

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Asta DRUKTEINIENĖ

TRAJECTORIES FORMATION FOR MOBILE MULTIDIMENSIONAL PIEZOROBOTS WITH NANOMETER RESOLUTION

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
INFORMATICS ENGINEERING (07T)

Vilnius „Technika 2011

Doctoral dissertation was prepared at Vilnius Gediminas Technical University in 2008–2011.

Scientific Supervisor

Prof Dr Habil Genadijus KULVIETIS (Vilnius Gediminas Technical University, Technological Sciences, Informatics Engineering – 07T).

The dissertation is being defended at the Council of Scientific Field of Informatics Engineering at Vilnius Gediminas Technical University:

Chairman

Prof Dr Habil Antanas ČENYS (Vilnius Gediminas Technical University, Technological Sciences, Informatics Engineering – 07T).

Members:

Prof Dr Dalius NAVAKAUSKAS (Vilnius Gediminas Technical University, Technological Sciences, Informatics Engineering – 07T),

Prof Dr Habil Rimvydas SIMUTIS (Kaunas University of Technology, Technological Sciences, Informatics Engineering – 07T),

Prof Dr Vytautas TURLA (Vilnius Gediminas Technical University, Technological Sciences, Mechanical Engineering – 09T),

Prof Dr Habil Piotras VASILJEVAS (Vilnius Pedagogical University, Technological Sciences, Mechanical Engineering – 09T).

Opponents:

Prof Dr Habil Rimantas BARAUSKAS (Kaunas University of Technology, Technological Sciences, Informatics Engineering – 07T),

Prof Dr Habil Vytautas GINIOTIS (Vilnius Gediminas Technical University, Technological Sciences, Measurement Engineering – 10T).

The dissertation will be defended at the public meeting of the Council of Scientific Field of Informatics Engineering in the Senate Hall of Vilnius Gediminas Technical University at 10 a. m. on 16 November 2011.

Address: Saulėtekio al. 11, LT-10223 Vilnius, Lithuania.

Tel.: +370 5 274 4952, +370 5 274 4956; fax +370 5 270 0112;

e-mail: doktor@vgtu.lt

The summary of the doctoral dissertation was distributed on 14 October 2011.

A copy of the doctoral dissertation is available for review at the Library of Vilnius Gediminas Technical University (Saulėtekio al. 14, LT-10223 Vilnius, Lithuania).

© Asta Drukeitinienė, 2011

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Asta DRUKTEINIENĖ

NANOMETRŲ SKYROS JUDANČIŲ DAUGIAMAČIŲ PJEZOROBOTŲ TRAJEKTORIJŲ FORMAVIMAS

DAKTARO DISERTACIJOS SANTRAUKA

TECHNOLOGIJOS MOKSLAI,
INFORMATIKOS INŽINERIJA (07T)

Vilnius „Technika“ 2011

Disertacija rengta 2008–2011 metais Vilniaus Gedimino technikos universitete.
Mokslinis vadovas

prof. habil. dr. Genadijus KULVIETIS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, informatikos inžinerija – 07T).

Disertacija ginama Vilniaus Gedimino technikos universiteto Informatikos inžinerijos mokslo krypties taryboje:

Pirmininkas

prof. habil. dr. Antanas ČENYS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, informatikos inžinerija – 07T).

Nariai:

prof. dr. Dalius NAVAKAUSKAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, informatikos inžinerija – 07T),

prof. habil. dr. Rimvydas SIMUTIS (Kauno technologijos universitetas, technologijos mokslai, informatikos inžinerija – 07T),

prof. dr. Vytautas TURLA (Vilniaus Gedimino technikos universitetas, technologijos mokslai, mechanikos inžinerija – 09T),

prof. habil. dr. Piotras VASILJEVAS (Vilniaus pedagoginis universitetas, technologijos mokslai, mechanikos inžinerija – 09T).

Oponentai:

prof. habil. dr. Rimantas BARAUSKAS (Kauno technologijos universitetas, technologijos mokslai, informatikos inžinerija – 07T),

prof. habil. dr. Vytautas GINIOTIS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, matavimų inžinerija – 10T).

Disertacija bus ginama viešame Informatikos inžinerijos mokslo krypties tarybos posėdyje 2011 m. lapkričio 16 d. 10 val. Vilniaus Gedimino technikos universiteto senato posėdžių salėje.

Adresas: Saulėtekio al. 11, LT-10223 Vilnius, Lietuva.

Tel.: (8 5) 274 4952, (8 5) 274 4956; faksas (8 5) 270 0112;

el. paštas doktor@vgtu.lt

Disertacijos santrauka išsiuntinėta 2011 m. spalio 14 d.

Disertaciją galima peržiūrėti Vilniaus Gedimino technikos universiteto bibliotekoje (Saulėtekio al. 14, LT-10223 Vilnius, Lietuva).

VGTU leidyklos „Technika“ 1908-M mokslo literatūros knyga.

© Asta Drukeitinienė, 2011

Introduction

Topicality of the problem. Increasingly, piezoelectric actuators are used in structures of robots, which can be described as resonance systems operating principles based in high-frequency oscillations excited. Devices that use piezoelectric actuators are characterized by high accuracy, small dimensions, low weight and power consumptions. A high-precision three degrees of freedom mobile piezorobots were created by Kaunas University of Technology and scientific society “Vibrotechnika” scientists R. Bansevicius and K. Ragulskis. It cannot only move in a two-dimensional space, but at the same time can carry objects or to have manipulation device.

One of fundamental autonomous systems development phase is the motion trajectory formation.

Classical interpolation methods are used to form motion trajectories. The results – functions that describe the moving object state at a certain point of time. However, these methods are suitable for robots that have wheels, feet or other dynamic parts.

Piezorobots created by scientists of scientific society “Vibrotechnika” have no additional motion-generating structures, but only direct contact with the static plane points. Linear motion generated by excitation of one segment of the electrode and the rotary motion are all the excitation electrode segments. Piezorobot motion trajectory is broken lines. Therefore, the classical trajectory formation methods cannot be applied. So there is a problem how describe the motion path for these devices.

The object of research. The object of this work is motion trajectories formation algorithms.

Aim and tasks of the work. The main aim of this work is to create motion trajectory formation methods for precision multidimensional piezorobots. In order to achieve the objective, the following tasks had to be solved:

1. To analyze literature about piezorobots designs, operating principles and methods of formation the motion trajectories.
2. To create motion trajectories formation methods taking into account possible electrode exciting schemes.
3. To perform quantitative characteristics investigation of formed motion trajectories.

Methodology of research. Literature research methods were used while analyzing constructions and operating principles of piezorobots, motion

trajectory formation methods. Mathematical modeling methods were used for creation of numerical trajectory formation algorithms and analysis. Comparative research methods were used during quantitative analysis of trajectory formation algorithms. The analysis results were summarized and the approach was expounded using the research generalization method.

Scientific novelty

1. Proposed first trajectories formation algorithm for piezorobot, which motion is generated with direct contact points.
2. Created new precision piezorobot trajectory calculation methods for the formation of different types of motion trajectories of the assessment motion resolution.
3. Created trajectory formation method for design and analyze moving in two-dimensional space autonomous systems.

Practical value. The research results were submitted to high-tech program "Research and Development of the Multi-degree-of-freedom Mechatronic Displacement Generation/Measurement Systems with Nanometer Resolution" (Nr. B-07017), research project „Modeling and Control of Mechatronic Multidimensional Robotic Devices With Nanometer resolution" (Nr. MIP-122/2010).

Trajectories' formation algorithms can be used in piezorobot behavior modeling software. Results of algorithms allow to solve control problems.

Defended propositions

1. Introduced the switching contacts method with selected optimal orientation angle of piezorobot can be used for tracking trajectories.
2. Created the tangents method can be used for forming high speed trajectories.
3. Suggested point-to-point and control point methods suitable for forming a high precision motion trajectories.
4. Results of the motion trajectory generation algorithms allow modeling behavior of piezorobots.

The scope of the scientific work. The scientific work consists of the general characteristic of the dissertation, three main chapters and general conclusions, list of literature, list of publications and addenda. The total scope of the dissertation – 124 pages, 70 numbered formulas, 97 pictures, 11 tables.

1. Analysis of High Precision Mobile Piezrobots Constructions

First chapter analyse robots using piezoelectric actuators, analysis of their structure and working principles are presented.

A lot of various walking robots were created using running wave principle that is used in ultrasonic motors. Usage of stick and slip concept as robot motion principle first time was presented by german scientist K. Besocke in 1986. The robot did operations in microscope scanning surfaces at the atomic scale.

In 1997 German scientists U. Rembold and S. Fatikov presented robot, called SPIDER-II. This robot used nine piezoelectric bimorphic motion changers that worked as robot legs.

At the end of the 9th decade NanoWalker robot (NanoWalker project) with three feet layd out in pyramid principle was created in USA. Such an approach was chosen due to the maintenance of stability during motion.

Big input was made by scientists of project *Miniaturised Robot for Micro Manipulation* (MINIMAN) from various European universities. In 2000 robot, named MINIMAN III, was presented. It consisted of platform with three piezo legs, that bended in any direction while exciting electrodes in different voltage. In 2002 the scientists U. Simu, S. Johansson and others from same project introduced robot MINIMAN V, built from two monolit piezoceramic parts, put on each others backs. The lower part was dedicated to motion by plane, on upper part the ball was placed with a special tip for working with objects. Each piezoceramic part has 6 feet, which move in three perpendicular directions.

According to project MINIMAN results in 2002 participants of another project MiCRoN Swedish scientist N. Snis and others demonstrated new mechanism of kvazistatic motion with piezoelectric bimorphic motion converters. This robot have 3 freedon degrees: generated direct robot motion by x y axis, made objects turn. Highest robot speed is 0.75 mm/s.

Examination of piezoelectric motors in Lithuania was started already in 1969. Scientists of Kaunas technology university (KTU) and members of scientific society “Vibrotechnika” – R. Basevičius and K. Ragulskis were the first ones who in 1989 presented 6 and 9 freedom degrees piezrobots that consisted of two kinematic pears: piezoelectric cylinder – passive sphere, piezoelectric disc – passive plane. Scientist R. Bansevičius demonstrated simple appliance of piezoelectric motor in creation of mass-consumer products as LEGO™ blocks and figures. Three freedom degree piezoelectric motor for motion or rotation by passive plane was presented. It was piezoceramics mounted on metal plate and electrodes divided to equal 120° sectors. Rotation is done due to running wave. During research works of positioning objects in

2007–2009, piezoelectric ring, piezoelectric cylinder and piezoelectric hemispheric piezorobots (Fig. 1) were created.

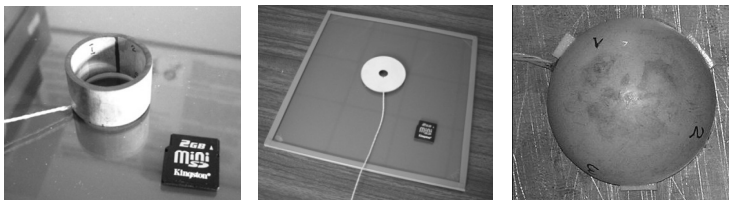


Fig. 1. Prototypes of piezorobots

Analyzing motion trajectory formation methods for various types of robots it was noticed that most commonly are used these methods: polynomial interpolation, interpolation by splines and Cornu spiral. The essence of all these methods – having initial points (nodes), to find continuous function to describe all given points. These methods are applied in dependence from mechanical features of robot, its construction.

Summing up the theoretical analysis, it is possible to state that motion of all created robots is generated using additional constructions, for example piezoelectric biomorphic actuators. Piezorobots created by scientists of scientific society “Vibrotechnika” use direct contact points with passive plane. These piezorobots have three contact points. Their motion direction depends on active contact point, i. e. piezorobot can move only by straight line or rotate. But piezorobots of this type are different from others because they can make motions at an angle, i. e. move in broken trajectories. Also they have high resolution motion and wide speed control range.

2. Trajectories Formation Algorithms for Mobile Piezorobots

The motion trajectories formation task can be divided into distinct phases (Fig. 2):

1. *Motion trajectory planning*: knowing the original path nodes and type of planning trajectory (broken lines or curve), functions of planning trajectory is formed. This task can be solved by using interpolation methods.
2. *Motion trajectory generation*: according to the use of electrode excitation schemes, motion resolution, planned trajectory type, and motion requirements, such as motion speed and motion accuracy, path

formation algorithm is selected. Motion trajectory is calculated, i. e. the coordinates of formed trajectory are received.

3. *Calculation of piezorobot motion parameters*: knowing the motion trajectory coordinates and electrodes excitation scheme, robot's motion parameters are determined: active contacts number, displacement length during linear motion, turning angle during rotational motion determined and turning direction (clockwise or counterclockwise).

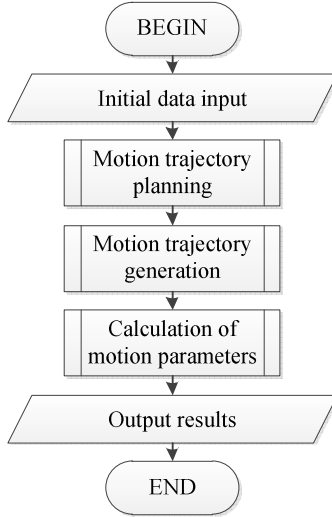


Fig. 2. The general trajectory formation algorithm

Piezorobot motion is formed between nodes $(x_1, y_1), (x_2, y_2) \dots (x_N, y_N)$, where $N > 1$. Planned trajectory between each pair of nodes can be described by parametric functions S by formula:

$$S_i = \begin{cases} S_{xi} = \phi(x_i, x_{i+1}, t); \\ S_{yi} = \psi(y_i, y_{i+1}, t). \end{cases} \quad (1)$$

where t – parameter of parametric function.

According to task requirements, the axis of symmetry of piezorobot must deviate as little as possible from the planned trajectory S . Therefore, must be defined maximum allowable deviation $\varepsilon_{\max}$ from function S . Coordinates g

located $\varepsilon_{\max}$ distance from planned trajectory are called coordinates of the boundary. These coordinates can be calculated by the formula:

$$g(x_g, y_g) = \begin{cases} x_g = -z \cdot K \cdot \left. \frac{\partial S}{\partial x} \right|_{x=x_s} + x_s; \\ y_g = z \cdot K + y_s, \end{cases} \quad (2)$$

where $K = \frac{\varepsilon_{\max}}{\sqrt{\left(\left. \frac{\partial S}{\partial x} \right|_{x=x_s} \right)^2 + 1}}$, $(x_s; y_s)$ – coordinates of planned trajectory;

$z = -1, 1$ boundary coordinates position with regard to coordinates of planned trajectory.

Using one segment excitation scheme for linear motion, contact switching method was created (Fig. 3).

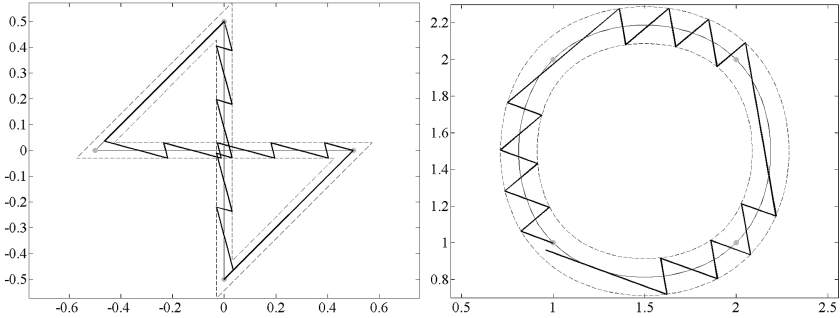


Fig. 3. Examples of motion trajectories formation with switching contacts method

This method can be used for making motion by broken lines or curves. When the electrodes are excited with the same force, which is directed along the axis of symmetry of the segments, piezorobot's motion direction coincides with the segment's symmetry axis. Since piezorobot center of the symmetry must move only between boundary coordinates, then straight line motion of the robot will cross the threshold of coordinates, and their intersection point will be motion coordinate. Mathematical model is complicated, but piezorobot motion control is the simplest of all methods developed. Trajectory formation algorithm with switching contacts method output these results: activated contact number, formatted trajectory coordinates and distance between these coordinates.

Using the linear excitation scheme for generating motion of one segment and torque excitation schemes for generating motion all segments, three path-making methods: *point-to-point*, *control points* and *tangents* – were created.

Point-to-point method is intended to shape the motion, when the planned trajectory is the broken line. This method is distinguished by precision and piezorobot motion speed as direct motion is carried out between determined nodes, and the rotary motion in nodes, that why contact switching depends only on the quantity of nodes.

Control points method principle is to divide planned trajectory into equal length segments, and to make rotation check in points joining these segments (Fig. 3a) evaluating motion resolution. These points are called control points. The method is suitable for the motion in continuous curves. Method of control points was created to form a high-precision trajectory.

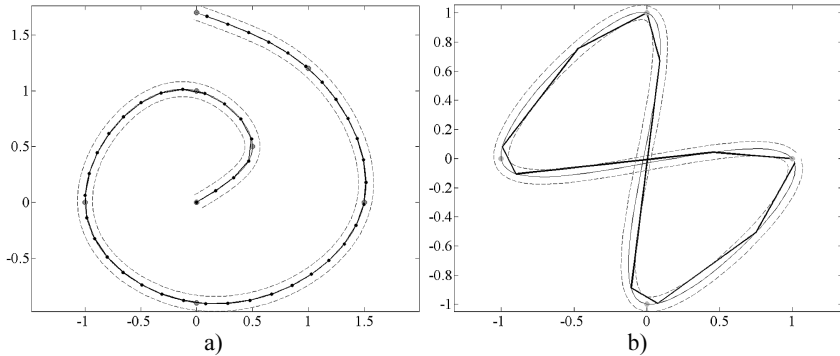


Fig. 4. Examples of trajectory formation: a) control points method;
b) tangents method

Method of tangents is designated to shape the trajectory that is optimal in respect of speed, but maintain the accuracy of motion. First it is checked if there is possibility to move from current node to another without intersecting marginal coordinates. If marginal coordinates are intersected, then it is searched for the tangent point at marginal coordinates and the point of motion coordinates calculated (Fig. 4b).

Management of piezorobot motion using these methods is more complicated as rotating motion is done and additionally rotation angle and rotation direction must be evaluated.

All the developed methods were implemented and numerical experiments that confirm the correctness of the methods of mathematical models, performed.

3. Formed Motion Trajectories Analysis

Trajectory formation depends on parameters such as motion resolution, piezorobot orientation angle and the trajectory curvature. Trajectory formed by any of these methods have quantitative characteristics, such as amount of switching contacts, the accuracy of trajectory, the motion displacement length. Amount of switching contacts and displacement length affects the piezorobot motion speed. The accuracy depends on the curvature of the planned trajectory. Dependencies of main parameters are analyzed and values to form optimal motion trajectory in respect to speed or accuracy are given.

During research of electrodes segment switching quantity and displacement length dependency from piezorobot orientation angle trajectory formed by contact switching method, optimal piezorobot orientation angle was determined by which maximal motion speed by any trajectory can be achieved. Optimal angle can be calculated by the formula:

$$\alpha_{\text{vid}} = \sum_{i=1}^K \left(\frac{a_i}{\sum_{i=1}^K a_i} \cdot \varphi_i \right), \quad (3)$$

where K – number of segments, a – segment length, φ – segment angle with x axis, i – segment number.

During investigation of contact switching quantity N with different amount of piezorobot electrodes $c = \{3, 6, 9\}$ shifting difference between piezorobot orientation angle and planned line angle with x axis (Fig. 5), it was noticed that piezorobot orientation angle must be smaller than angle between piezorobot segments symmetry axis.

Permissible generated trajectory deflection from the planned trajectory (Fig. 6), which depends on the piezorobot motion resolution and on the type of trajectory, was calculated and experimental defined during the investigation.

Below is given correction of deflection calculation with planned trajectory evaluation applying descriptive statistics.

After comparative analysis of control points and motion trajectories formed by tangent methods, it was noticed that trajectories formed with control points method have more than double amount of contact switches than ones formed by tangent method (Fig. 7).

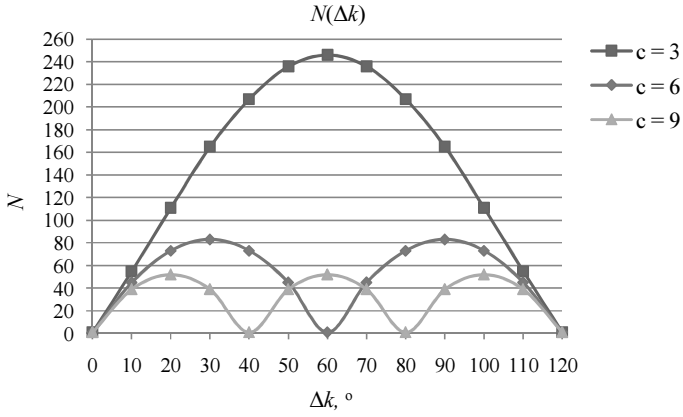


Fig. 5. Dependence of amount of switching contacts on the piezorobots orientation angle and straight-line orientation angle difference

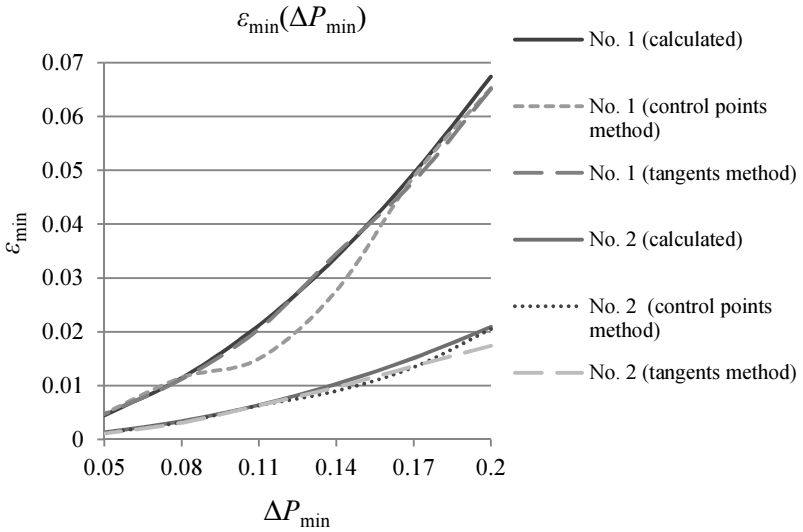


Fig. 6. The smallest deviation dependence on the motion resolution, when using control point's algorithm and tangents algorithm

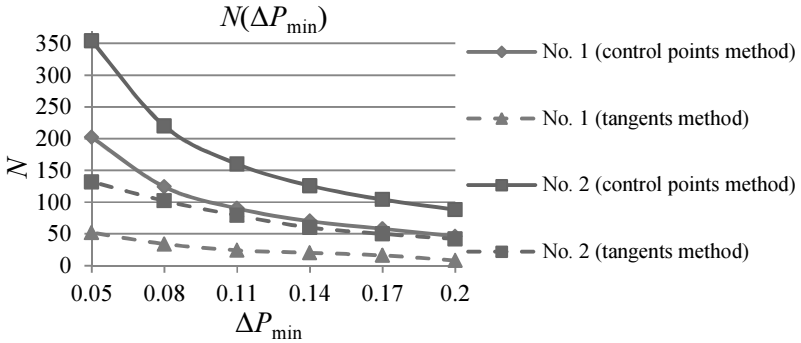


Fig. 7. Contact switching quantity dependencies of the displacement length graph

A conclusion can be made that the control points method can be used to shape high-precision motion trajectories, especially in the points of the trajectories where curvature radius is rapid decline.

Motion trajectory formation with control points method was analyzed according to the minimum angular displacement. Three points were selected. Trajectory, which segments are close to straight line, was planned. It was noticed that quantities of switching contacts depend on the inner radius R of piezorobot. Generated trajectory switching contacts quantity T and control point's quantity T^* ratio was calculated, when minimum displacement is 0.5, 0.3 and 0.1 (Fig. 8).

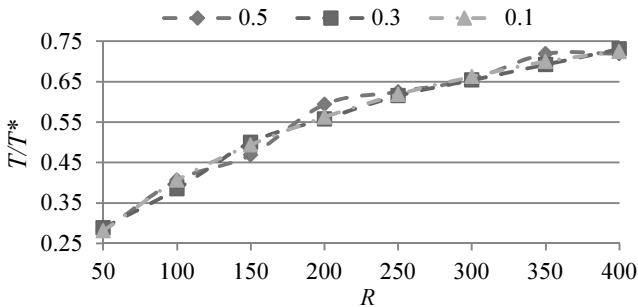


Fig. 8. Generated trajectory switching contacts quantity and control point's quantity ratio dependence on inner radius of piezorobot

Results of experiment showed, that changing motion resolution leaves contacts quantity T and control point's quantity T^* ratio almost constant. Also the exploration of the loss of accuracy δ_ε in shaping trajectories done. Research results presented in Fig. 9.

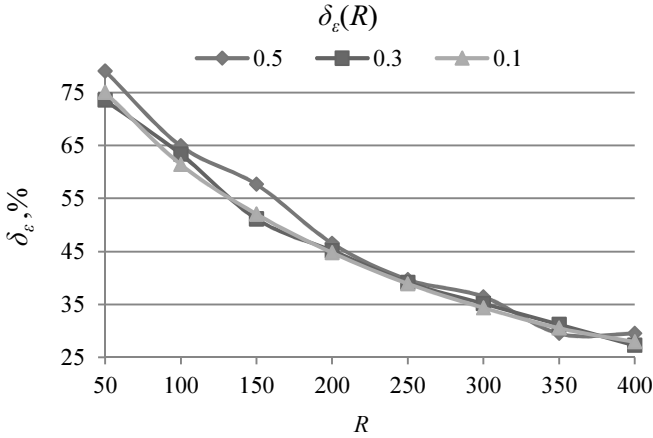


Fig. 9. Loss of accuracy depending from geometric dimensions of piezorobot

It is clear from research results that loss of accuracy is more dependent on piezorobot geometric dimensions than on minimal length of displacement. The bigger R , the more precise planned curve.

Summarizing results of experiments the formula of calculation for optimal piezorobot orientation angle was derived. It was identified, that this angle must be twice smaller than angle between symmetric axes of electrodes segments. A comparative analysis of trajectories formed by control points and tangents methods, showed that control points method can be used to shape high-precision motion trajectories. Trajectories formed by control points method have more than double amount of contacts switching than method of tangents. That's why speed of piezorobot will be slowest and motion duration longest.

After analyzing precision of formed trajectories, a conclusion can be made, that selection of proper geometrical measurements of piezorobot it is possible to increase precision of formed trajectory about 25 %.

General Conclusions

1. High precision piezorobots work analysis showed that for motion generation is not used direct piezoelectric motion actuators, but is used additional structures (legs, wheels), which allows to forming trajectory using classical methods: polynomial interpolation, interpolation by splines and Cornu spiral. There is no such piezorobot that uses direct contact points for motion generation.
2. Analysis of trajectory formation methods showed that taking into consideration piezorobots structure and motion principles no one of trajectory formation methods are valid to created piezorobots.
3. New motion formation algorithms, considering piezorobot electrodes segments exiting schemas, motion resolution and trajectory type, were created. According to algorithm results it is possible to model piezorobot behavior and solve robot control tasks.
4. After quantitative analysis of formed motion trajectories, determined that such parameters as piezorobot geometrical measurements, quantity of electrodes, their symmetry axis orientation to planned trajectory, motion resolution have impact on formed trajectory characteristics: quantity of electrodes segments switching, motion displacement length, accuracy of trajectory replication.
5. According to the analysis results it is possible to state that in order to maintain the accuracy of replication trajectory it is recommended to use point to point and control points methods. In order to increase the motion speed the most appropriate is the method of tangents. After selecting angle which is twice smaller than angle between symmetric axes of electrodes segments, method of switching contacts that distinguishes by simple control of piezorobot can be used. Selecting of proper geometrical measurements of piezorobot is possible to increase precision of formed trajectory using control points method about 25 %.
6. Calculation methodology of minimum deflection from planned trajectory was created for each trajectory formation method. Evaluation of this parameter allows prognosticate critical stops of the piezorobot.

List of Published Works on the Topic of the Dissertation

In the reviewed scientific periodical publications

Bansevicius, R.; Drukteinienė, A.; Kulvietis, G.; Mazeika, D. 2010. Switching Leg Method for Trajectory Planning of Mobile Piezorobot, *Journal of Vibroengineering* 12(1): 26–33. ISSN 1392-8716. (Thomson ISI Master Journal List).

Bansevicius, R.; Drukteinienė, A.; Kulvietis, G. 2009. Trajectory Planning Method of Rotating Mobile Piezorobot, *Journal of Vibroengineering* 11(4): 690–696. ISSN 1392-8716. (Thomson ISI Master Journal List).

Bansevicius, R.; Drukteinienė, A.; Kulvietis, G. 2009. Trajectory Planning Method of Mobile Piezorobot, *Lietuvos matematikos rinkinys. Lietuvos matematikų draugijos darbai* 50: 172–177. ISSN 0132-2818. (Thomson ISI Web of Science).

Bansevicius, R.; Drukteinienė, A.; Kulvietis, G. 2010. Movement Trajectory Planning Algorithm of Rotating Mobile Piezorobot, *Solid State Phenomena: Mechatronic Systems and Materials. Mechatronic Systems and Robotics*. 164: 371–376. ISSN 1012-0394.

In the other editions

Bansevicius, R.; Drukteinienė, A.; Kulvietis, G. 2010. Adaptive Moving Algorithm of Mobile Piezorobot, in *Proceedings of the 16th International Conference on Information and Software Technologies, held in Kaunas on 21–23 April, 2010* [16-osios tarptautinės konferencijos „Informacinės technologijos 2010“ įvykusios Kaune 2010 m. balandžio 21–23 d., mokslinių pranešimų rinkinys]. Kaunas: Kauno technologijos universitetas, 143–149. ISSN 2029-0063 (Thomson ISI Proceedings).

Bansevicius, R.; Drukteinienė, A.; Kulvietis, G. 2011. Path-Planning Algorithms Analysis of Hemispheric Mobile Piezorobot, in *17th International Conference on Information and Software Technologies. Research Communications, held in Kaunas on 27–29 April, 2011* [17-osios tarptautinės konferencijos „Informacinės technologijos 2011“ įvykusios Kaune 2011 m. balandžio 27–29 d., mokslinių pranešimų rinkinys]: 31–38. ISSN 2029-0039.

About the author

Asta Drukteinienė was born in Šiauliai, on 4 of April 1979. In 2002 receives a five-year first degree in Physics and Informatics with a minor in secondary school pedagogy from Šiauliai University. 2008 Master of Informatics, Faculty of Mathematics and Informatics, Šiauliai University. In 2008–2011 – PhD student of Vilnius Gediminas Technical University. In 2005–2010 was working as assistant at the Department of Information Technologies in Šiauliai University. At present – lecturer at the Department of Information Technologies.

NANOMETRŲ SKYROS JUDANČIŲ DAUGIAMAČIŲ PJEZOROBOTŲ TRAJEKTORIJŲ FORMAVIMAS

Mokslo problemos aktualumas. Vis dažniau robotų konstrukcijose naudojami pjezoelektriniai judesio keitikliai, kuriuos galima apibūdinti kaip rezonansines sistemas, kurių veikimo principas pagrįstas aukšto dažnio virpesių žadinimu. Įrenginiai, kuriuose naudojami pjezoelektriniai judesio keitikliai, pasižymi dideliu tikslumu, mažais matmenimis, nedidele mase ir energijos sąnaudomis. Kauno technologijos universiteto (KTU) ir mokslinės draugijos „Vibrotechnika“ mokslininkų R. Bansevičiaus ir K. Ragulskio sukurti preciziniai trijų laisvės laipsnių judantys pjezorobotai gali ne tik judėti dvimatėje erdvėje, bet ir tuo pačiu pernešti objektus ar turėti manipuliavimo objektais aparatą.

Vienas iš pagrindinių tokios autonominės sistemos kūrimo etapų – judesio trajektorijų formavimas.

Judesio trajektorijų formavimui naudojami klasikiniai interpoliavimo metodai, kurių rezultatai – funkcijos aprašančios judančio objekto būsenas tam tikru laiko momentu. Tačiau šie metodai tinka robotams turintiems ratus, kojas ar kitas dinamines dalis.

Mokslinės draugijos „Vibrotechnika“ mokslininkų sukurti pjezorobotai neturi papildomų judesį generuojančių struktūrų, o tik kontaktus su statine plokštuma. Tiesiaeigis judesys generuojamas žadinant vieną elektrodų segmentą, o sukamasis judesys – žadinant visus elektrodų segmentus. Pjezorobotų judesio trajektorija yra laužtė. Todėl klasikiniai trajektorijų formavimo metodai netinka ir iškyla problema kaip aprašyti tokio įrenginio judesio trajektoriją.

Tyrimų objektas. Darbo tyrimų objektas – judesio trajektorijų formavimo algoritmai.

Darbo tikslas ir uždaviniai. Pagrindinis darbo tikslas – sukurti precizinių daugiamatį pjezorobotų judesio trajektorijų formavimo metodus. Darbo tikslui pasiekti reikia išspręsti šiuos uždavinius:

1. Atlikti literatūros analizę apie pjezorobotų konstrukcijas, veikimo principus bei judesio trajektorijų formavimo metodus.
2. Sukurti pjezorobotų judesio trajektorijų formavimo algoritmus atsižvelgiant į elektrodų segmentų žadinimo schemas.
3. Atlikti sukurtais algoritmais suformuotų judesio trajektorijų kiekybinių charakteristikų tyrimą.

Tyrimų metodika. Literatūros analizė atlikta tiriant pjedorobotų konstrukcijas ir veikimo principus, trajektorijų formavimo metodus. Matematinio modeliavimo metodai taikomi skaitinių algoritmų sudarymui ir analizei. Lyginamosios analizės metodai naudoti tiriant suformuotų trajektorijų kiekybines charakteristikas. Apibendrinant gautus rezultatus ir pateikiant praktines rekomendacijas buvo taikomi apibendrinimo metodai.

Mokslinis naujumas

1. Pasiūlytas pirmasis judesio trajektorijos formavimo algoritmas su integruotais klasikiniiais trajektorijų formavimo metodais planuojant judesio trajektoriją pjedorobotui su tiesioginiais kontaktų taškais.
2. Sukurti nauji analogų neturintys precizinių pjedorobotų trajektorijų generavimo metodai, formuojant įvairaus tipo trajektorijas, žadinant elektrodų segmentus skirtingomis žadinimo schemomis ir esant įvairiam elektrodų segmentų kiekiui. Judesio trajektorijos generavimas atliekamas įvertint pjedorobotų tiesiaieigio judesio ir posūkio skyrą.
3. Sukurtas trajektorijų formavimo metodas, leidžiantis projektuoti ir analizuoti autonomines judančias dviejų dimensijų plokštumoje sistemas.

Praktinė vertė. Tyrimų rezultatai pateikti aukštųjų technologijų programoje „Mechatroninių nanometrų skyros daugiamačių poslinkių generavimo/matavimo sistemų kūrimas ir tyrimas“ (Nr. B-07017), mokslinių tyrimų projekte „Mechatroninių nanometrų skyros daugiamačių robotizuotų įtaisų modeliavimas ir valdymas“ (Nr. MIP-122/2010).

Trajektorijų formavimo algoritmas gali būti taikomas pjedorobotų judesį modeliuojančiai programinei įrangai. Sukurtų algoritmų rezultatai leidžia spręsti pjedorobotų judesio valdymo uždavinius.

Ginamieji teiginiai

1. Sukurtasis kontaktų perjungimo metodas, parinkus optimalų pjedoroboto orientacijos kampą, tinkamas trajektorijų sekimo uždaviniams spręsti.
2. Sukurtasis liestinių metodas tinkamas formuoti trajektorijas, kuriomis pjedoroboto vidutinis judėjimo greitis būtų didžiausias.
3. Pasiūlytieji nuo taško prie taško ir kontrolinių taškų metodai tinkami formuoti aukšto tikslumo judesio trajektorijas.
4. Judesio trajektorijų generavimo algoritmų rezultatai leidžia modeliuoti pjedorobotų elgseną.

Darbo apimtis. Darbą sudaro įvadas, trys skyriai, išvados, literatūros sąrašas, publikacijų sąrašas ir priedai. Bendra disertacijos apimtis – 124 puslapiai, 70 formulių, 97 iliustracijos, 11 lentelių, 6 priedai.

Pirmajame skyriuje analizuojama literatūra apie pjezoelektrinius judesio keitikius naudojančius judančius robotus, išanalizuotos jų struktūros bei veikimo principai. Pateikti klasikiniai judesio trajektorijų formavimo metodai. Skyriaus pabaigoje formuluojamos išvados.

Antrajame skyriuje formuluojamas pjezoroboto judesio trajektorijos formavimo uždavinys. Pateikiami detalūs trajektorijų formavimo algoritmų aprašymai bei matematinio modelio realizavimo rezultatai.

Trečiajame skyriuje tiriamos sukurtais algoritmais suformuotų judesio trajektorijų kiekybinės charakteristikos. Pasiūlyta metodika nustatant mažiausią judesio trajektorijos atsilenkimą nuo planuojamos trajektorijos bei parenkant optimalų pjezoroboto orientacijos kampą.

Darbo pabaigoje pateikiamos išvados apie atliktus tyrimus ir gautus rezultatus.

Bendrosios išvados

1. Atlikus pasaulio mokslininkų sukurtų pjezorobotų darbų analizę nustatyta, kad šie robotai judėjimo generavimui naudoja ne tiesioginius pjezoelektrinius keitikius, bet ir papildomas konstrukcijas (ratus, kojas ir pan.), o tai leidžia formuoti judesio trajektorijas klasikiniiais metodais: interpoliavimas polinomialais, įvairaus tipo splainais, Kornu spirale. Tačiau nėra pjezoroboto, kurioje judesio generavimui naudotų tiesioginius kontakto taškus.
2. Atlikus robotų judesio klasikinių trajektorijų formavimo metodų analizę, nustatyta, kad atsižvelgiant į nagrinėjamo pjezoroboto struktūrą, segmentų žadinimo schemas ir judėjimo principus nei vienas trajektorijos formavimo metodas netinka sukurtų pjezorobotų judesio trajektorijų formavimui.
3. Sukurti nauji judesio trajektorijų apskaičiavimo algoritmai įvertinantys pjezoroboto elektrodų segmentų žadinimo schemas, judesio skyrą bei trajektorijos tipą. Šie judesio trajektorijų formavimo algoritmai gali būti taikomi daugiamačių pjezorobotų judesio modeliavimui. Todėl remiantis algoritmų rezultatais galima spręsti pjezorobotų valdymo uždavinius.
4. Atlikus suformuotų judesio trajektorijų kiekybinę analizę, nustatyta, kad parametrai, tokie kaip pjezoroboto geometriniai matmenys, elektrodų segmentų kiekis, jų simetrijos ašių orientacija planuojamos

trajektorijos atžvilgiu, judesio skyra įtakoja formuojamos trajektorijos charakteristikas: elektrodų segmentų perjungimo kiekį, judesio poslinkio ilgį, suplanuotos trajektorijos atkartojimo tikslumą.

5. Remiantis tyrimo rezultatais galima teigti, kad norint išlaikyti trajektorijos atkartojimo tikslumą rekomenduojama naudoti nuo taško prie taško ir kontrolinių taškų metodus. Siekiant didesnio judėjimo greičio tinkamiausias yra liestinių metodas. Parinkus pjezoroboto orientacijos kampą 2 kartus mažesnį už kampą tarp elektrodų segmentų simetrijos ašių, galima naudoti ir kontaktų perjungimo metodą, kuris pasižymi ir paprastu pjezoroboto valdymu. Taip pat parinkus tinkamus pjezoroboto geometrinius matmenis, formuojant trajektoriją kontrolinių taškų metodu, trajektorijos atkartojimo tikslumą galima padidinti daugiau nei 25 %.
6. Sukurtos mažiausio atsilenkimo nuo suplanuotos trajektorijos apskaičiavimo metodikos kiekvienam judesio trajektorijos formavimo metodui. Šio parametro įvertinimas leidžia prognozuoti pjezoroboto kritinės sustojimo būsenas.

Trumpos žinios apie autorę

Asta Drukteinienė gimė 1979 m. balandžio 4 d. Šiauliuose.

2002 m. įgijo Fizikos bakalauro laipsnį bei fizikos ir informatikos mokytojo kvalifikacinį laipsnį Šiaulių universitete. 2008 m. įgijo informatikos magistro laipsnį Šiaulių universiteto, Matematikos ir informatikos fakultete. 2008–2011 m. – Vilniaus Gedimino technikos universiteto doktorantė. 2005–2010 m. dirbo asistente Informacinių technologijų katedroje Šiaulių universitete. Šiuo metu dirba lektore.

Asta DRUKTEINIENĖ

TRAJECTORIES FORMATION FOR MOBILE MULTIDIMENSIONAL
PIEZOROBOTS WITH NANOMETER RESOLUTION

Summary of Doctoral Dissertation
Technological Sciences, Informatics Engineering (07T)

Asta DRUKTEINIENĖ

NANOMETRŲ SKYROS JUDANČIŲ DAUGIAMAČIŲ PJEZOROBOTŲ
TRAJEKTORIJŲ FORMAVIMAS

Daktaro disertacijos santrauka
Technologijos mokslai, informatikos inžinerija (07T)

2011 10 03. 1,5 sp. l. Tiražas 70 egz.
Vilniaus Gedimino technikos universiteto
leidykla „Technika“,
Saulėtekio al. 11, 10223 Vilnius,
<http://leidykla.vgtu.lt>
Spausdino UAB „Ciklonas“
J. Jasinskio g. 15, 01111 Vilnius