Simultaneous Optimization of a Wheeled Mobile Robot Structure and a Control Parameter

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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 a controller parameter 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 of 0.15 [m] high, and angled stairs of 0.15 [m] high. In the numerical simulations, 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.

I. 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 reduction in mobility on a flat landscape.

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]. Figure 2 shows the linkage structure of Zaurus. Zaurus has three kind of linkage mechanism; front fork, side link, and rear link. Zaurus can change its linkage mechanism along the faces of the landscape because each link is connected by free joints.

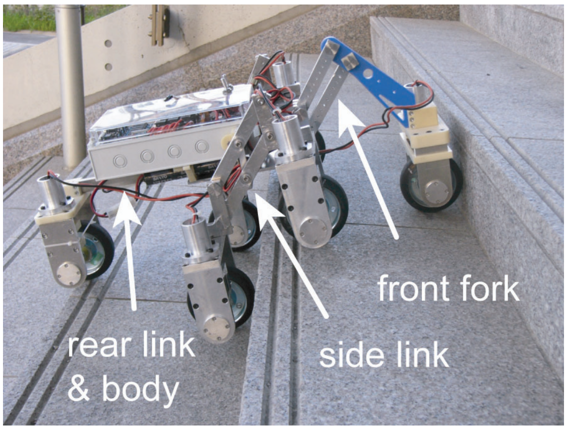


Figure 1 Overview of a wheeled mobile robot, “Zaurus”.

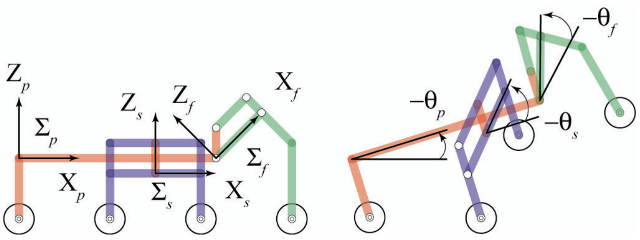


Figure 2 Linkage mechanism of Zaurus.

In our previous research, 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.

II. SIMUTANEOUS OPTIMIZATION METHOD

A. *Open Dynamics Engine*

Open Dynamics Engine (ODE) is being developed by Russell Smith since 2001 [10]. 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.

B. *Simulataenous Optimizaion Method*

Figure 3 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 value.

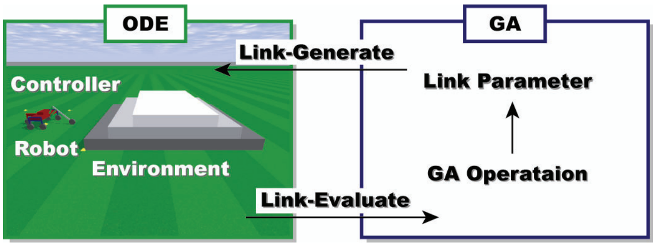


Figure 3 Diagram of an optimization method using Open Dynamics Engine and Genetic Algorithm.

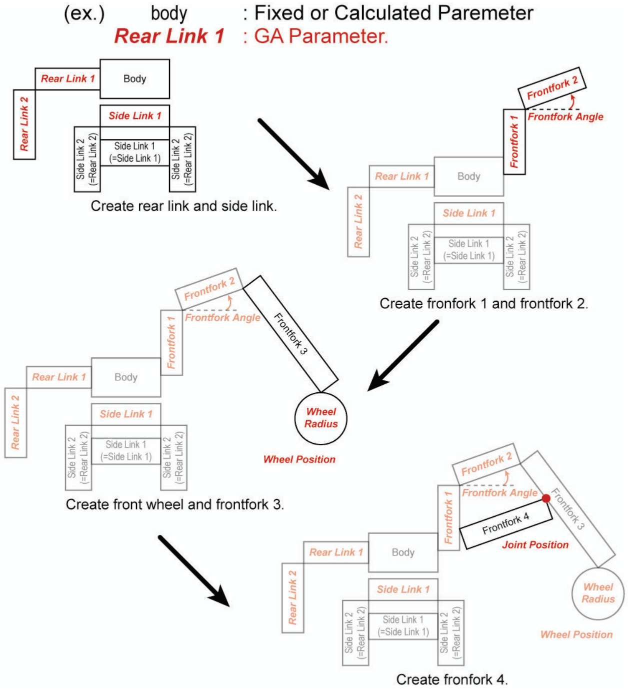


Figure 4 How to create linkage mechanism using gene's parameters.

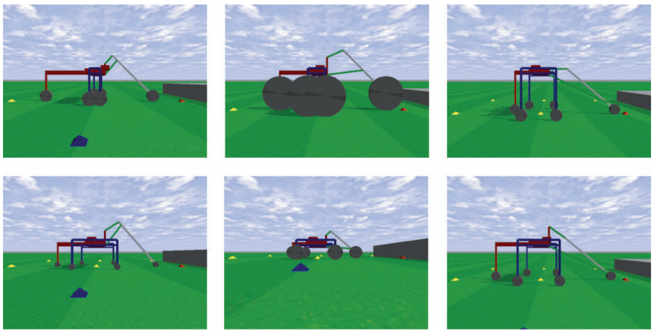


Figure 5 Genes generate various wheeled mobile robots.

Figure 4 shows how to create a mobile robot linkage mechanism from a gene. The body size and weight is constant. First, the rear link length and height are decided by gene parameters. One gene parameter decides the side link length, and its height is same as rear link. Three parameters fix the front fork height, length and angle. Front wheel diameter and position are given from two parameters, and six wheels has same diameter. Finally, the middle part of front fork is fixed by joint's position.

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 (COG) 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 5 shows the various mobile robots generated from genes.

C. *Evaluation Function*

The genes are evaluated in three kinds of benchmark environments as shown in Figure 6. 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. A gene is evaluated by the summation of the evaluation value in each benchmark environment.

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

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

Here, i is the environment ID. x_e is the position of the mobile robot when the simulation is finished, then the f_{xi} is position assessment. t_e is the remaining time when the simulation is finished, then the f_{ti} is time assessment. τ is the consumption torque for driving a wheel, then the $f_{\tau i}$ is energy assessment. e is the error of target velocity and traveling velocity of mobile robot, then the f_{ei} is control assessment. $\boldsymbol{r} = [r_x\ r_t\ r_\tau\ r_e]^T$ 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).

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

Generally, each evaluation value is normalized and weighting values are evaluated. In this research, sigmoid function, $f(x)$, used as the normalize function which output is 0.5 if the evaluate item equals the reference value. Furthermore, the sigmoid function shows the high gradient at the $x = 0$, in other words, the evaluation values widely changes. Therefore the gene which shows almost same performance around the reference value is expected the high growth.

If the genes are simulated continuously, the output of sigmoid function will be close to 1.0. In that case, the gene which shows best performance becomes new reference value, and new simulation will be started again.

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

$$\mathit{Evaluation\ \ Value} = \sum_i \{w_x f_{xi} + w_t f_{ti} + w_\tau f_{\tau i} + w_e f_{ei}\} \tag{3}$$

Here, w_x, w_t, w_τ, and w_e are the weight for each evaluation items. In general, these parameters are decided by the optimization purpose. In our research, each evaluation items are treated as the same importance, then all weights become 1 because the evaluation items, f_{xi}, f_{ti}, $f_{\tau i}$, and f_{ei}, are already normalized by using sigmoid function, Eq. (2).

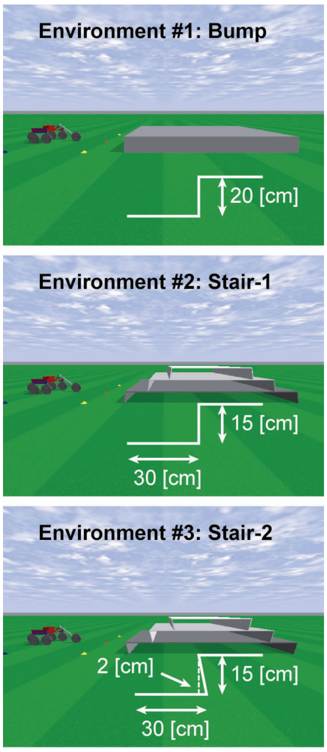


Figure 6 Three kinds of typical environments.

III. SIMULATION

A. Simulation Assumption

A One generation has 100 genes, and 150 generations are simulated. A gene is simulated in one environment until 12000 simulation step (1 step = 0.005 [s]) or traveling distance comes at more than 5 [m]. The gene is simulated three kinds of typical environments and it is evaluated by a summation of the evaluation values.

An initial generation is generated randomly. In this research, we prepared two kind of initial generations. Both generations (Gene #1, #2) are generated randomly, moreover 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 value, the gene which expresses the existing mobile robot parameters (Figure 7) is simulated (Figure 8). 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 these results, we defined the reference values, $\boldsymbol{r}$, in Equation (1).

B. Simulation Result

Figure 9 shows the overview of optimized Gene #1, and optimized Gene #2. The optimized Gene #1 is has larger linkage mechanism (front fork, side link, and rear link) than existing robot and COG of body came backward. Meanwhile, the optimized Gene #2 has almost same size of linkage mechanism as existing robot but vehicle height became lower than existing robot, and COG of body came forward.

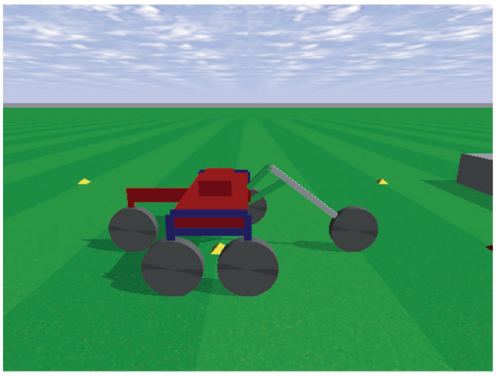


Figure 7 Overview of existing mobile robot.

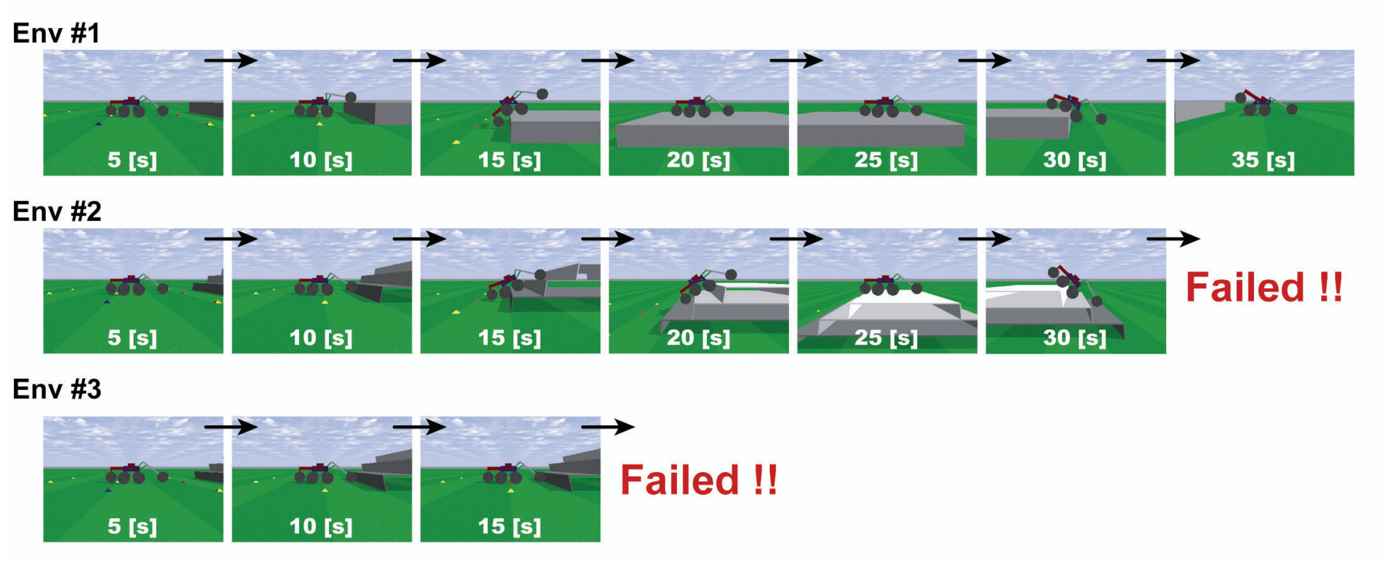
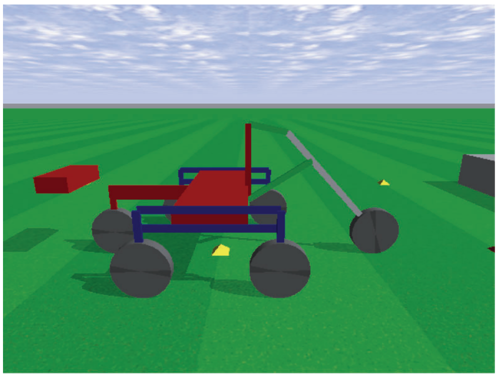
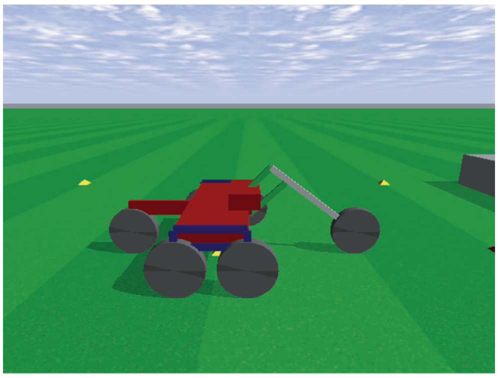


Figure 8 Dynamics simulation results using existing mobile robot.



(a)



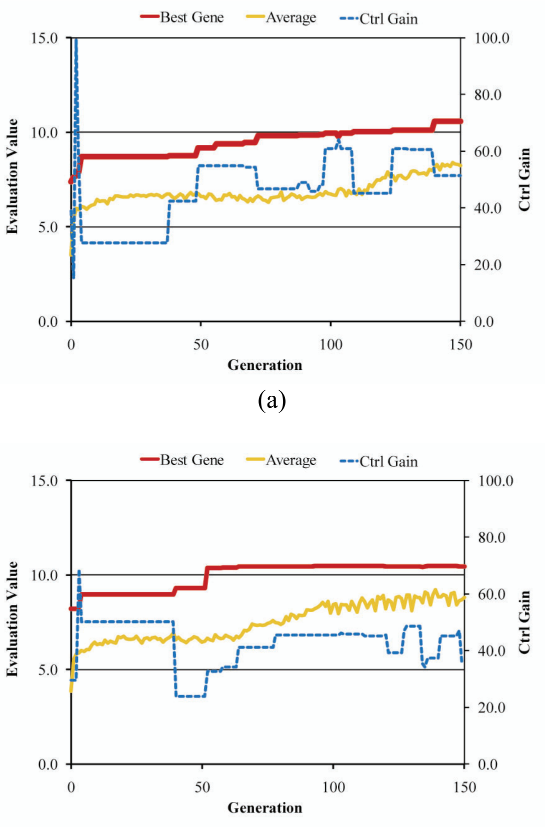
(b)

Figure 9 Overview of the optimized mobile robots.
(a) Gene #1, (b) Gene #2.

Figures 10 and 11 show the simulation results using two kind of initial generations. Figure 10 shows transition of the evaluation value and control gain. The horizontal axis shows the simulation generation, and vertical axis shows the evaluation value and control gain. In Figure 10 (a), the Gene #1 is optimized in 150 generations constantly, and near the 150 generations, the optimized gene achieved passing through the three environments. In Figure 10 (b), the Gene #2 is achieved passing through the three environments at 50 generations. As shown in the graph, the control gain is not necessarily the high gain even though the evaluation value is growing up. These results show that the control parameter is optimized with the linkage structure of the mobile robot.

To confirm the effectiveness of the simultaneous optimization, various control parameters are simulated using final linkage structure. Figure 11 shows the control parameter evaluation. The horizontal axis shows the control gain, and vertical axis shows the evaluation value using the final linkage structure. As regards the control parameter, the simulation results showed the high control gain is not always showing the good performance, and optimized control gain shows best performance. Finally, we obtained the optimized control gains; 51.2 for Gene #1 and 35.8 for Gene #2.

Figure 12 shows the dynamics simulation results of each optimized genes. The optimized Gene #1 in Figure 12 (a) could pass through the three environments, and optimized Gene #2 in Figure 12 (b) could pass through the three environments in short time comparing with Gene #1.



(a)

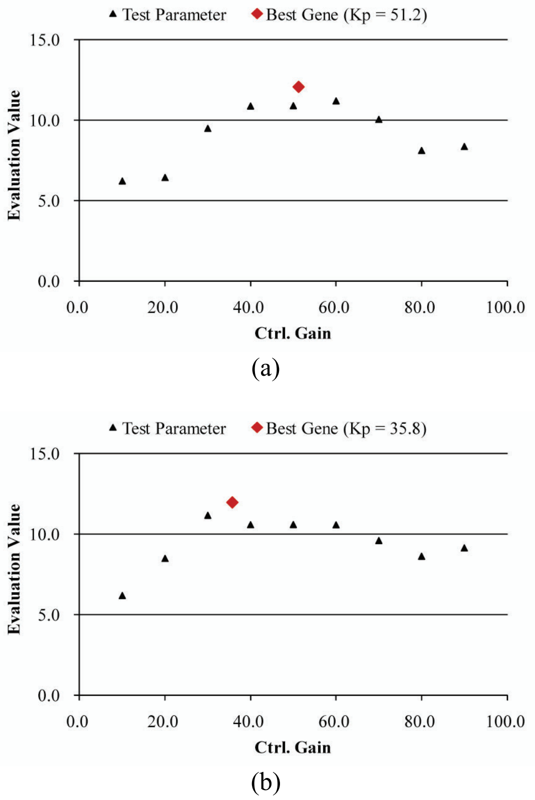
(b)

Figure 10 Transition of the evaluation value and control parameter. (a) Gene #1, (b) Gene #2.

IV. CONCLUSTION

In this research, we proposed the simultaneous optimization method for a passive linkage mechanism and a 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 final robot structure. Consequently, our proposed method achieved simultaneous optimization and showed its effectiveness in this research.



(a)

(b)

Figure 11 Control parameter confirmation. (a) Gene #1, (b) Gene #2.

ACKNOWLEDGEMENT

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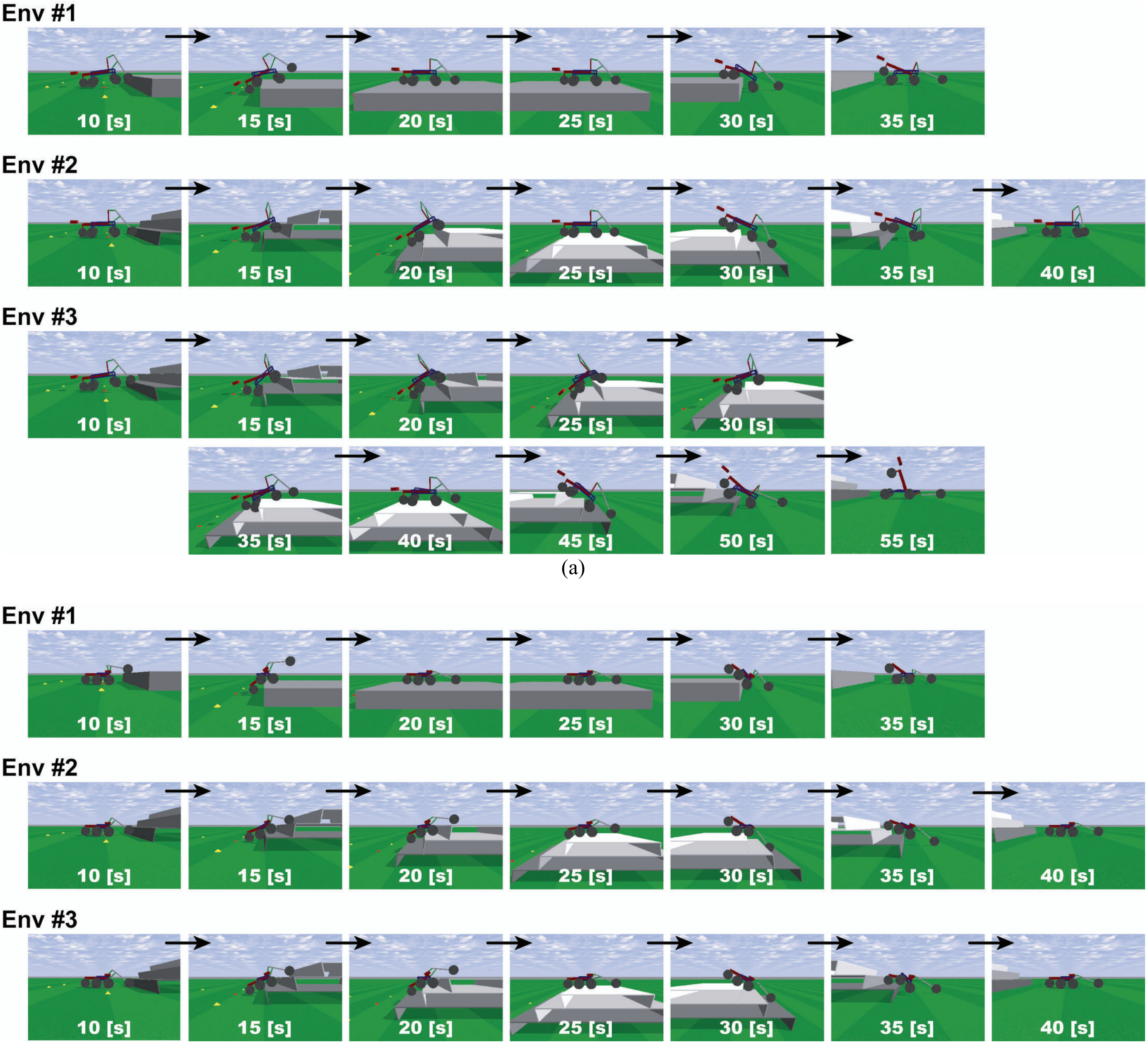

(a)

(b)

Figure 12 Dynamics simulation results using optimized linkage structure. (a) Gene #1, (b) Gene #2.