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VSGA Method Based Trajectory Planning of a Novel Limb-robot

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Abstract

A new progressive genetic algorithm (PGA) was developed for trajectory planning of a novel limb-robot. The proposed trajectory planning method can be applied to get an optimal joints trajectory from the initial to the end position and orientation. On the basis of the genetic algorithm a new kind of variable structure genetic algorithm (VSGA) is proposed to solve the problem of trajectory planning of the limb-robot in complicate environments. The VSGA changes the original structure by abandoning Elitist Model, expectation selection, reproducing population and changing the probability of crossover and mutation. Experiments results show that the PGA is effective in static environments and the VSGA does well in complicate environments.

Keywords: *limb-robot; trajectory planning; VSGA method*

1. Introduction

An increasing interest in the development of special climbing robots has been witnessed in last decades. The motivations behind it are to increase operation efficiency and protect human health and safety in dangerous tasks, such as cleaning high-rise buildings, spray painting and sand blasting of gas tanks, inspecting and maintaining nuclear facilities. Climbing robots, with their capabilities to adhere to wall surfaces and move around carrying appropriate sensor or tools, are able to replace human workers in these dangerous duties and eliminate costly erection scaffolding [1].

And at the same time, climbing robots should have the operation capability. Japanese researcher professor Noriho Koyachi developed a new concept of limb structure of walking robots [2]. The major Characteristic of limb structure is that the “limb” of a robot can be used to both walk and operate. This paper introduces such a limb-robot.

Limb-robot is a joint type robot which is difficult to plan its motion in dynamic spaces. The problem of motion planning with obstacle avoidance has been extensively studied over the last decade. The main task of motion planning for robot end effectors is to find an collision-free trajectory from an initial to a final configuration. Henrich et al. [3] presented a heuristic hierarchical search method for an industrial robot with 6 degree of freedom (DOF). The collisions are detected in the Cartesian workspace by a hierarchical distance computation based on the given CAD model, which is done by adjusting the step size of the search to the distance between the robot and the obstacle. Recently, genetic algorithms (GAs) have been applied to robot path and motion planning problems. Yano and Tooda [4] applied a genetic algorithm to solve the position and movement of an end effector on the tip of a two joint robot arm. He defined objective functions in both Cartesian space and joint space, and combined them to optimize the robot trajectory. Optimum solutions with smooth trajectories and minimal joint rotation were obtained. Shintaku [5] proposed a simple method based on a genetic algorithm, where a polynomial approximates time histories of the trajectory in joint space. The genetic algorithm determines the parameters of the polynomial to minimize the fitness of the objective function. Pack developed a method to search for valid solution in configuration space based on genetic algorithm. He formulated the trajectory planning problem with point obstacles. His method can also be extended to an n-dimensional space. Lianfang Tian and Curtis Collins [6]

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also proposed a genetic algorithm based trajectory planning method for a two degree of freedom robot manipulator whose workspace includes several point obstacles.

In this paper, a novel motion and trajectory planning method for a three-limed robot's end effectors is developed. Unlike the robots that referred by the researchers above (their joint hypothetically can rotate from 0 to 2π), the motion planning of the limb-robot is more difficult because of the restraint of its joint. Especially in the dynamic environments this will bring abortion of the almost all individual in the current population. Furthermore, the algorithm can easily stop or oscillate at a local pole. The proposed VSGA can be used to solve the problem and find a feasible planning finally.

The rest of the paper is organized as follows. In section 1, the novel mechanical structure of the limb-robot is introduced in brief. Section 2 presents the mathematical description of the path planning for the limb-robot, and then the motion planning using genetic algorithm is given. Section 3 VSGA is proposed to solve the problem of motion planning in dynamic environment. Experiments results are presented in section 4. Conclusions are drawn in section 5.

2. Mechanical Structure

The purpose of the limb-robot is semi-autonomous reconnaissance in dynamic and unstructured environments. We choose a mechanical structure illustrated in Figure 1 with nine joints driven by nine motors so that the robot can walk and operate flexibly. The dimension of the prototype robot is approximately 240mm in height, 230mm in width. The robot weight, without onboard hardware, is approxim- ately 7700 gram.

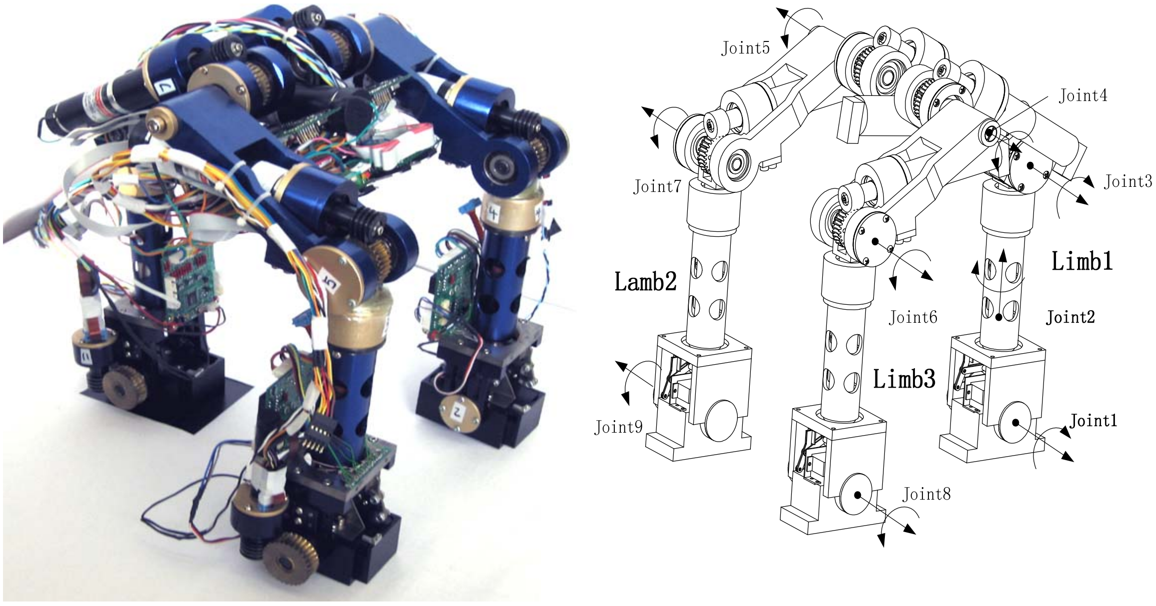


Figure 1. The limb-robot with suction cups prototype

The simulation experiments in this paper are realized in the human-robot interface based on Java/Java3D develop platform. This interface integrates the command user interfaces, mission planner, motion planner, trajectory planner, dynamics algorithm and 3D virtual environment in one, which make operator easily control and supervise the robot.

3. Motion Planning of Limb-robot Based on Progressive Genetic Algorithm

3.1. Configuration Description

Define the configuration as follow:

$$c_i = [\theta_{i1}, \theta_{i2}, \cdots, \theta_{in}] \quad i = 1, \cdots, m \qquad (1)$$

Where n is the number of robot joints, m is the total number of the amount of robot configuration in a path. Then the path can be defined as:

$$p = \{c_1, c_2, \cdots, c_m\} \qquad (2)$$

Robot path planning is defined as follow:

(1) Robot should move along the “p” path to arrive at the aim point.

(2) Impliedly, ci can represent the configuration of robot at any time.

(3) If the “p” path is accordant with the two above, then it is a feasible path.

(4) If the “p” path is accordant with the optimization rule such as shortest path or shortest time, then it is a optimization path.

3.2. Parameter Coding

GA is a search engine based on neighborhood concept. We have the definition: on the assumption that c1 and c2 is two of the robot configuration, where $c_1 = [\theta_{11}, \theta_{12}, \cdots, \theta_{1n}]$, $c_2 = [\theta_{21}, \theta_{22}, \cdots, \theta_{2n}]$.If a given angle ε is accordant with the condition $\max\{|\theta_{1i} - \theta_{2i}|\} < \varepsilon$ for all the element of the sets $\{(\theta_{11}, \theta_{21}), (\theta_{12}, \theta_{22}), \cdots, (\theta_{1n}, \theta_{2n})\}$, then c1 and c2 is neighborhood each other. If predefine a fixed angle ε which is the maximum angle movement of any joint from one configuration to other, then any configuration can be represented as $[s_1, s_2, \cdots, s_n]$,

Where $s_i \in \{-2, 0, +2\}$ represent the rotation direction of joint i. So a completed path of robot can be represented as:

$$([s_{11}, s_{12}, \cdots, s_{1n}], [s_{21}, s_{22}, \cdots, s_{2n}], \cdots, [s_{m1}, s_{m2}, \cdots, s_{mn}]) \qquad (3)$$

Each individual of GA population is represented by the vector (3). When $\varepsilon \to 0$ and $m \to \infty$, vector (3) will steer the robot to the aim position.

3.3. Fitness Evaluation

Genetic algorithm is an optimization method with multi constrained condition. Fitness function is essentially objective function in optimization problem. The optimization trajectory should be accordant with the rule as follow:

$$Fitness = C_{\max} - d \qquad (4)$$

Where, d is the distance of the initial position and target position of robot end effectors; Cmax is a positive constant.

3.4. Operator Genetic Algorithm

Firstly fitness proportion method is used to realize reproduction. According to fitness function, reproduction probability is gotten which is used to decide the number of offspring of current individual. The individual that has a bigger copy probability would have more offspring. The individual that has smaller copy probability may be eliminated. Then decide the crossover probability Pc, and construct the matching pool in term of Pc. The individual in the matching pool is matched randomly. The position of crossover is also decided randomly. Finally, the individual has the opportunity of the probability Pm to mutate.

3.5. Implement of Genetic Algorithm

Thus the step of the genetic algorithm is as follow:

Step 1: decide the range of each factor and the length of the chromosome code.

Step 2: randomly produce n individual to construct the initial population P(0).

Step 3: decode each individual and get the fitness of each individual.

Step 4: operate the population P(t) according to the reproduction, crossover and mutation operator, then produce the population P(t+1).

Step 5: repeat the step(3) and step(4) until the current phase target is achieved or approached.

Step 6: repeat the step (1)~(5) until the final position is achieved.

According to the algorithm above, the joint trajectory is gotten as Figure 2.

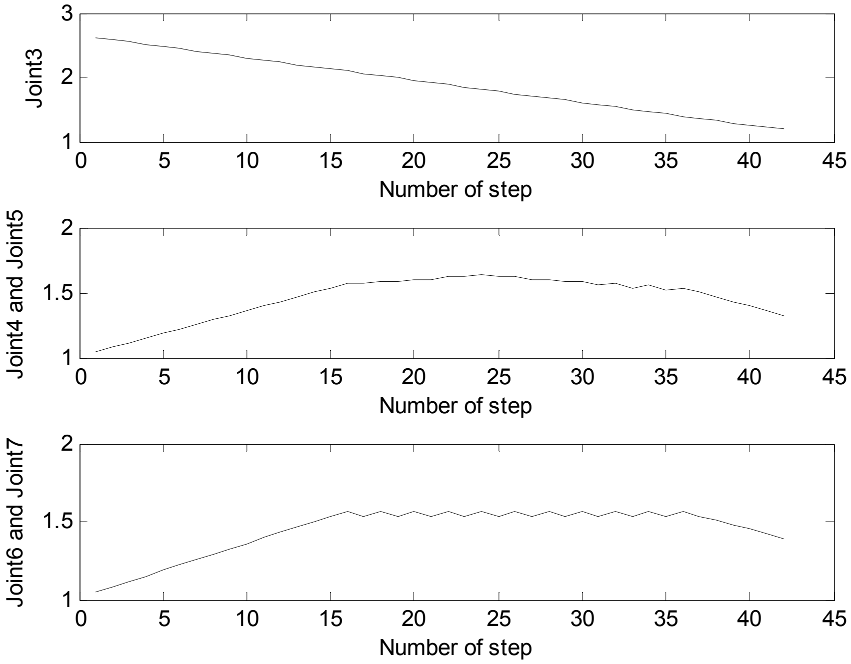
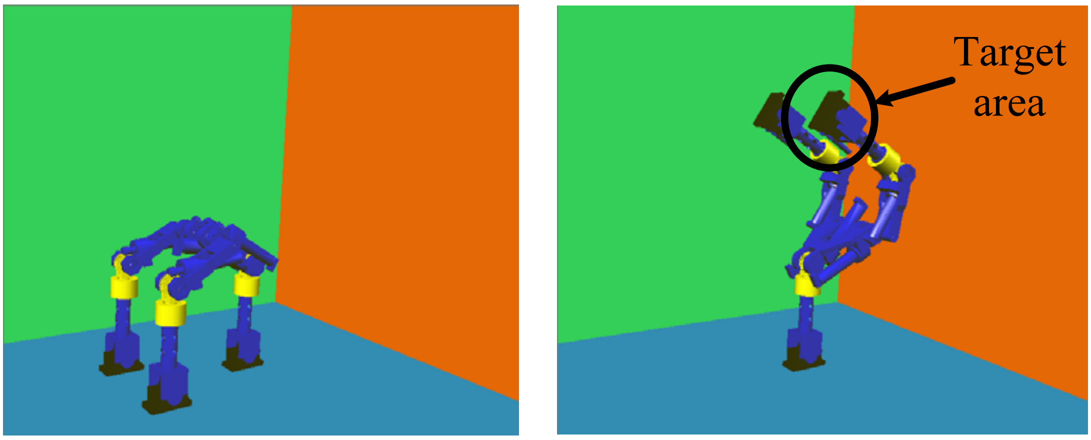


Figure 2. The joint trajectory computed by the genetic algorithm

Joint 3, 4, 5, 6 and 7 are used to realize this motion. Our objective is to let the robot end effectors attain the final position. Fig.3 shows that the initial and final position and orientation of the limb-robot.



(a) (b)

Figure 3. The initial and final position and orientation

4. VSGA

Now let us suppose that an obstacle appear and the robot may collide with the obstacle. The results using the genetic algorithm above are shown as Figure 4.

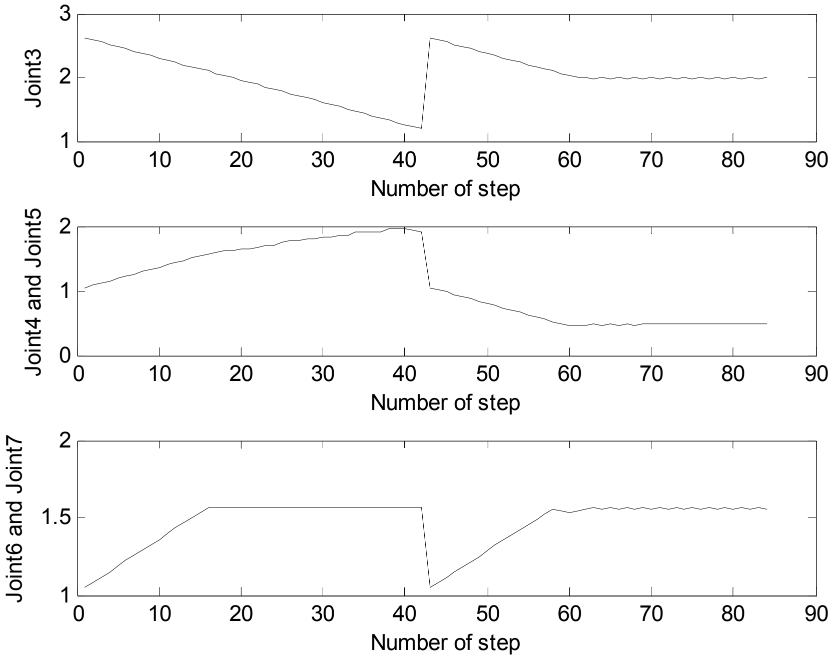


Figure 4. The joint trajectory computed by when robot

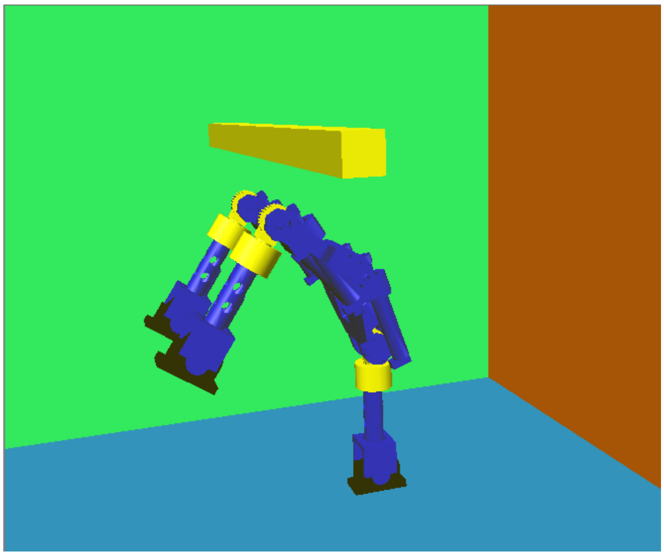


Figure 5. The robot oscillate at the obstacle area

In Figure 4 we can see the latter trajectory is an oscillation at a local pole. This is because the individual in the latter population are all aborted. To solve the problem the VSGA is developed here. The algorithm changes the original structure by abandoning Elitist Model, expectation selection, reproducing population and changing the probability of crossover and mutation.

4.1. Fitness Evaluation

Fitness function can be defined as follow:

$$Fitness = C_{\max} - \sum_{i=1}^{4} w_i f_i \tag{5}$$

Where, C_{max} is a positive constant; $f_1 \in \{0,1\}$ represents the effectiveness of the current configuration; f_2 represents the amount of collision between robot and obstacle; f_3 represents the distance between robot and objective; f_4 is the step length. In the process of population evolvement, the individual with higher fitness would have more chance to participate in the competition in the next generation; the individual with lower fitness would be eliminated gradually.

4.2. Elitist Model and Reproduce Population

In the genetic algorithm above Elitist Model will provide the motion direction until the robot gets to the target area. In dynamic environments Elitist Model will bring forth an oscillation at a local pole. So in such a generation Elitist Model should be abandoned. In addition, because of the restraint of joints and existence of some obstacles almost all the individual abort. The current population will be replaced by a new population produced randomly.

4.3. Expectation Selection Method

Expectation selection method is shown as follow:

(1) Compute the expectation $\overline{f_i}$ of the fitness

$$\overline{f_i} = \frac{1}{n}\sum_{i=1}^{n} f_i \tag{6}$$

(2) Compute the expectation of each individual in the population

$$\overline{R_i} = \frac{f_i}{\overline{f_i}} \tag{7}$$

4.4. Adjusting the Probability of Crossover and Mutation

The probability of selection and mutation can be adjusted adaptively according to the formulation as follow:

$$P_{\mathrm{c}} = P_{\mathrm{c}0} - \frac{f_{t,\mathrm{c}}^{i} - f_{t,\min}}{f_{t,\max} - f_{t,\min}} \cdot \frac{1}{1+e^{-\mathrm{k_c}\Delta_i}} \tag{8}$$

$$P_{\mathrm{m}} = P_{\mathrm{m}0} - \frac{f_{t,\mathrm{m}}^{i} - f_{t,\min}}{f_{t,\max} - f_{t,\min}} \cdot \frac{1}{1+e^{-\mathrm{k_m}\Delta_i}} \tag{9}$$

Where $f_{t,\mathrm{c}}^{i}$ is the bigger fitness one between the two crossover individual; $f_{t,\mathrm{m}}^{i}$ is the fitness of the individual that are going to mutate; P_c is crossover probability; P_m is mutation probability; P_{c0} is initial crossover probability; P_{m0} is initial mutation probability; K_c is constant, decided by experiments; K_m is constant, decided by experiments.

4.5. Experiments Results

In allusion to the environment referred above we used the proposed VSGA to plan the robot's motion. Figure 6 is the final position and orientation of the limb-robot and Figure 7 is the joints trajectory.

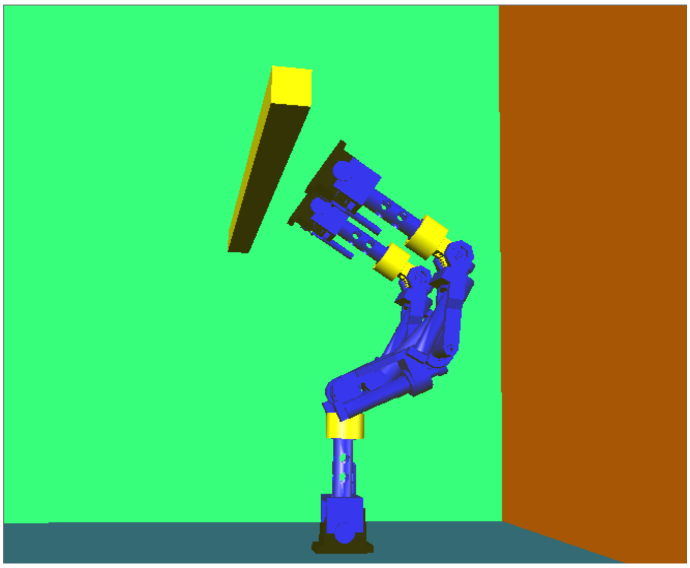


Figure 6. The final position and orientation

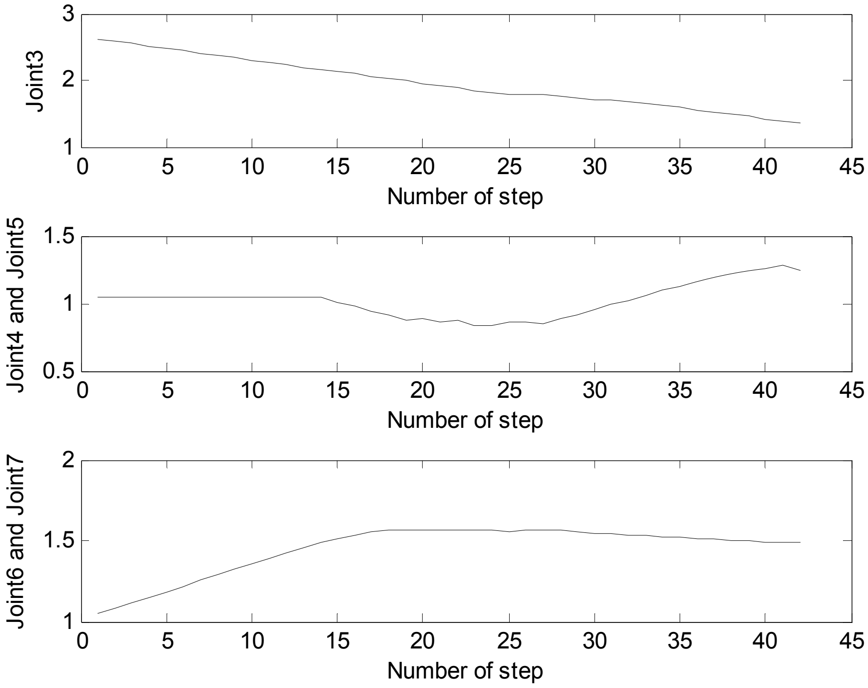
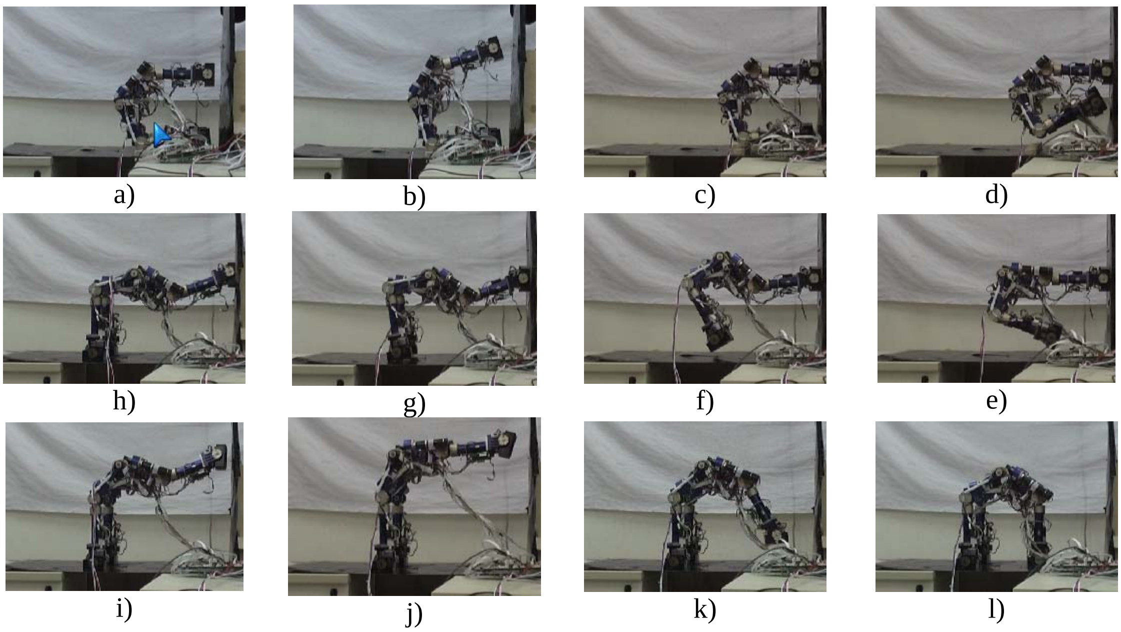


Figure 7. The joints trajectory computed by variable structure GA

Simulations results show that the VSGA can solve the motion planning problem in dynamic environments. The joints trajectory has slim oscillation in some phase seen from Figure 6. These oscillation can be eliminated easily.

Experiments photos shown in Figure 8 indicate that the VSGA is effective in a motion planning of the three limb robot.



a) b) c) d)

h) g) f) e)

i) j) k) l)

Figure 8. The experiment of the combined motion

5. Conclusion

This paper proposed a novel limb-robot with nine joints driven by nine motors in order to both walk and operate flexibly. A novel progressive genetic algorithm is developed for the motion planning of the limb-robot. Simulation example shows the feasibility of the genetic algorithm. The VSGA is proposed to realize motion planning of the limb-robot in dynamic environments. Experiments results show the validity of this kind of genetic algorithm.

References

[1] J Xiao, JZ Xiao, N Xi. Fuzzy Controller for Wall-Climbing Microrobots. *IEEE Transaction on Fuzzy System*. 2004; 12: 466-480.

[2] N Koyachi, T Arai, H Adachi, Y Itoh. “*Integrated Limb Mechanism of Manipulation and Locomotion Fro Dismantling Robot-Basis concept for control and mechanism*”. Proceedings of the 1993 IEEE/Tsukuba International Workshop on Advanced Robotics. 1993: 81-84.

[3] Henrich D, Wurll C, Worn H. *On-line path planning by heuristic search*. In: IECON’98 Proceedings of the 24th Annual Conf. of the IEEE Industrial Electronics Society, New York, NY, USA. 1998: 2239-2244.

[4] Yano F, Tooda Y. Preferable movement of a multi-joint robot arm using genetic algorithm. *In: Part of the SPIE Conf. on Intelligent Robots and Computer Vision*. 1999; 3837: 80-88.

[5] Shintaku E. Minimum energy trajectory for an underwater manipulator and its simple planning method by using a genetic algorithm. *Adv Robotics*. 1999; 13: 115-138.

[6] LF Tian, C Collins. An effective robot trajectory planning method using a genetic algorithm. *Mechatronics*. 2004; 14: 455-470.

[7] R LAL TUMMALA, RANJAN MUKHERJEE, NING XI. Climbing the walls. *IEEE Robotics & Automation Magazine*. 2002: 10-19

[8] N Koyachi, T Arai, H Adachi, Y Itoh. “*Integrated Limb Mechanism of Manipulation and Locomotion Fro Dismantling Robot-Basis concept for control and mechanism*”, Proceedings of the 1993 IEEE/Tsukuba International Workshop on Advanced Robotics. 1993; 81-84. Tsukuba Japan.

[9] Lianfang Tian, Curtis Collins. An effective robot trajectory planning method using a genetic algorithm. *Mechatronics*. 2004; 14: 455-470.

[10] VD Cueva, F Ramous. Cooperative genetic algorithm: a new approach to solve the path planning problem for cooperative robotic manipulators sharing the same work space. *IEEE/RSJ International Conference on Intelligent Robots and Systems*. 1998: 267-272.

[11] LC Jiao, L Wang. A novel genetic algorithm based on Immunity. *IEEE Transactions on systems, man, and cybernetics*. 2000; 30(5): 552-561.

[12] Gao Sheng, Zhao Jie, Cai Hegao. Adaptive genetic algorithm to the path planning of loosely

coordinated multi-robot manipulators. *Journal of Harbin Institute of Technology*. 2003; 1: 72-7.

[13] T Arai, H Adachi, et. Integrated Arm and Leg Mechanism and Its Kinematic Analysis. *IEEE International Conference on Robotics and Automation*. 1995: 994 – 999.

[14] N Senjo, R Murata, T Arai. *Control of Walk and Manipulation by A Hexapod with Integrated Limb Mechanism MELMEATIS-1*. Proceedings of the 2002 IEEE international Conference on Robotics and Automation. 2002: 3553-3558.

[15] Y Takahashi, T Arai, Y mae, K Inoue, N Koyachi. *Development of Multi-Limb Robot with Omnidirectional Manipulability and Mobility*. Proceedings of the 1996 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS'2000). 200: 2012-2017.

[16] T Takubo, T Arai, K Inoue, T Konishi. Integrated Limb Mechansim Robot ASTERISK. *Journal of Robotics and Mechatronics*. 2006, 18(2): 203-214.

[17] T Takubo, T Arai, K Inoue, H Ochi, T Konishi, T Tsurutani, Y Hayashibara. Integrated Limb Mechanism Robot ASTERISK. *Journal of Robotics and Mechatoronics*. 2006; 18(2): 203-214.

[18] S Fujii, K Inoue, T takubo, T Arai. Climbing up onto Steps for Limb Mechanism ROBOT ASTERISK. *23rd International Symposium on Automation and Robotics in Construction*. 2006: 225–230.

[19] K Kato S. Hirose. Development of Quadruped Walking Robot for Humanitarian Demining. Proposition of the System and Basic Experiment of Several Foot-end-effectors. *Robotics and Mechatronics*. 2000; 12(3): 261-267.

[20] S Hirose, K Kato. Development of Quadruped Walking Robot with the Mission of Mine Detection and Removal - Proposal of Sharp-Feedback Master-Slave Arm. *IEEE International Conference on Robotics and Automation*. 1998: 1713-1781.

[21] Y Ota, K Yoneda, Y Muramatsu, S Hirose. *Development of Walking and Task Performing Robot with Bipedal Configuration*. Proceeding of IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2001). 2001: 247–252.

[22] JL Oliveira, LP Reis, BM Faria, F Gouyon. An Empiric Evaluation of a Real-Time Robot Dancing Framework based on Multi-Modal Events. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(8): 233-240.

[23] XH Chen. A Rough Neural Network Algorithm for multisensor Information Fusion. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(6): 123-129.