Adaptive Learning Based on Genetic Algorithm for Rover in Planetary Exploration

*Fumito Uwano[1], Akinori Murata [2], Keiki Takadama[3]

[1]The University of Electro-Communications, W6-309, 1-5-1 Chofugaoka, Chofu, Tokyo, Japan, E-mail: uwano@cas.hc.uec.ac.jp

[2] The University of Electro-Communications, W6-309, 1-5-1 Chofugaoka, Chofu, Tokyo, Japan, E-mail: kouho.aki@cas.hc.uec.ac.jp

[3] The University of Electro-Communications, W6-309, 1-5-1 Chofugaoka, Chofu, Tokyo, Japan, E-mail: keiki@inf.uec.ac.jp

ABSTRACT

Towards continuous planetary surface exploration by a rover (i.e., space prove), this paper proposed the adaptive learning mechanism based on Genetic Algorithm (GA) which promotes a rover to get out of stuck and immobilized situations through the learning of its appropriate motions. For this propose, we developed the rover with two movable joints stabilizer like an arm, which learns how to use them by the proposed mechanism. In detail, the proposed mechanism explores an appropriate sequence of the movements (i.e., rotations) of the two joints stabilizer to get out of stuck and immobilized situations. To evaluate the effectiveness of the proposed mechanism, we conducted the field experiment of our rover in Black Rock Desert, USA as the planetary exploration. The experimental results found the following implications: (1) our rover can get out of stuck and immobilized situations by an appropriate sequence of the motions of two movable joints, which are found through the learning by the proposed mechanism; and (2) the success rate of getting out of stuck and immobilized situations is 0.95.

1 INTRODUCTION

Planetary exploration is important to discover information of unknown planet. To continue such exploration, a rover is a one of potential space probes in terms of exploring the environment of the planet. Although a rover can explore efficiently if it has enough information of the planet, it is generally difficult to acquire such information before launching of satellite, which suggests that a rover should explore a planet with the minimum amount of information. Due to a lack of information, a rover cannot escape to meet stuck and immobilized situations like sandy ground (e.g., the regolith of Moon) and rugged ground (e.g., the crater of Mars). Several researches addressed this issue [1], but they cannot guarantee to work well especially in unexpected situations, which are often met in space exploration. To overcome this problem, this paper focuses on the mechanism which enables a rover to cope with unexpected situations (i.e., to get out of unexpected stuck and immobilized situations) through the learning of its appropriate motions. What should be noted here is that our proposed mechanism enables a rover to adapt to unexpected situations by changing its motions autonomously, while most of the conventional mechanisms limit to adapt to unexpected situations due to the predetermined motions.

For this purpose, we developed the rover with two movable joints stabilizer like an arm, which learns how to use them by the proposed mechanism. In particular, this paper addresses the rugged ground as one of stuck and immobilized situations. Concretely, we propose the adaptive learning mechanism based on Genetic Algorithm (GA) [2] which promotes a rover to get out of stuck and immobilized situations through the learning of its appropriate sequence of the motions (i.e., rotations) of the two joints stabilizer. To evaluate the effectiveness of the proposed mechanism, we conducted the field experiment of our rover in Black Rock Desert, USA as the planetary exploration.

This paper is organized as follow. Section 2 explains the overview of the developed rover. Section 3 describes the proposed mechanism based on GA as the core of our mechanism. Section 4 introduces the field experiment and shows its results. Finally, our conclusion is given in Section 5.

2 CREATED ROVER

Figure 1 Our rover

We created a CanSat type rover (CanSat is a small rover like a can). Table 1 determines constitute of our rover. The created rover constitutes the motor driver circuit for controlling sensors and actuators, MCU and its peripheral circuit, a motor. This is equipped with a various sensors such as a GPS receiver, a photodetector, a pressure sensor, a gyro sensor, an encoder, an acceleration sensor. The software of the control of MCU periodically acquires information from sensors and controls mission sequence form the release from the rocket to the run on the ground in real time by controlling actuators. This rover was designed for a small planetary probe proof experiment in ARLISS which means A Rocket Launch for International Student Satellites to measure crashworthiness of landing and running performance to reach the goal. Table 2 and 3 show the weight and size of our rover. In Table 2, parachute enables the rover to land on the ground with constant speed. From these tables, our rover is small and light.

Table 1. Constitute of the rover

Item	Name
MCU	Raspberry Pi 2 Model B
Acceleration sensor	MMA7455L
Photodetector	CDS cell
Gyro sensor	STmicroL3GD20
motor	maxon motor 436470
tire	polyacetal resin and sponge
battery	Energizer ultimate lithium

Table 2. Weight of the rover

Component	Weight (g)
Parachute	130
Rover	899
Total weight	1029

Table 3. Size of the rover

Componet	length (mm)
Diameter of tire	146
Length of the body	230

The rover has two wheels which are connected to gear motor in Figure 1. This wheels are made from polyacetal resin and are glued around sponge for absorbing shocks of landing. In addition, this has a studded tire like soccer shoes to improve the running performance in sandy area. A prior experiment verifies maintaining a grip power in the sandy area and run idle moderately without stall by low torque and it is possible to improve performance when getting stuck in the sand by combining with two movable joints in the stabilizer.

2.1 Two movable joints stabilizer

Figure 2 Stabilizer

Figure 2 represents the two movable joints stabilizer (inside of the red square). Stabilizer is a mechanism to adjust the vertical direction of the rover. In this paper, we created the characteristic stabilizer which has the two movable joints to get out of stuck and immobilized situations.

From Figure 2, the stabilizer is consist of a tire made from sponge and joints which are controlled by two servo motors. The sponge tire has a role to protect the servo motors and a battery on the bottom of the body when landing and to reduce the friction when running on the ground. The two joints are

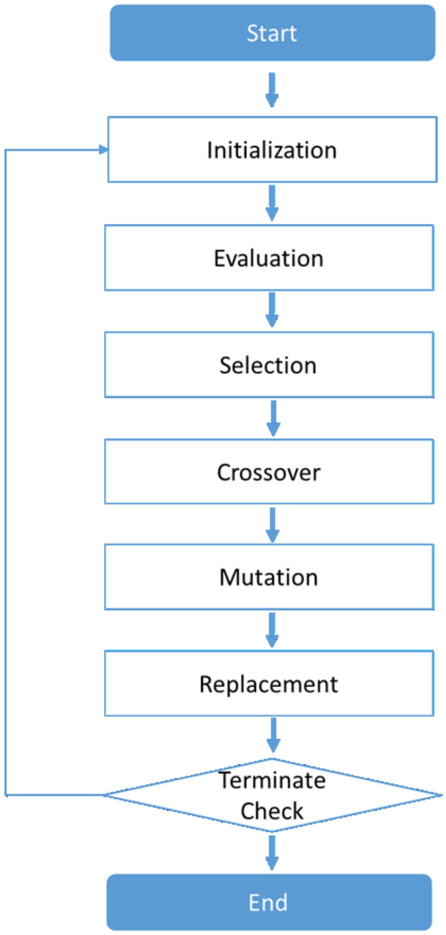


Figure 3 Flowchart of GA

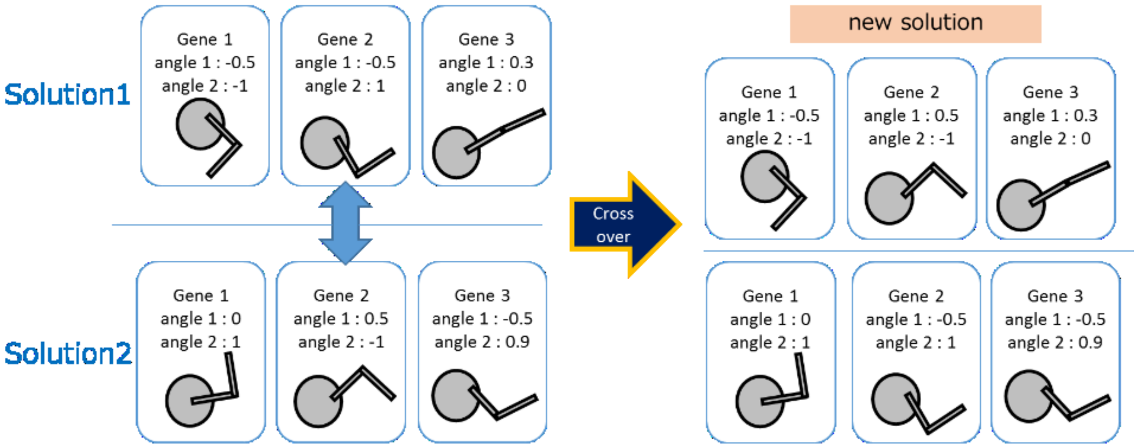


Figure 4 Proposed learning algorithm

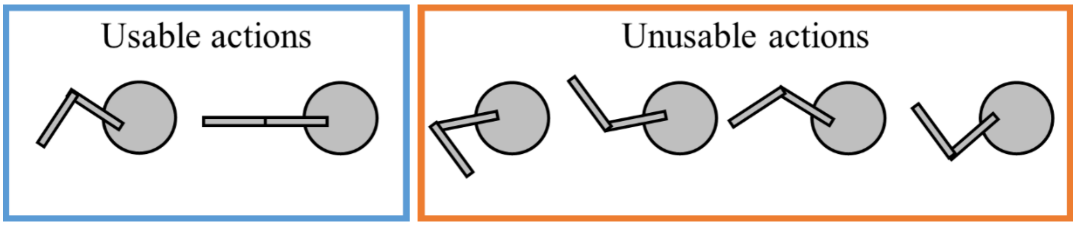


Figure 5 Initialize solution

used for posture control and getting out of stuck. The rover moves the stabilizer to pierce the bottom of the stabilizer and stabilizer pushes up on this body from the piercing point during the stuck. The rover takes this movement on the condition that the rover cannot escape the stuck. This movement are used by machine learning and the rover learns the movement of the stabilizer autonomously.

3 GA BASED EXPLORATION

3.1 Genetic Algorithm (GA)

The genetic algorithm is optimization techniques based on the evolutionary computation. This is powerful and broadly applicable to stochastic search. Figure 3 shows flow of GA. The mechanism is inspired by a framework of evolution such as crossover, mutation and the natural selection. The candidate for the solution which expressed by a gene is seen as an individual, and an individuals with the high degree of adaptation are preferentially selected, crossovered and mutated. This is repeated every generation and a reasonable solution can be found. A brief algorithm of GA is summarized as follows.

1. Initialization:
The N individuals are generated randomly as the initial population.
2. Evaluation:
The fitness of individuals are calculated according to the fitness function.
3. Selection:
The higher fitness individual is stochastically selected to be a parent of new individual.
4. Crossover:
The selected individuals are crossed over each other to generate new individuals.
5. Mutation:
The some bits of the generated new individuals are inverted with a certain probability (i.e., the mutation rate)
6. Replacement:
The new individuals are replaced with the individuals which have the lower fitness in the population. Return to step 2.

2.1 Exploration Algorithm

Our exploration algorithm enables the rover to learn how to use the motion of the stabilizer. Concretely, the rover learns the angles of the two movable joints to get out of the stuck and immobilized situations.

To get out of stuck and immobilized situations by using minimum amount of information, we propose the exploration algorithm based on GA. The proposed mechanism manipulates the two movable joints of the stabilizer. Although the proposed mechanism has the same flow as current GA, this mechanism has two capabilities not belonging to GA; Solution and evaluation.

1. Solution of our mechanism

The proposed mechanism generates the solution in Figure 4. The solution has any number of the block called gene (i.e., there are three blocks in Figure 4). The building block has the angles of the two movable joints of our rover (i.e., the pose of the rover). This thing suggests that the solutions represent the motions of our rover. Furthermore, the solution is variable in terms of the number of the genes. The first gene of the solution has the number of the usable gene. This number is not changeable without the mutation of GA. The rover manipulates the stabilizer for the times of this number by following this sequence. As the example of this, if the rover selects the

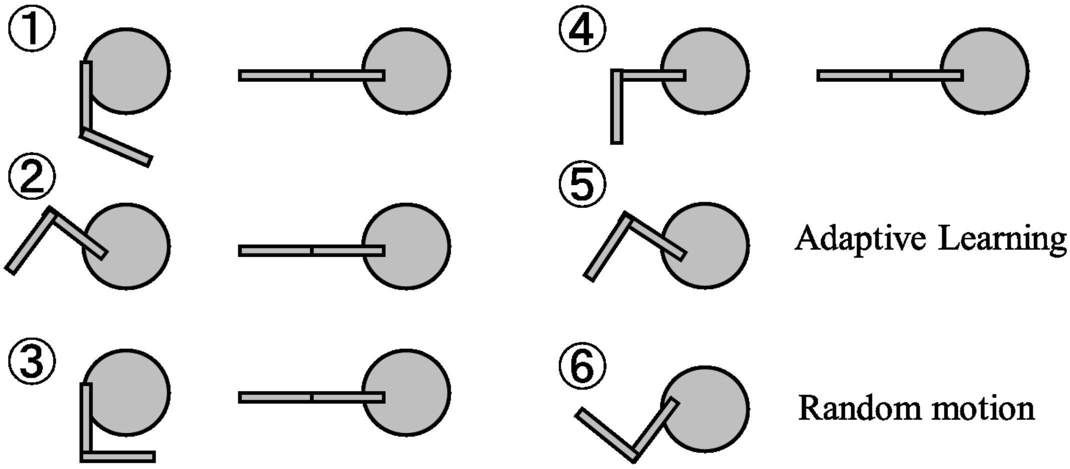


Figure 7 Motion set for the experiment

solution as Figure 5 which has two as the number of the usable gene, the rover manipulates the stabilizer by following the motion which contains the information of the first two genes. Since the rover spends the same time to manipulate the stabilizer, it spends more time for less number of the usable gene.

2. Evaluation for our mechanism

The proposed mechanism evaluate the motion of our rover as the fitness in terms of how is he moving by using encoder, gyro censor and acceleration censor. The evaluation has two criteria, one is how much the rover rotated the tire per second (i.e., the rotation arrow of Figure 6) and the other is the angle which the rover moved (i.e., the two direction arrow of Figure 6).

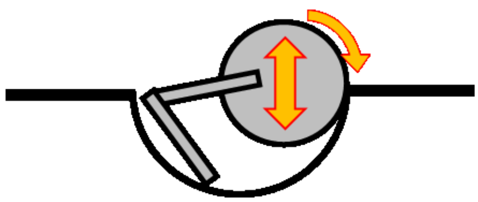


Figure 6 Evaluation

Concretely, the rover evaluate the own motions by following equation as fitness function. In this equation, *fitness* determines the fitness value of the motion of the rover. The rover calculates the fitness value from the encoder pulse by Equation *Ef(x)* and moving angle (*pitch* in the equation). $\widetilde{pulse}$ determines the average pulse between right and left tire measured by the encoder and *step* is the number of the usable actions of the solution. There are the values which discounts the parts of the fitness, respectively for normalization.

$$fitness = \frac{Ef(\widetilde{pulse} - step \cdot 400)}{100} + \frac{pitch}{10}$$

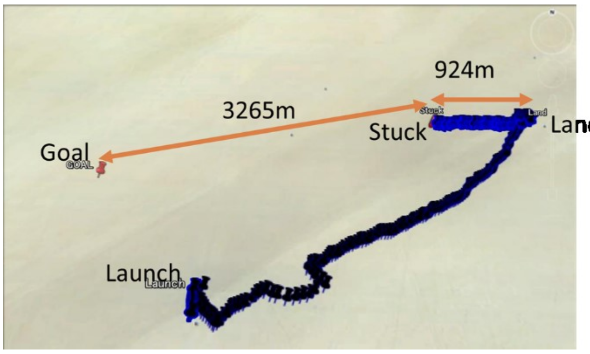
$$Ef(x) = \begin{cases} x \ (x < threshold) \\ threshold \cdot \gamma^{|threshold - x|} \ (otherwise) \end{cases}$$

4 EXPERIMENT

To validate the performance of our rover, we apply the rover to the environment which the rover may stuck in Black Rock Desert, Nevada, U.S.A as ARLISS. In this experiment, we evaluate the number of the overcoming stuck. There are parameters in Table 4. In Table 4, population size indicates the number of the solution which the rover has, and solution size indicates the number of the gene which belongs to the solution. Generation size shows the maximum cycle of GA. The proposed GA mutate the solution with mutation probability, and initialize the angles of the joints to 0.9 and -0.9 (the fifth line of the table), the fitness to 0 (the sixth line of the table) and the step to 2 (final line of the table) for each solution. From the initialize, the rover has same 6 solutions same as Figure 5 at first. The solution has two usable actions (by following initialize step) and four unusable actions, and the angles of the usable actions in the solution are (0.9,-0.9) and (0.0), respectively (by following initialized angle). Our rover has the motion set to get out of stuck and immobilized situations shown in Figure 7. Figure 7 shows the six motions, the motions from 1 to 4 indicate the phases of using the motions set by us empirically; the 5^{th} motion indicates the phase of adaptive learning and; the 6^{th} motion indicates the phase of random action for the tire of the rover. The rover behaves the 6 motions in turn, and repeats this.

Table 4. Parameters

Contents	Value
Population size	6
Solution size	6
Generation size	1000
Mutation probability	0.3
Initialized angle	(0.9, -0.9)
Initialize4fd fitness	0
Initialize step	2



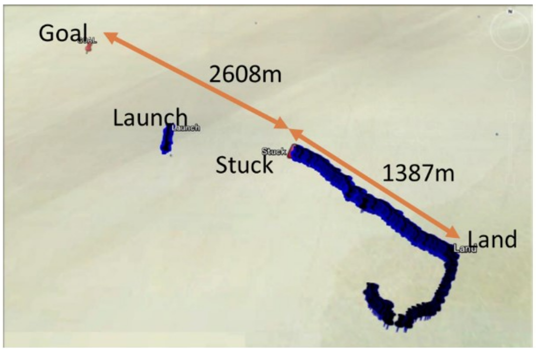


Figure 9 Result of ARLISS

4.1 Environment

We applied the rover to ARLISS as the environment for the experiment in order to make the rover become the space probe of the planetary exploration.

ARLISS

Figure 3 Example of Black Rock Desert

We conducted the experiment in A Rocket Launch for International Student Satellites (ARLISS) which is held in Black Rock Desert, Nevada, U.S.A (e.g., Figure 8). The goal of the rover launched by rocket can land and reach the destination while getting out of stuck areas in the case of such areas.

4.2 Result

We show the result of ARLISS as Figure 9. In Figure 9, "Launch" is the point of launching, "Land" is the point which the rover landed. "Goal" is goal point. The left side and right side of Figure 9 represent the results of first launch and second launch, respectively. From the result, the rover can run after the launch. However, the rover cannot reach the goal because of stuck in both situations. This result suggests that the rover can run around 1000m on the ground on which it stuck easily.

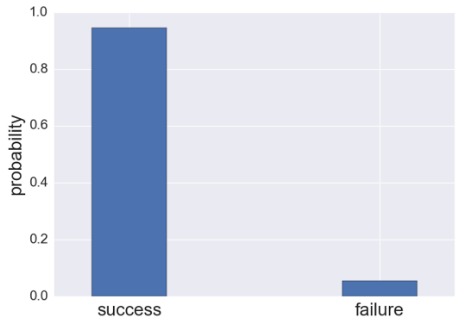


Figure 10 Success rate

Figure 10 determines the number of overcoming stuck through ARLISS. The vertical axis and the horizontal axis determine probability and success or failure, respectively. From the result, the rover can get out of stuck with high probability. In detail, the success probability is 0.95 and the failure probability is 0.05. This result suggests that since the rover can overcome almost all the stuck, the stabilizer enables the rover to get out of those stuck.

4.3 Discussion

From the result, it is clear that our rover can overcome stuck, and the proposed GA can acquire the effective motion for overcoming stuck.

4.3.1 The stabilizer

Since the two movable joints of the stabilizer can behave with many variations, the rover can get out of stuck by many kinds of the motions. There are a lot of the motions by the stabilizer, which both angles of the two joints are 180 degree. From the results, there are the two effects of the stabilizer, the moving motion of the center of the gravity and the push-up motion of the rover. As for the example for both effects, there is the situations of Figure 11. The left side and the right side of Figure 10 represent the situations for the effects of the moving the center of the gravity and the push-up of the rover, respectively. The left

Figure 11 Example of stack

side of this figure represents that the rover is turned over, and the tires of the rover cannot tough the ground deeply enough to overcome that situation. In this situation, the rover swings the stabilizer in order to move the center of the gravity, and get out of stuck. Such a thing suggests that moving the stabilizer enables the rover to get out of stuck by moving the center of the gravity. Furthermore, the right side of Figure 11 represents that the rover cannot go straight because it crashes to the obstacles of the ground. In this situation, the rover sticks the stabilizer into the ground in order to move itself up to the ground. From the results, the rover can move itself up to the ground and get out of the stuck by sticking the stabilizer in the ground. It is clear that the stabilizer of the rover can behave many motions to get out of the stuck.

Figure 4 Deep obstacle

Figure 12 shows the deep obstacle of the rover. In the experiment, the rover can get out of this stuck by using the tire and the stabilizer. Since the tire of the rover is buried with over a half heights of the tire, the rover cannot get out of the obstacles by using only the tire in this situation. However, our rover can get out of that obstacle by using stabilizer. This result suggests that the stabilizer is effective to get out of the stuck. Especially, to get out of the stuck of the deep obstacle, our two movable joints stabilizer becomes necessary.

4.3.2 The algorithm

Since the algorithm of the proposed mechanism enables the rover to get out of stuck and immobilized situations, the algorithm with adaptive learning is effective. Furthermore, such a result suggests that the combination of the motions is important than one motion in order to get out of stuck and immobilized situations. The rover can get out of stuck and immobilized situations by using many motions in situation as Figure 12. Concretely, if the rover selects any other motion, since it tries any other approach, the probability to get out of stuck and immobilized situations becomes high. On the other hand, the rover tries some motion at many times in the failure result. As the result of that, the rover makes the situation which it cannot get out of stuck and immobilized situations by that trying. From the results, the number of try should not be more not less.

5 CONCLUSION

This paper proposed the adaptive learning method based on GA to promote the rover to get out of stuck and immobilized situations for continuous planetary surface exploration. For this purpose, we developed the rover with two movable joints stabilizer like an arm, which learns how to use them through the learning of its motions by the proposed mechanism. In detail, the proposed mechanism explores an appropriate sequence of the movements (i.e., the angles of the two movable joints) of the stabilizer to get out of stuck and immobilized situations.

To evaluate the effectiveness of the proposed mechanism, we conducted the field experiment of our rover in Black Rock Desert, USA as the planetary exploration. The experimental results found the following implications: (1) our rover can get out of stuck and immobilized situations by an appropriate sequence of the movements of two movable joints, which are found through the learning by the proposed mechanism; and (2) the success rate of getting out of stuck and immobilized situations is 0.95. As for the future works, the following research issue should be done: (1) an improvement of our method to find the optimal solutions with the minimum learning time, and (2) an extension of our method to learn the motion of the tire in addition to the learning of the motion of the stabilizer.

References

[1]Karl Iagnemma, Shinwoo Kang, Hassan Shibly and Steven Dubowsky, “Online Terrain Parameter Estimation for Wheeled Mobile Robots with Application to Planetary Rovers”, IEEE TRANSACTIONS ON ROBOTICS, Vol.20, No.5, Octover 2004.

[2] David E. Goldberg, “Genetic Algorithms in Search, Optimization, and Machine Learning”, Addison-Wesley: Reading, MA, 1989.