equal segments. Such electrodes divide allow excite slider move in any direction and rotary motion.

For piezoconverter is used piezoceramic made from PZ 27 piezoceramic material. Polarization vector is routed along the thickness. Contact cylinders made from steel.

For piezoconverter's exciting are used three electrodes exciting schemes, when exciting one electrode sector at a time, which is generating rectilinear movement. If phases of voltage in each electrode are different 120 degrees, then actuated running wave and generated rotary movement. Harmonic variation low with 40V amplitude is used for exciting voltage. Electrodes can be divided into a greater number of sectors, but exciting principle should remain the same.

2. Trajectory planning algorithm

Function $y = f(x)$ of motion are given. Function $f(x)$ must be continuous at each point

$$\lim_{x \to a} f(x) = f(a), \tag{1}$$

where $a \in [x_0; x_n]$.

Its derivatives $f'(x)$ at those points must be continuous too.

Mobile piezorobot initial coordinates coincides with the function coordinates $(x_0; y_0)$. Determined angle α between first power actuator and x axis, and limit ϵ, which cannot exceed the micro robot center (Fig. 2).

Primarily, described $g^*(x, y)$ and $g^{**}(x, y)$ functions for definition of limits of movement. Normal, which is going per functions $f(x)$ and $g^*(x, y)$ or $g^{**}(x, y)$ coordinates $(x_{fi}; y_{fi})$ and $(x_{gi}; y_{gi})$, length is equal to ϵ.

Then, simultaneous equations will be

$$\begin{cases} y_{gi} - y_{fi} = -\frac{1}{f'(x_{fi})}(x_{gi} - x_{fi}), \\ \epsilon = \sqrt{(x_{gi} - x_{fi})^2 + (y_{gi} - y_{fi})^2}, \end{cases} \tag{2}$$

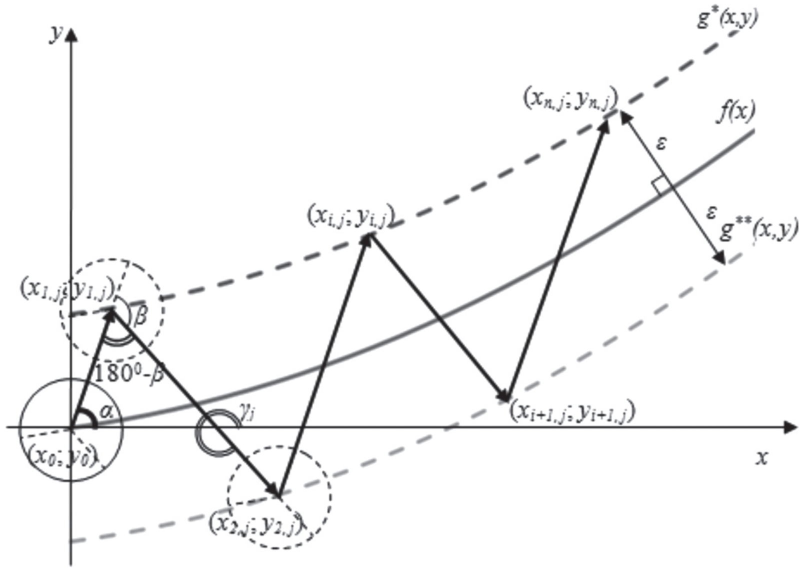


Fig. 2. Mobile piezorobot motion trajectory by given function $f(x)$.

where $i = 0, 1, 2, \ldots, n$ is function's point number. From (2) can find marginal coordinates:

$$g_i^*(x_i, y_i) = \begin{cases} x_{gi} = -\frac{\epsilon \cdot f'(x_{fi})}{\sqrt{f'(x_{fi})^2+1}} + x_{fi}, \\ y_{gi} = \frac{\epsilon}{\sqrt{f'(x_{fi})^2+1}} + y_{fi}, \end{cases} \tag{3}$$

and

$$g_i^{**}(x_i, y_i) = \begin{cases} x_{gi} = \frac{\epsilon \cdot f'(x_{fi})}{\sqrt{f'(x_{fi})^2+1}} + x_{fi}, \\ y_{gi} = -\frac{\epsilon}{\sqrt{f'(x_{fi})^2+1}} + y_{fi}. \end{cases} \tag{4}$$

If mobile piezorobot is constructed with m power actuators, angle between axes of actuators are

$$\beta = \frac{360^0}{m}. \tag{5}$$

Then angles between each power actuator and x axis are

$$\gamma_j = \alpha + \beta(j-1), \tag{6}$$

where $j = 1, 2, \ldots, m$ is power actuators number. To describe the movement of the mobile piezorobot, it is necessary to determinate these types of movement directions:

1) General direction of movement with regard x axis is $d_x = 1$ (x value is increases) or $d_x = -1$ (x value is decreases). A value is choosing depending on goal position.

2) Function direction between points $(x_{fi}; y_{fi})$ and $(x_{fi+1}; y_{fi+1})$ are

$$d_{xi} = \begin{cases} 1 & (x_{fi+1} - x_{fi} \geqslant 0), \\ -1 & (x_{fi+1} - x_{fi} < 0), \end{cases} \tag{7}$$

$$d_{yi} = \begin{cases} 1 & (y_{fi+1} - y_{fi} \geqslant 0), \\ -1 & (y_{fi+1} - y_{fi} < 0). \end{cases} \tag{8}$$

To find point x_{fi} at function $f(x)$, must find minimum distance from mobile piezorobot position $(x_i; y_i)$ to that point. So

$$((x_i - x_{fi})^2 + (y_i - f(x_{fi}))^2) dx_{fi} = 0. \tag{9}$$

Solving (9) equation can find coordinate x_{fi}. Coordinate x_{fi+1} is equal

$$x_{fi+1} = x_{fi} + d_x s_i, \tag{10}$$

where $s_i \geqslant \epsilon$ is step moving through function.

3) Power actuators directions are

$$x_j = \begin{cases} 1 & (0^0 \leqslant \gamma_j \leqslant 90^0 \vee 270^0 \leqslant \gamma_j \leqslant 360^0)\ , \\ -1 & (90^0 < \gamma_j < 270^0), \end{cases} \tag{11}$$

$$y_j = \begin{cases} 1 & (0^0 \leqslant \gamma_j \leqslant 180^0), \\ -1 & (180^0 < \gamma_j < 360^0). \end{cases} \tag{12}$$

4) Possible mobile piezorobot moving directions. Micro robot movement straight line intersect functions $g^*(x, y)$ and $g^{**}(x, y)$. Thus $x_{gi} = x_{i+1,j}$, $y_{gi} = y_{i+1,j}$ where $(x_{i+1,j}; y_{i+1,j})$ mobile piezorobot movement coordinates. Then simultaneous equations are solving with each function $g^*(x, y)$ and $g^{**}(x, y)$:

$$\begin{cases} y_{i+1,j} - y_{i,j} = k_j (x_{i+1,j} - x_{i,j}), \\ \begin{pmatrix} x_{i+1,j} \\ y_{i+1,j} \end{pmatrix} = g_i^*(x_i, y_i), \\ y_{fi} = f(x_{fi}), \end{cases} \tag{13}$$

and

$$\begin{cases} y_{i+1,j} - y_{i,j} = k_j (x_{i+1,j} - x_{i,j}), \\ \begin{pmatrix} x_{i+1,j} \\ y_{i+1,j} \end{pmatrix} = g_i^{**}(x_i, y_i), \\ y_{fi} = f(x_{fi}), \end{cases} \tag{14}$$

where k_j coefficient of straight line direction

$$k_j = tan\gamma_j. \tag{15}$$

From (13) and (14) simultaneous equations, can evaluate possible movement points $(x_{i+1,j}; y_{i+1,j})$. Then possible mobile piezorobot movement directions

$$r_{xi,j} = \begin{cases} 1 & (x_{i+1,j} - x_{i,j} \geqslant 0), \\ -1 & (x_{i+1,j} - x_{i,j} < 0), \end{cases} \tag{16}$$

$$r_{yi,j} = \begin{cases} 1 & (y_{i+1,j} - y_{i,j} \geqslant 0), \\ -1 & (y_{i+1,j} - y_{i,j} < 0), \end{cases} \tag{17}$$

For selecting right moving point, conditions must be met:

1) point must be on the same moving direction as power actuator $r_{xi,j} = x_j$ and $r_{yi,j} = y_j$;
2) point must be on the same moving direction as function $r_{xi,j} = d_{xi}$ and $r_{yi,j} = d_{yi}$;
3) maximum distance from current mobile piezorobot position.

In some situations there is no point which met these conditions. Then choose coordinate which is invert moving direction and it must be minimum distance from current mobile piezorobot position.

3. Results of analysis

Mobile piezorobot with three power actuators ($m = 3$) moving trajectory by given different functions is analyzed. Limit $\epsilon = 0, 1$. Trajectory, when function $y = x^2$, $\alpha = 90^0$ is presented in Fig. 3a, when function $y = \sqrt{x}$, $\alpha = 90^0$ is presented in Fig. 3b, function $y = \sin x$, $\alpha = 45^0$ is presented in Fig. 3c, when function $y = \sin^3 x$, $\alpha = 60^0$ is presented in Fig. 3d.

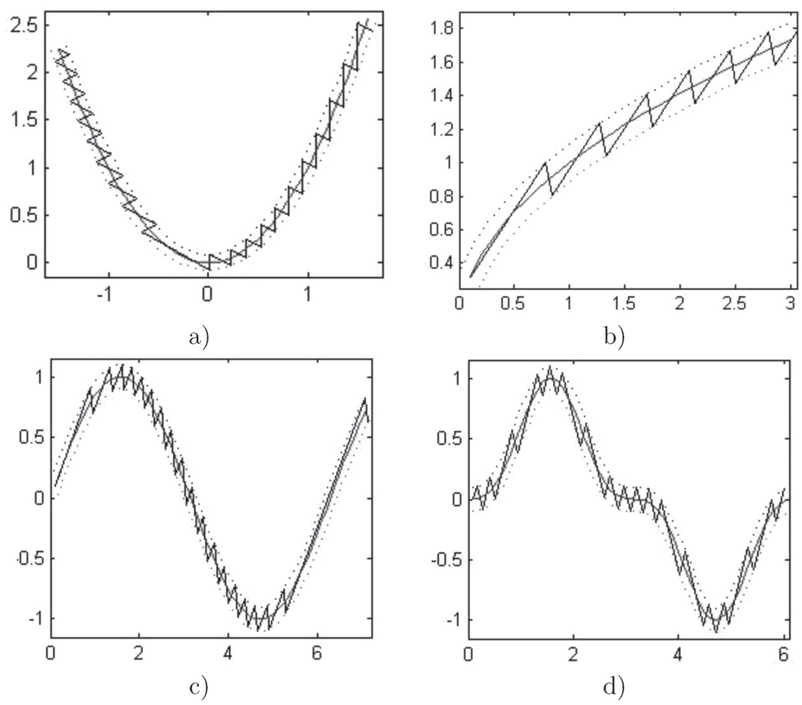


Fig. 3. Mobile piezorobot movement trajectory.

The presented results prove the feasibility of proposed mathematical model.

Conclusions

The moving, but not rotating, mobile piezorobot trajectory planning method is presented. The developed method is based on simultaneous equations solving and right movement point selection. The presented results prove the feasibility of proposed mathematical model.

Acknowledgement. This work has been funded by the Lithuanian State Science and Studies Foundation, Project No B-07017, Contract No B-16/2007.

References

1. A. Baumann. *Robot Motion Planning in Time-varying Environments*. `http://tumb1.biblio.tu-muenchen.de/publ/diss/in/2001/baumann.pdf`
2. M. Egerstedt. *Motion Planning and Control of Mobile Robots*. Doctoral thesis. Stockholm, 2000.
3. L. Labakhua , U. Nunes, R. Rodrigues, F. Leite. Trajectory planning methods for autonomous car-like vehicles. *Annals of the University Of Craiova*, 3(30), 2006.
4. S.M. LaValle. *Planning Algorithms*. Cambridge University Press, USA, 2006.
5. K. Ragulskis, R. Bansevicius, R. Barauskas, G. Kulvietis. *Vibromotors for Precision Microrobots*. Hemisphere Publishing Corp., USA, 1988.
6. Y. Shen, K. Huper. *Optimal Joint Trajectory Planning for Manipulator Robot Performing*. `http://www.araa.asn.au/acra/acra2004/papers/shen.pdf`
7. D.H. Shin, S. Singh. *Path Generation for Robot Vehicles Using Composite Clothoid Segments*. Tech. Report. Robotics Institute, Carnegie Mellon University, 1990.
8. H. Xu, S.X. Yang. A novel tracking control method for a wheeled mobile robots. *Electronic Journal of Computational Kinematics*, 1(1), 2002.

REZIUMĖ

R. Bansevičius, A. Drukteinienė, G. Kulvietis. Mobilaus piezoroboto trajektorijos planavimo metodas

Darbe analizuojami judančių mikrorobotų trajektorijų planavimo būdai bei tyrinėjamas naujas trajektorijos planavimo metodas piezorobotui, turinčiam tris judėjimo kontaktus. Pateikiamos judėjimo lygčių sistemos tokio tipo mobiliems robotams, kurie juda duotaja funkcija. Eksperimentiniai rezultatai patvirtina matematinio modelio tinkamumą.

Raktiniai žodžiai: mobilus piezorobotas, piezokeitiklio elektrodai, trajektorijų planavimo būdai.