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Simultaneous Optimization of a Robot Structure and a Control Parameter using Evolutionary Algorithm and Dynamics Engine

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Abstract– A wheeled mobile mechanism with a passive and/or active linkage mechanism for traveling in the outdoor environment is developed and evaluated. In our previous research, we developed a wheeled mobile robot which has six wheels and a passive linkage mechanism, and its maneuverability was experimentally verified. The ability to climb over a 0.20 [m] high bump, which is twice height of the wheel diameter of 0.10 [m], was achieved, and the mobile robot can climb up continuous steps of 0.15 [m] high.

In this research, we optimized the mobile robot linkage mechanisms and controller parameters by evolutionary algorithm and dynamics engine in numerical simulations. The evolutionary algorithm employed in this research is Genetic Algorithm, and Open Dynamics Engine is used for dynamics calculation. To optimize the linkage mechanism and a controller parameter, we investigated outdoor environment for the mobile robot, for example obstacles, steps, and stairs. And, we selected typical three kinds of outdoor environments, 0.20 [m] high bump, right angle stairs, and angled stairs. In the numerical simulation, though the mobile robot using parameters which express our existing robot could climb up/down the 0.20 [m] high bump, but it could not achieve climbing up/down the two kinds of stairs. On the other hand, the optimized parameter mobile robot could climb up/down the three kinds of typical environments.

1. Introduction

This work concerns one of the most important issues for mobile robots, designing a structure and a controller for effective mobility. Recently, a wheeled mobile mechanism with a passive and/or active linkage mechanism for outdoor environment is developed and evaluated; for example, the NASA/JPL developed the Rocker-Bogie mechanism installed in Sojourner [1, 2], Kuroda et al. developed the PEGSUS mechanism installed in Micro 5 [3], EPFL developed original passive linkage mechanism installed in Shrimp [4] and CRAB [5], and Chugo et al. developed a prototype vehicle with a Rocker-Bogie mechanism and Omni-wheels [6]. The common features of these robots are small diameter wheels, a passive linkage mechanism and high mobility on rough terrain without a reduction in mobility on a flat surface.

In our previous research, we developed a wheeled mobile robot, “Zaurus” (Figure 1), which had six wheels and a linkage mechanism, and its maneuverability was experimentally verified [7, 8, 9]. The ability to climb over a 0.20 [m] high bump, which is twice height of the wheel diameter of 0.10 [m], was achieved, and the mobile robot can climb up continuous steps of 0.15 [m] high.

Here, the mobile robots ability of traveling outdoor environments depends on its linkage structures and control parameters. In this paper, we propose a simultaneous optimization method for an outdoor mobile robot structure and a controller parameter using evolutionary algorithm and dynamics engine. Our proposed method shows its effectiveness in numerical simulations.

2. Simultaneous Optimization Method

2.1. Open Dynamics Engine

Open Dynamics Engine (ODE) is being developed by Russell Smith since 2001. ODE is a library for simulating articulated rigid body dynamics. It is fast, flexible and robust, and it has build-in collision detection.

In our research, ODE was used as the development environment for modeling the mobile robot and traveling environment because of its high calculation cost.

2.2. Simultaneous Optimization Method

Figure 2 shows the diagram of the simultaneous optimization method. Genetic Algorithm (GA) generates the mobile robot parameters, for example length of the links, wheels diameter, and controller parameters. ODE creates a mobile robot using these parameters and evaluates their evaluation cost.

In this research, the optimization parameters are the length and angle of the front-fork, rear link, and side link, wheel radius, center of gravity of a robot's body, and proportional control gain. This optimization problem has 2^{96} searching space because the number of optimization parameter is 12 and each parameter is expressed in 8bit. Figure 3 shows the various mobile robots generated from genes.

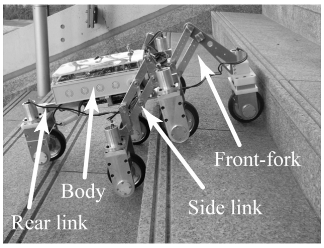


Figure 1 Overview of a mobile robot, "Zaurus".

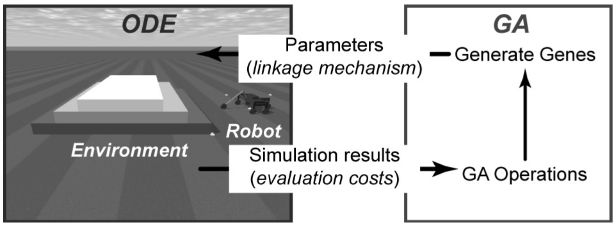


Figure 2 Diagram of our optimization program using Open Dynamics Engine and Genetic Algorithm.

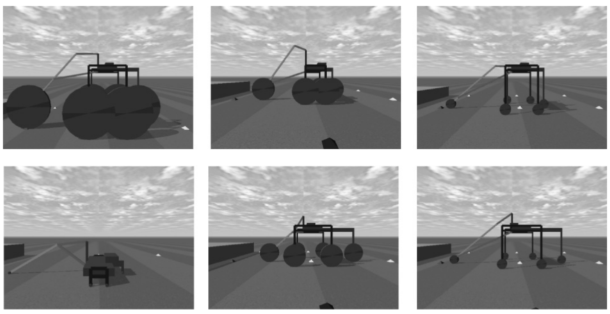


Figure 3 Genes generate various mobile robots.

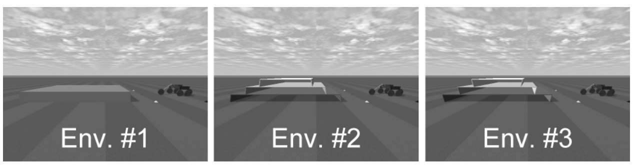


Figure 4 Three kind of typical environments.

2.3. Evaluation Function

The information of genes is evaluated in three kinds of benchmark environments as shown in Figure 4. Environment #1 (Env. #1) is a single 0.20 [m] height of bump, Environment #2 (Env. #2) and Environment #3 (Env. #3) are three-step stairs which consists of 0.30 [m] tread and 0.15 [m] rise. The tread face and rise face cross at right angles in Env. #2 and the tread face and rise face take the form of an acute angle in Env. #3. Each gene is evaluated by the summation of the evaluation cost in each benchmark environment.

Equation (1) shows a fitness function for a gene which is simulated in one benchmark environment.

$$\begin{aligned} &position &&: f_{xi}(x_e - r_x) \\ &time &&: f_{ti}(t_e - r_t) \\ &torque &&: f_{\tau i}\left(r_\tau - \sum \tau\right) \\ &control &&: f_{ei}\left(r_e - \sum e\right),\quad e_t = v_{ref} - v_t \end{aligned} \tag{1}$$

Here, x_e is the position of the mobile robot when the simulation is finished. t_e is the remaining time when the simulation is finished. τ is the consumption torque for driving a wheel. e is the error of target velocity and traveling velocity of mobile robot. $\boldsymbol{r} = [r_x\ r_t\ r_\tau\ r_e]^T$ is reference values for evaluation. In this research, the simulation results using existing robot parameters are used as the reference values.

$f(x)$ is sigmoid function shown in Equation (2).

$$f(x) = \frac{1}{1 + \exp(-x)} \tag{2}$$

A gene's evaluation cost is obtained from Equation (3).

$$Evaluation\ Cost = \sum_i \left\{ f_{xi} + f_{ti} + f_{\tau i} + f_{ei} \right\} \quad (i : Environment\ Number) \tag{3}$$

3. Simulation

3.1. Simulation Assumption

One age has 100 genes, and 150 ages are simulated. A gene is simulated in one environment until 12000 step (= 60 [s]) or traveling distance comes at more than 5 [m]. The gene is simulated three kind of typical environments and it is evaluated by a summation of the evaluation costs.

An initial gene is generated randomly. In this research, we prepared two kind of initial genes. Both genes (Gene #1, #2) are generated randomly, but Gene #2 has one gene which expresses the existing robot parameters. Gene #2 is expected the existing robot's linkage mechanism is optimized in the short simulation time, and Gene #1 is expected to generate a novel linkage mechanism.

To be used as reference, the gene which expresses the existing mobile robot parameters is simulated. In the Env. #1, the gene achieved climbing over and down the 0.20 [m] bump. In the Env. #2, the gene achieved climbing up the stairs, but could not achieve climb down the stairs. In the Env. #3, the gene could not achieve climbing up and down the stairs. Based on the these results, we defined the reference values, ***r***, of Equation (1).

3.2. Simulation Result

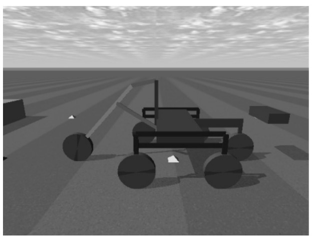
Figure 5 shows the overview of optimized Gene #1, and optimized Gene #2. The optimized Gene #1 is has large linkage mechanism (front-fork, side link, and rear link) and COG of body came backward. Meanwhile, the optimized Gene #2 has almost same linkage mechanism as existing robot but vehicle height became lower than existing robot, and COG of body came forward.

Figures 6 and 7 show the simulation results using two kind of gene.

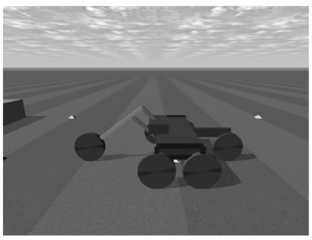
Figure 6 shows transition of the evaluation cost and control parameter. The horizontal axis shows the simulation age, and vertical axis shows the evaluation cost and control parameter. In Figure 6 (a), the Gene #1 is optimized in 150 ages constantly, and near the 150ages, the optimized gene achieved passing through the three environments. In Figure 6 (b), the Gene #2 is achieved passing through the three environments at 50 ages.

Figure 7 shows the control parameter evaluation. The horizontal axis shows the control gain, and vertical axis shows the evaluation cost. As regards the control parameter, the simulation results showed the high control gain is not always showing the good performance. Finally, we obtained the optimized control gains; 51.2 for Gene #1 and 35.8 for Gene #2.

Figure 8 shows the dynamics simulation results of each optimized genes. The optimized Gene #1 in Figure 8 (a) could pass through the three environments, and optimized Gene #2 in Figure 8 (b) could pass through the three environments in short time comparing with Gene #1.

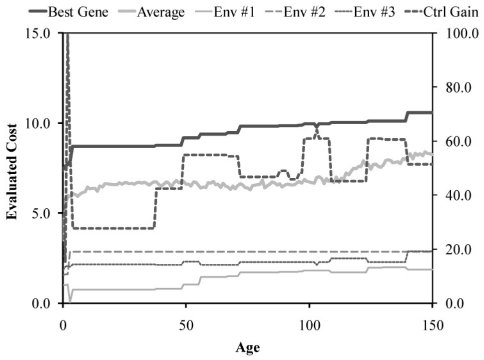


(a): Gene #1

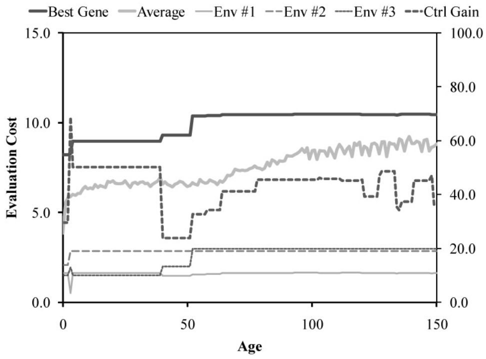


(b): Gene #2

Figure 5 Overview of the optimized mobile robots.

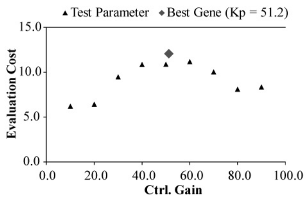


(a): Gene #1

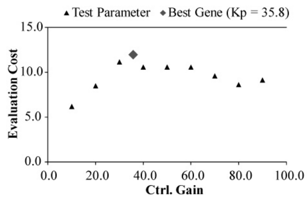


(b): Gene #2

Figure 6 Transition of the evaluation cost and control parameter.



(a): Gene #1



(b): Gene #2

Figure 7 Control parameters evaluation.

4. Conclusion

In this research, we proposed the simultaneous optimization method for passive linkage mechanism and control parameter using evolutionary algorithm and dynamics engine.

In the simulation, two kind of initial genes are evaluated in the three kind of typical environments. Both genes (Gene #1, #2) are generated randomly, but Gene #2 has a gene which expresses the existing robot parameters. The gene which expresses the existing robot parameters achieved climbing up and down the 0.20 [m] bump, however, it could not achieve climbing over and down the two kind of stairs. On the other hand, the optimized genes, Gene #1 and Gene #2, achieved traveling through the three kind of typical environments. And, the obtained control parameters compared with other control parameters and showed best performance for each robot structure. Consequently, our proposed method showed effectiveness in this research.

Acknowledgments

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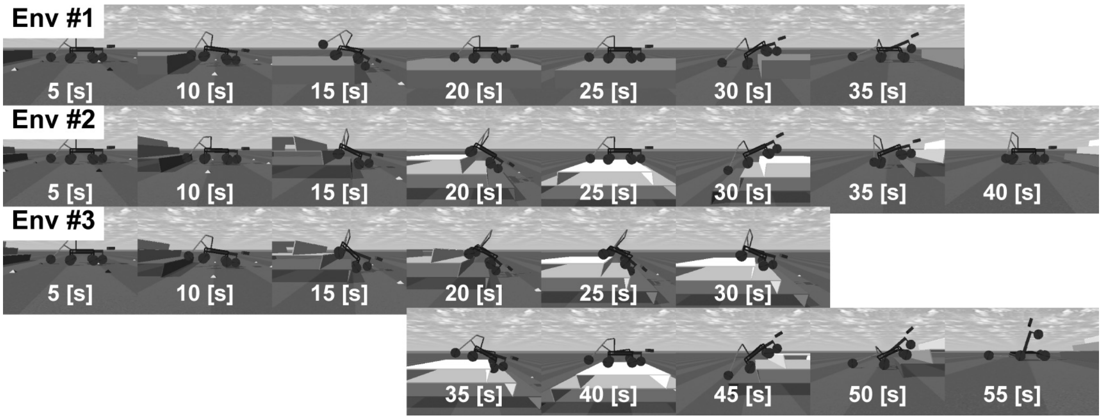
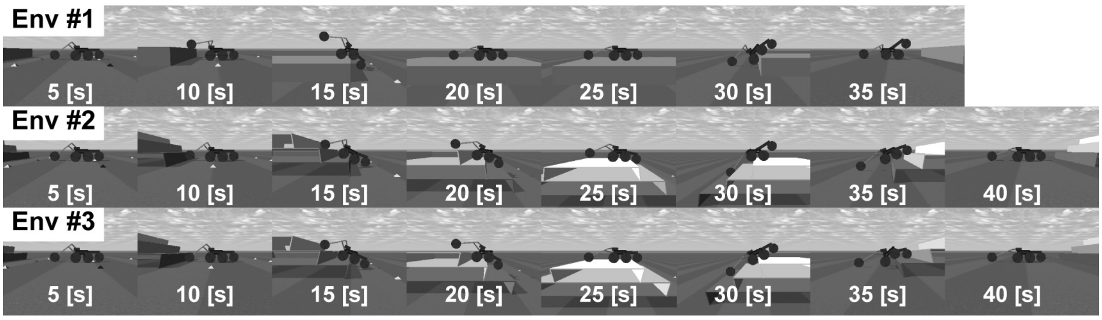


(a): Gene #1



(b): Gene#2

Figure 8 Simulation results using optimized parameters.