Tele-Navigated Trajectory Evaluation based on Similarity of Command Path by using Virtual Electrostatic Potential Field for Planetary Rover

Yasuharu KUNII*,Hiroyuki MAEHARA**, Ryota KARITANI**

*Dpet. of Electrical, Electronic and Communication Engineering, Chuo University
** Dept. of EECE, Graduate School of Chuo University
e-mail: { kunii, hiroyuki_12, ryota_11 }@hmsl.elect.chuo-u.ac.jp

Abstract

In our previous work, we have discussed evaluation method for a tele-navigated trajectory of a mobile robot such as planetary rover, with virtual potential field caused by obstacles. It was based on a discrete transition comparison of electrostatic potential values along a navigated path, which on each waypoint receive from virtual electric charges on obstacles. The potential values (its transition), along the path, received from all charges were assumed to indicate some kind of dangerousness, and their transition are defined as human intentions and evaluated the quality by comparing them with the original path. In this paper, a correlation between potential transitions is introduced to evaluate navigated path continuously. The correlation coefficient is defined as evaluation criterion representing the quality of navigated path. Furthermore, size of obstacle is also introduced into the improved method. The method was discussed with simulation results using virtual geographical map, and finally, it shows its validity by evaluations with actual navigation algorithms.

1 Introduction

In recent years, various planetary exploration missions have been planned for some purposes, such as elucidations of the origin and the evolution of the solar system, investigations of new energy sources and resources for prospective usage, and so on [1][4][6][7][8]. The surface exploration missions utilizing robot technologies have been discussed in many of them. Especially, a rover has been committed for detailed observational data by wide range surface exploration. In recent years, the first Mars rover: Sojourner, which was launched in Mars Pathfinder mission of NASA and landed on Mars in 1997, is still fresh in our memory, and moreover, Mars Exploration Rovers landed in 2004 achieved a splendid result discovering the evidence of the existence of water. Now, Mars Science Laboratory landed in 2012 has been expected new results, therefore expectations to robot technologies will be swelling strongly.

A rover has to cruise on a long distance and in a wide area safely. However, it faces various difficulties in its mission, for example, difficulties with prediction against unknown and unstructured terrains [9][10]. In order to tackle those subjects, its operation often has been carried out in tele-navigation scheme, in which human operator generates a safety path with environmental measured data before its cruising. However, a measured position of an obstacle might be changed during its cruise, because of measurement error depending on the measuring distance. The position error is increasing, as its distance is getting far from an obstacle. It means that the initial path would be created with wrong map data, and the path might collide to an obstacle. Therefore the rover should not trace the initial path exactly, and it should adapt the path to the latest environment map. So its navigated path might be changed, and it is necessary to evaluate whether corrected path is along the operator’s intention. Here, we assume that the initial path by an operator is a result of his/her feeling of oppression received from obstacles changes. Thus, the feeling is numerically defined as some kind of potential received from obstacles to the path. In our previous work, the navigated path evaluation method with virtual electrostatic potential field was previously proposed, which was evaluate the path by comparing its potential transition with the one of the path command, and the method has been confirmed with various evaluation results of simulations and experiments [2].

In this paper, we discuss improvement of the proposed evaluation method on two points, the one is the introduction of the size of obstacles, and the other is new evaluation criterion with correlation of potential transitions. Finally, the improved method is applied on trajectories of Command Data Compensation and Morphin algorithms as actual navigated path evaluation test [3][5].

2 Improvement of proposed method

During consideration of a command path by an operator, he or she would get the most suitable path according to a feeling of oppression received from obstacles. We have applied a potential field to evaluate a tele-navigated trajectory on this point of view. On the other hand, we cannot have ideal potential value to represent human feeling or ideal path, and therefore, the evaluation has been discussed with comparing transitions of potential values along each path. In this research, virtual electrostatic potential field has been introduced, that is generated with a virtual point charge on an obstacle. The comparison of potential transitions for paths has been discussed on each waypoint, thus its result became discrete. Furthermore, the size of an obstacle has never been considered, and the similarity index of trajectories was just subtraction of potential values on each waypoint. Those have caused a miss evaluation.

2.1 Introduction of distributed charge

Uniform distributed charge is introduced into proposed method, and an obstacle is redefined as a circumcircle. A electric charge, shown in Fig.1, is put on the center of each obstacle virtually. Its potential is equal to 1.0 on the surface of an obstacle as shown in Fig.2. In those assumptions, total electric charge Q is equally distributed in a circumscribed circle of an obstacle. The potential U is given by eq.(1) with charge density: ρ, the vacuum permittivity: ε_0, the volume of distributing electric charge Q: V, a point of V: r.

$$U(r) = \frac{1}{4\pi\varepsilon_0}\int \frac{\rho(r')}{|r-r'|}dV' \qquad (U(\infty)=0) \qquad (1)$$

It is a formula calculating a potential value from an area of density ρ. As a potential value of distributed electric charge is equal to one generated by total electric charge Q which would be concentrated on the center of circumscribed circle, it is calculated in range of $d > R_L$, and $0 \le d \le R_L$ by following equation eq.(2).

$$U(d) = \begin{cases} \dfrac{\rho_0}{\varepsilon_0 d}\displaystyle\int_0^d r^2 dr + \dfrac{\rho_0}{\varepsilon_0}\displaystyle\int_d^{R_L} r dr = \dfrac{Q}{4\pi\varepsilon_0 R_L}\dfrac{1}{2}\left[3-\left(\dfrac{d}{R_L}\right)^2\right] & (0 \le d \le R_L) \\ \dfrac{\rho_0}{\varepsilon_0 d}\displaystyle\int_0^{R_L} r^2 dr = \dfrac{Q}{4\pi\varepsilon_0 d} & (R_L < d) \end{cases} \qquad (2)$$

Total potential value form all obstacles is given by following eq.(3).

$$P = \sum_{j=1}^{N_{obst}} U_j \qquad (3)$$

Here, on the boundary of a circumcircle of each obstacle ($d = R_L$), Q is determined that potential U becomes 1. And here, N_{obst} is the total number of obstacles, P is total potential value received from all the obstacles.
These formulas also enable to capture a sign of the collision and make difference between initial path and trajectory efficiently.

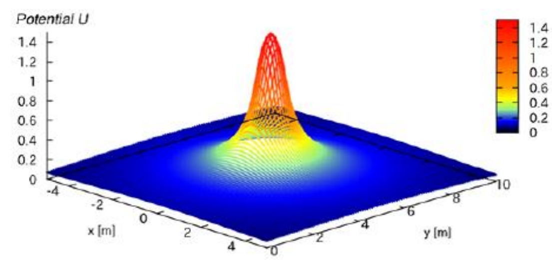

Fig.1 Virtual Electrostatic Potential Field from Obstacle

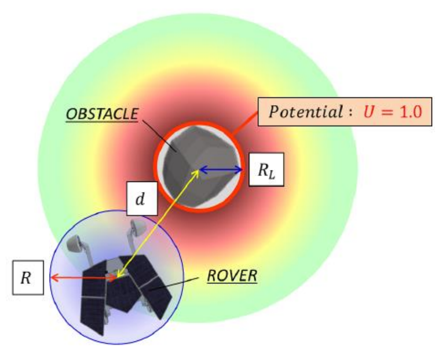

Fig.2 Rover in Virtual Potential Field

2.2 New Safety Rate with correlation

In the previously proposed method, a navigated trajectory and the initial path are compared only on each waypoint, and its differences have been represented as changes of potential P_I and P_T before and after cruising respectively. Safety Rate, which is the index indicating the safety of navigation, was calculated by eq.(4), and here, the safety was defined that the difference from the initial path.

$$\mathrm{SR} = \frac{\sum_{i=1}^{N_{node}}|P_I(i) - P_T(i)|}{N_{node}} \qquad (4)$$

However, this equation is just the average of the potential difference, so it doesn't represent the similarity of potential profiles exactly. As a result, even if it takes higher or lower value, it could not discuss the similarity of profiles. Therefore, a correlation between potential profiles is introduced, in which redefines Safety Rate (SR) as reliability of a navigated result, as follows.

$$SR = \frac{\sum_{i=1}^{n}(P_I(i) - \overline{P_I})(P_T(i) - \overline{P_T})}{\sqrt{\sum_{i=1}^{n}(P_I(i) - \overline{P_I})^2}\sqrt{\sum_{i=1}^{n}(P_T(i) - \overline{P_T})^2}} \qquad (5)$$

When the SR is closer to 1, a rover can be understood to have better tracking result along an initial path. On the other hand, if it indicates 0, it means that the result deviated from the operator's intention.

3 Validity of improved evaluation method

3.1 Discussion with simple path tracking

As the first discussion, the evaluation results are compared before and after the application of above-mentioned improvements. We apply evaluation methods to two kinds of traversal results with and without an autonomous path compensation scheme for comparison of results by each evaluation method in a environmental map including much error on obstacle positions, because the result of no compensation should have much possibility that the rover collides to an obstacle. In this discussion, the validity of our improvements is examined with the more clear traversal failure case.

Fig.3 shows simulated traversal results of a tele-navigated rover with changing obstacle positions because of measurement error, wheel slippage and self-position estimation error. The gray circle is an initial obstacle position, the red line is the initial commanded path, the brown circle is a latest measured obstacle position, and the blue line is the cruising result with compensation adapting for changing obstacle positions. Fig.4 shows potential transition results along paths with the previous method, and Fig.5 is with the improved method.

The rover has much possibility to collide with three obstacles as shown in Fig.3. However, in Fig.4, all signs of collision cannot be caught in the potential profile with the previous method in which an obstacle size has never considered. Furthermore, SR had small values that mean both paths are quite close, as shown in Tab.1. In contrast, the improved method considering the size of obstacles can find all omens of collision with where large potential values stand up. SR, calculating the similarity of potential graphs, also confirms those collisions (Tab.1).

Here, the improved method has been able to prove that it gives us more detailed and accurate evaluation results.

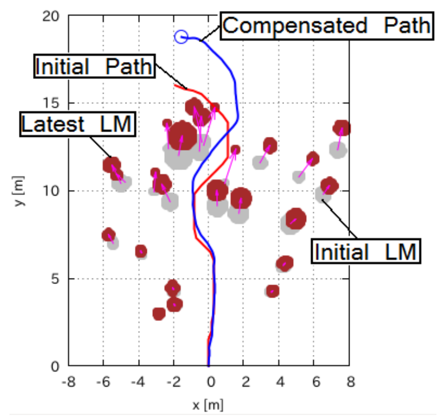

Fig.3 Cruised Trajectory

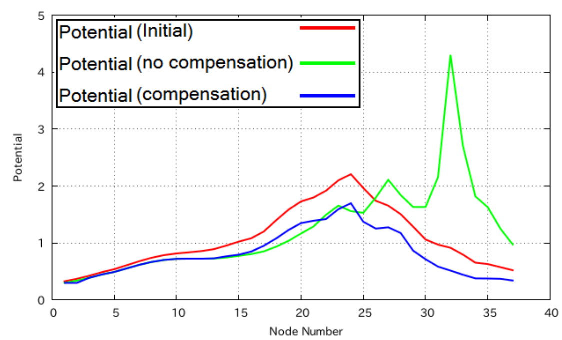

Fig.4 Potential at each point with previous method

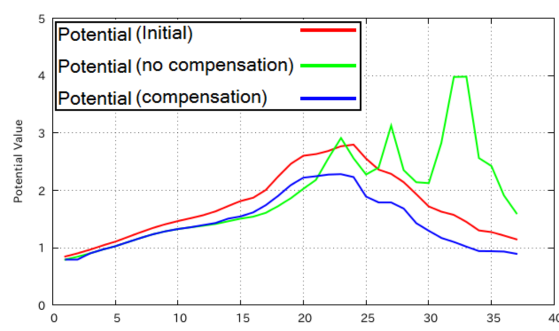

Fig.5 Potential at each point with improved method

Table1. Safety Rate of simulation result

	SR (w/o compensation)	SR (w compensation)
Before	0.289	0.475
After	0.482	0.971

3.2 Discussion with Morphin & CDC

We proceed to practical evaluation of our improved method with actually installed autonomous path compensation algorithms. Here, we apply two compensation methods which are Morphin and CDC[3][5]. The Morphin algorithm is actually used on the NASA rovers (MER etc.), and the CDC (Command Data Compensation) algorithm was proposed by ourselves.

Fig.6 shows simulated traversal result of a rover, Fig.7 is potential curves of each path according to the evaluation method, and each SR calculated from Fig.7 is shown in Table. 2. .Morphin reaches to the goal safely by avoiding obstacles on the initial path, and CDC also adapted its compensated cruising path to the latest measured map, which has more accurate obstacle positions, without any collision. Potential curves of Fig.7 also indicate safer travels of Morphin and CDC than the one without any algorithm. In those results, CDC clearly has more similarity of the initial path than the result of Morphin, and it means CDC is better method in the point of view following operator's intention. New SRs also support this result, and CDC has higher value than others.

Finally, the improved method has been able to provide us the discussion about the quality of navigation results, even if the rover has cruised along each different path.

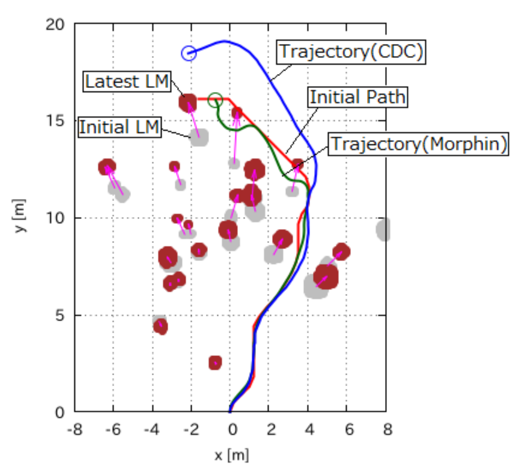

Fig.6 Cruised Trajectory

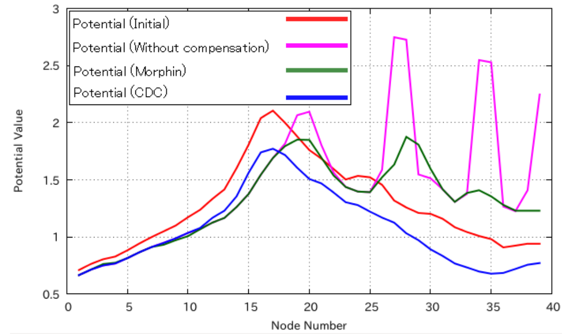

Fig.7 Potential by each traversal method

Table2. Safety Rate by each traversal method

SR (no compensation)	SR (Morphin)	SR (CDC)
0.359	0.710	0.976

4 Conclusions

In this paper, we discussed improvements of proposed evaluating method of navigated trajectory, based on electrostatic potential field. Two improved items have been discussed, one was introduction of obstacle size with circumcircle of each obstacle and controlling potential value on its border, and other was the redefine of the evaluation criterion with correlation of traversal paths. According to an evaluated result for tele-navigated path without any autonomy, the improved evaluation method and criterion showed their validities with catching collisions to obstacles and indicating similarity of paths, respectively. Furthermore, they discussed with autonomous algorithms installed on actual rovers, and their result showed a feature of each algorithm. Finally, the improved method and the new evaluation criterion confirmed their better evaluating ability for navigated path.

References

[1] G. Udomkesmalee and S. A. Hayati, "Mars Science Laboratory focused technology program overview", IEEE Aerospace Conference, pp. 961-970, 2005.

[2] Y. Kunii, R. Karitani, "Evaluation of Tele-Navigation System using Command Data Compensation", the 39th Annual Conference of the IEEE, pp. 7811-7816, 2013

[3] Y. Kunii, R. Karitani, T. Uekusa, “Evaluation of Tele-Navigation System using Command Data Compensation and Field Test in Izu-oshima Volcanic Island, Japan”, 10th IFAC Symposium on Robot Control, pp. 889-894, 2012.

[4] Max Bajracharya, Mark W. Maimone, and Daniel Helmick, “Autonomy for Mars Rovers: Past, Present, and Future”, Published in IEEE computer Society, pp.44-50, Dec 2008.

[5] Joseph Carsten, Arturo Rankin, Dave Ferguson and Anthony Stentz, “Global Path Planning on Bord the Mars Exploration Rovers”, Aerospace Conference, 2007 IEEE, 3-10 March 2007

[6] http://marsrovers.jpl.nasa.gov/home/index.html (as of April 2014)

[7] Genya Ishigami, Keiji Nagatani, and Kazuya Yoshida, “Path Following Control with Slip Compensation on Loose Soil for Exploration Rover”, Proceedings of the 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems, October 9-15, 2006, Beijing, Chaina

[8] Genya Ishigami, Keiji Nagatani, and Kazuya Yoshida, “Slope Traversal Experiments with Slip Compensation Control for Lunar/Planetary Exploration Rover”, 2008 IEEE International Conference on Robotics and Automation, Pasadena, CA, USA, May 19-23, 2008

[9] Daniel M. Helmick, Stergios I. Roumeliotisy, Yang Cheng, Daniel S. Clouse, Max Bajracharya, and Larry H. Matthies, “Slip-Compensated Path Following for Planetary Exploration Rovers”, Advanced Robotics, Vol.20, No.11, pp.1257-1280, 2006.

[10] Rowan McAllister, Thierry Peynot, Robert Fitch and Salah Sukkarieh, “Motion Planning and Stochastic Control with Experimental Validation on a Planetary Rover”, 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems, October 7-12. 2012, Vilamoura, Algarve, Portugal