514. Trajectory planning method of rotating mobile piezorobot

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Abstract. This paper presents method of trajectory planning of mobile piezorobots. An algorithm is introduced to evaluate motional trajectory 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, trajectory planning method.

Introduction

Trajectory planning in two-dimensional space of mobile piezorobot with power actuators was analyzed. Mobile piezorobots are devices capable of manipulating objects of small mass in a limited space but with very high accuracy (0.1 μm) [1, 2].

Trajectory planning (also called kinodynamic motion planning) is one of principal elements of robot motion planning. Different trajectory planning methods are used for autonomous robots. Generally are used splines [3, 4, 5, 6]: cubic, trigonometric, exponential and β-splines. Spline functions are formed by joining polynomials together at fixed points. Most popular of them are cubic splines. They have two features [7]: have paths of minimal curvature and are easy to generate online.

Clothoids curves [8, 9] are used too. These curves allow generation of smooth trajectories also with smooth changes in curvature as well as smooth transitions from a straight line to a circle arc or vice versa [5].

All these methods are generating trajectory through a set of prescribed points referred to as way points. In our research, a moving function is given. Mobile piezorobot can rotate and dynamically change its power actuators directions. Then all power actuators are active. Only one power actuator is active at a time. So moving path is straight line of mobile piezorobot. With this method, trajectory of mobile piezorobot exactly matching given function, but is more advanced control of piezorobot than with switching leg method [10]. This paper deals with analysis of how much mobile piezorobot must be turn around and which power actuator must be active to move on.

Mobile piezorobot model

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

Electrodes cover all bottom space of the ring and are divided in three equal segments (Fig. 1b). Such electrode division allows excitation of slider move in any direction as well as rotary motion.

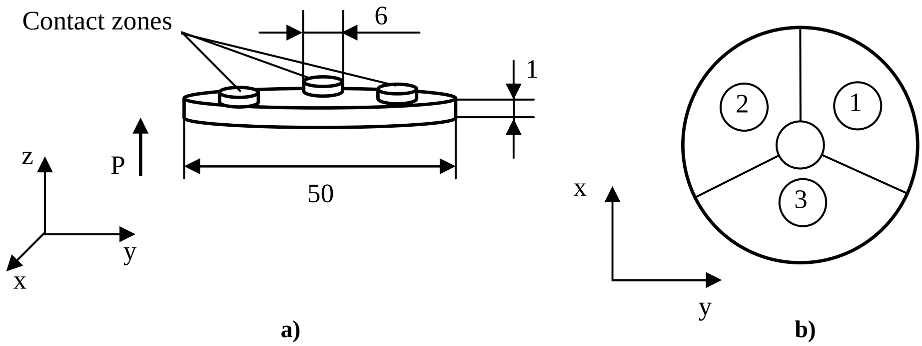

Fig. 1. Construction of mobile piezorobot: a), b) electrodes positions

Piezoconverter is fabricated from piezoceramic material of type PZ 27. Polarization vector is routed along the ring thickness. Contact cylinders are made from steel.

For piezoconverter excitation three electrodes exciting schemes are employed, 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 running wave is induced, which generates rotary movement. Harmonic variation with 40 V amplitude is used as excitation voltage.

Electrodes can be divided into a greater number of sectors, but exciting principle should remain the same.

Trajectory planning algorithm

Requirements for piezorobot movement:

1. Move given by function $\psi = f(x, y)$. Function ψ must be continuous at each point
   $\lim_{(x,y)\to(a,b)} f(x,y) = f(a,b)$, where $a \in [x_0; x_n]$, $b \in [y_0; y_n]$.
   Its derivatives $\frac{\partial f}{\partial x}$ at those points must be continuous too.
2. For motion only one power actuator is active at a time.
3. Mobile piezorobot can rotate. Then are active all power actuators.
4. Minimum deflection ε from function ψ .

Definable initial data: c – power actuators number, angle α_0 between first power actuator and x axis, Δs – maximum step of mobile piezorobot, D – general direction of movement with regard to x axis. If $D = 1$, then x value increases or $D = -1$, then x value decreases. A value is chosen depending on start and end position.

Mobile piezorobot movement straight line intersects given function at point (x_i; y_i) (**Error! Reference source not found.**). So it is necessary to solve simultaneous equations and find point, where circle with radius Δ*s* intersect function ψ :

$$\begin{cases} (x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2 = \Delta s^2; \\ f(x_i, y_i) = 0. \end{cases} \tag{1}$$

where $(x_{i+1}; y_{i+1})$ – intersect points, $(x_i; y_i)$– piezorobot center coordinates, i = 1, 2 ...*n* point number.

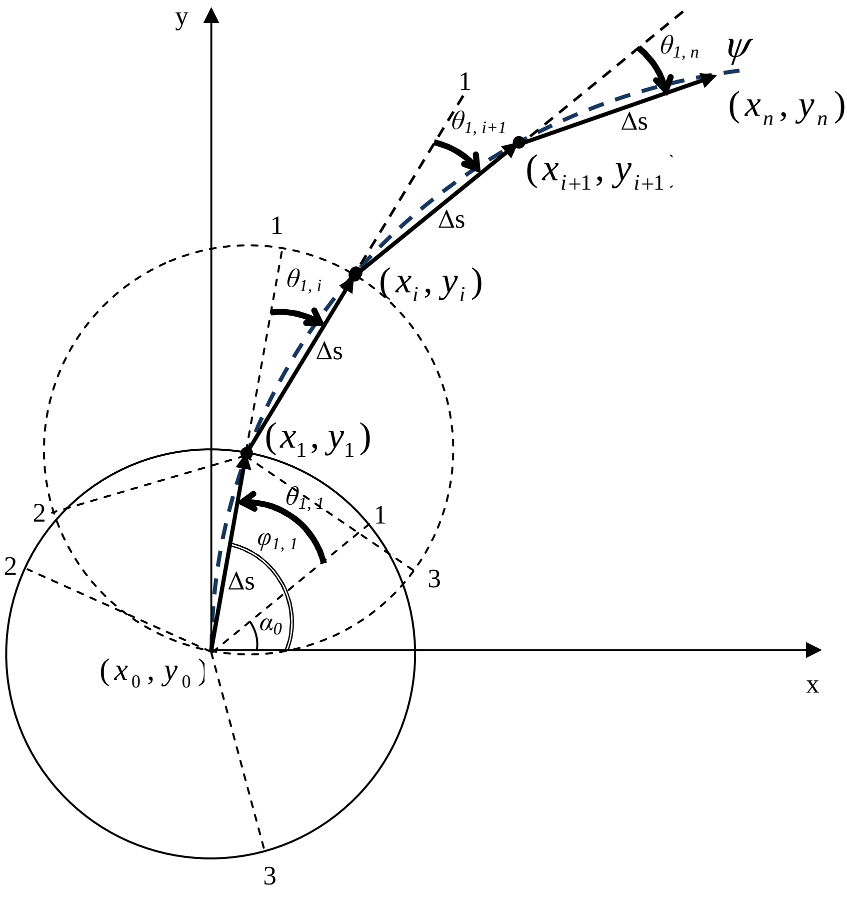

Fig. 2. Moving trajectory of mobile piezorobot

For selecting right moving point, it is necessary to determinate these types of movement directions:

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

$$d_{xi} = \begin{cases} 1, & \text{if } x_{fi+1} - x_{fi} \geq 0 \\ -1, & \text{if } x_{fi+1} - x_{fi} < 0 \end{cases}, \tag{2}$$

$$d_{yi} = \begin{cases} 1, & \text{if } y_{fi+1} - y_{fi} \geq 0 \\ -1, & \text{if } y_{fi+1} - y_{fi} < 0 \end{cases}, \tag{3}$$

where $x_{fi+1} = x_{fi} + D \cdot \Delta s$, $y_{fi+1} = f(x_{fi+1})$.

2. Possible directions of mobile piezorobot movement:

$$r_{xi} = \begin{cases} 1, & \text{if } x_i - x_{i+1} \geq 0 \\ -1, & \text{if } x_i - x_{i+1} < 0 \end{cases}, \tag{4}$$

$$r_{yi} = \begin{cases} 1, & \text{if } y_i - y_{i+1} \geq 0 \\ -1, & \text{if } y_i - y_{i+1} < 0 \end{cases}. \tag{5}$$

For selecting right moving point (x_{i+1}, y_{i+1}), conditions must be met $d_{xi} = r_{xi}$ and $d_{yi} = r_{yi}$. Then angle φ between motion straight line and x axis is calculated.

Because

$$y_{i+1} - y_i = \mathrm{tg}\varphi_i \cdot (x_{i+1} - x_i), \tag{6}$$

then

$$\varphi_i = \mathrm{ctg}\left(\frac{y_{i+1} - y_i}{x_{i+1} - x_i}\right). \tag{7}$$

Angles between each power actuator and x axis are:

$$\gamma_j = \alpha + \beta(j-1), \tag{8}$$

where $\beta = \dfrac{360^0}{c}$ angle between axes of actuators, j = 1, 2 ..., c is power actuators number.

Then calculate rotation angle θ for each power actuator, when mobile piezorobot is rotating clockwise and counterclockwise. Matrix $\theta_{c\times m}$ is constructed. Number of rows c is equal to number of power actuators; number of columns m indicates rotation direction. If $m = 1$, then mobile piezorobot is turning clockwise:

$$360° + \gamma_j - \varphi_i \equiv \theta_{j1} (\mathrm{mod}\, 360). \tag{9}$$

If $m = 2$, then turning counterclockwise:

$$360° - \gamma_j + \varphi_i \equiv \theta_{j2} (\mathrm{mod}\, 360). \tag{10}$$

Then

$$\theta = \begin{bmatrix} \theta_{11} & \theta_{12} \\ \theta_{21} & \theta_{22} \\ \dots & \dots \\ \theta_{c1} & \theta_{c2} \end{bmatrix}. \tag{11}$$

From this matrix one may determine minimum value – angle of turning $\theta_{\min} = \min(\theta)$.

By placing this value into matrix one can determine turn direction (by column number) and which power actuator must be active to move on (by row number).

For calculation of next moving step angle α_i must be recalculated:

$$\alpha_{i+1} = \begin{cases} \alpha_i - \theta_{\min}, & \text{if} \quad m = 1 \\ \alpha_i + \theta_{\min}, & \text{if} \quad m = 2 \end{cases}. \tag{12}$$

Results of analysis

Mobile piezorobot is analyzed, having three power actuators (c = 3) and with moving trajectory that is given by different functions. Trajectory, when function $y = x^2$, $\alpha = 120^0$, $\Delta s = 1$ is presented in Fig. 3. Table 1 lists power actuator number, which must be active as well as indicating how much mobile piezorobot must be rotated.

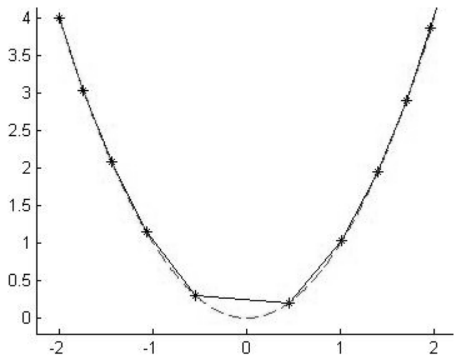

Fig. 3. Mobile piezorobot trajectory, when $y = x^2$, Δs = 1

Table 1. Power actuators number, which must be active and mobile piezorobot rotation angles.

i	***j***	**Rotation direction**	θ_{min}, °	$\Delta \bar{s}$	x_i	y_i
1	0	0	0	0	-2	4
2	1, 2, 3	counterclockwise	44,96263	0,784746	-2	4
3	2	0	0	1	-1,74181	3,033906
4	1, 2, 3	counterclockwise	2,473426	0,043169	-1,74181	3,033906
5	2	0	0	1	-1,44217	2,079854
6	1, 2, 3	counterclockwise	4,248668	0,074153	-1,44217	2,079854
7	2	0	0	1	-1,07267	1,150623
8	1, 2, 3	counterclockwise	10,00015	0,174536	-1,07267	1,150623
9	2	0	0	1	-0,54742	0,299673
10	1, 2, 3	counterclockwise	52,61647	0,918331	-0,54742	0,299673
11	2	0	0	1	0,447634	0,200376
12	1, 2, 3	clockwise	58,70465	1,024589	0,447634	0,200376
13	3	0	0	1	1,012649	1,025457
14	1, 2, 3	counterclockwise	11,85715	0,206946	1,012649	1,025457
15	3	0	0	1	1,396076	1,949028
16	1, 2, 3	counterclockwise	4,663259	0,081389	1,396076	1,949028
17	3	0	0	1	1,703148	2,900715
18	1, 2, 3	counterclockwise	2,637977	0,046041	1,703148	2,900715
19	3	0	0	1	1,966094	3,865525

Fig. 4 illustrates trajectory when the same function ($y = x^2$, $\alpha = 120^0$) is given, but moving step is smaller ($\Delta s = 0.1$)**Error! Reference source not found.**.

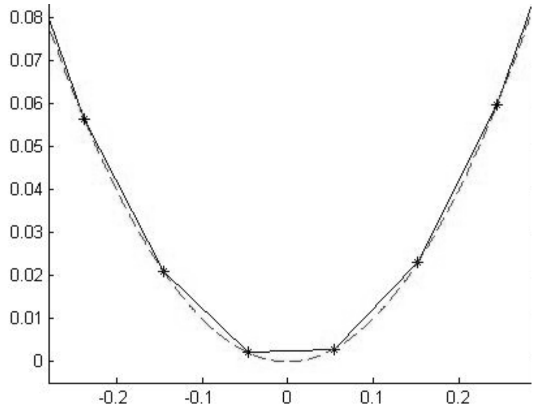

Fig. 4. Mobile piezorobot trajectory fragment, when $y = x^2$, $\Delta s = 0.1$

Trajectory, when function y = 1/14 (x+4) (x+1) (x-1) (x-3) + 0.5, $\alpha = 30^0$, $\Delta s = 1$ is presented in **Error! Reference source not found.Error! Reference source not found.**.

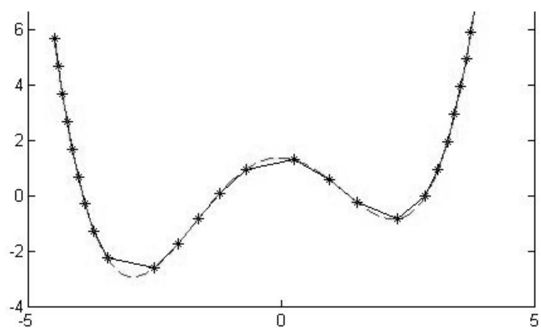

Fig. 5. Mobile piezorobot trajectory, when y = 1/14 (x+4) (x+1) (x-1) (x-3) + 0.5

Conclusions

Trajectory planning method for rotating mobile piezorobot is presented. The developed method is based on selection of correct rotation angle. There are no complicated simultaneous equations to be solve therefore the mathematical model is fairly simple and is able to quickly calculate trajectory of mobile piezorobot. Presented results demonstrate the applicability of proposed mathematical model.

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