The 2009 IEEE/RSJ International Conference on
Intelligent Robots and Systems
October 11-15, 2009 St. Louis, USA

Development of the Arm-Wheel Hybrid Robot "Souki-II" (Total System Design and Basic Components)

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Abstract— We proposed new arm-wheel hybrid robot "Souki-II" which consists of a body, a pair of large bore wheels which sandwich the body and rotates around the same axis from the body, articulated hand attached to the body, and free caster attached around the wrist of the hand. Souki-II showed high terrain adaptive motion by using the large bore wheels and free caster of the hand. We also showed that the mobility can be enhanced when multiple units are connected together. Souki-II can also take the mode of a manipulator. For the joint mechanism of the Souki-II, we introduced a unit actuator system and a cover member with spiral groove to pass the electric harness and to assist in heat dissipation. From the experiments of the constructed models, we could demonstrate the innovative performance of the proposed Souki-II system.

I. Introduction

Mobile robots capable of moving across irregular terrain and manipulating some objects would be beneficial for many missions, such as investigations in disaster areas, marking of land mines and the exploration of other planets.

We had already presented the "Super Mechano Colony (SMC)-Rover" as shown in Fig.1([1], [2], [4], [5]). The SMC Rover consists of a mother rover and some child rovers. Child rovers normally work as wheels of the mother rover by docking to the mother rover. When the mother rover finds some interesting objects, it detaches some of the child rovers and lets them move independently. When the child rovers complete the mission, they will return to the mother rover and dock to then act as one of the wheels. Energy and information is also supplied to the child rovers while they are connected to the mother rover. The arm equipped single wheel rover 'Uni-Rover' ([3], [6], [7], [8]) (Fig.1) has been developed for this application. The Uni-Rover can take both locomotion mode and manipulation mode. As the Uni-Rover is designed specially for the SMC rover, its motion degrees of freedom were rather limited.

In this paper we propose Souki-II, the advanced model of the Uni-Rover with higher degrees of freedom in motion, to make it applicable not only for the planetary rover but also to other types of applications requiring arm-equipped wheel systems. We will discuss the design of the mechanisms in detail.

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II. Arm-Wheel Hybrid Robot Concept

In this section, the basic concept of Souki-II, which is capable of moving across irregular terrain and is able to manipulate some objects, is described.

II-1 Total configuration

Uni-Rover had 5 DOF, three for the arm joint, one for the arm rotation against the cylindrical wheel and one for the gripping motion. In this former configuration, the arm was attached to one side of the wheel because the rotation of the arm was designed for manipulation and also for locomotion in wheeled mode. This configuration saved excessive actuators but the centre of gravity of the rover was shifted to one side of the wheel decreasing its mobility by some degrees.

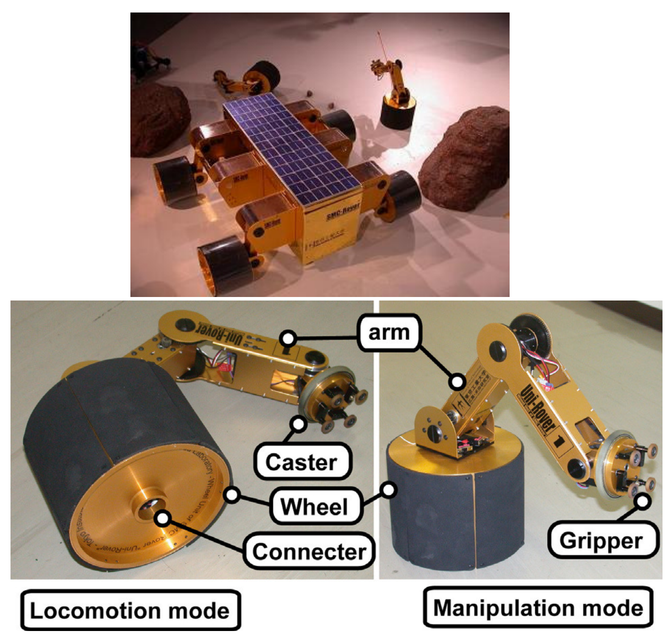


Fig. 1. Overall view of SMC-Rover and Uni-Rover

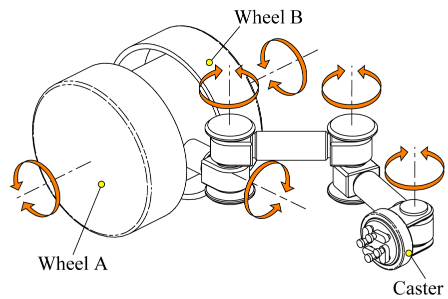
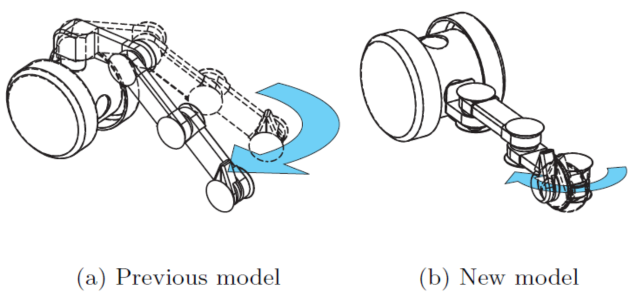


Fig. 2. Overall view of the Souki-II

To increase the mobility, we selected a symmetrical arm configuration for the Souki-II as shown in Fig.2, consisting of one manipulator arm and two active wheels attached to both sides of the cylindrical body. The Souki-II has 7 DOFs, three for the arm joints, two for each wheel, one for arm rotation relative to the body and one for the gripper as shown in Fig.2.



(a) Previous model (b) New model

Fig. 3. deployment of DOF

II-2 Arm Design

As for the design of the arm and its joint configuration, we paid special attention to the steering function of the Souki-II in wheeled mode as shown in Fig.3. The configuration as shown in Fig.3 (a) is considered first. In this configuration, steering of Souki-II is achieved by generating a difference between the velocity of the two wheels as well as by changing the angle and position of the passive wheel on top of the arm. The angle and position of the passive wheel are adjusted by changing the angle of rotation of the arm, elbow and shoulder. However, we found a problem with this configuration namely the slipping effect while the roller of the wrist joint is changed for the purpose of steering. Because of this slippage, the energy efficiency is reduced in the steering mode.

To solve this problem, we introduced the joint configuration as shown in Fig.3 (b). This configuration enables us to change the angle of the wrist roller with little friction and thus making it more energy efficient.

II-3 Docking function

By connecting a series of Souki-II the ability to move across irregular terrain and its efficiency can be greatly improved. The improvement of ability by connecting some robots has been proposed by "Gunryu"[9]. When a series of Gunryu are connected they have a higher capability than individually. Souki-II can also have a similar kind of capability as Gunryu by connecting individual modules. The action of connection and disconnection of Souki-II is easy because the connection can be done only by gripping the other Souki-II. It is suitable for realizing the "SMC Rover" system as shown in Fig.4.

There are two types of docking postures shown in Fig.4. One posture is to maintain a horizontal arm posture as shown in Fig.5 (a). In this posture the arm is kept horizontal.

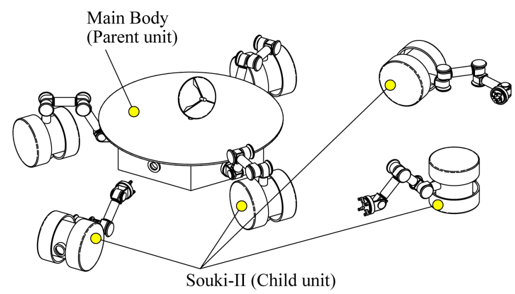


Fig. 4. SMC Rover system with Souki-II

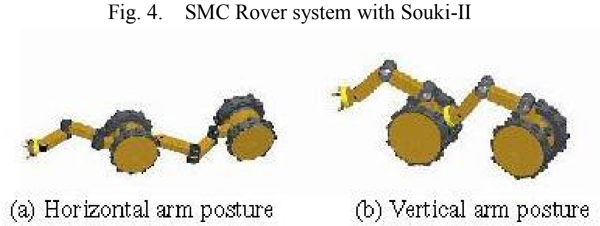


Fig. 5. docking position options

Another position is the vertical arm position as shown in Fig.5 (b). In this position, the arm is vertical and grips the rear part of the arm rotation axis of the leading robot. If there is a step between these two Souki-II's, by adjusting the arm joint angle, Souki-II can adjust the angle of the docking component. This second docking mechanism is comparatively simple when compared to the horizontal arm position. Steering is achieved by adjusting the arm rotation angle.

For the reasons given above the vertical docking position has been deemed more useful.

III. Mechanisms of Souki-II

It is difficult for Souki-II to maintain the stability on the posture as shown in Fig.6. To carry out the proposed work in this posture the arm should be light and the center of gravity of the body should be in the opposite direction to the arm. Considering these points, each part of Souki-II is designed as below.

III-1 Body mechanism

To maintain stability whilst operating, body elements have been placed underneath the arm as in Fig.7. The multistage gears for the wheel driving actuators are attached to the side of body. The reduction ratio of this gear is 252. The arm axis uses the same actuator unit.

The active wheels consisting of circular plates and foam rubber surround the body.

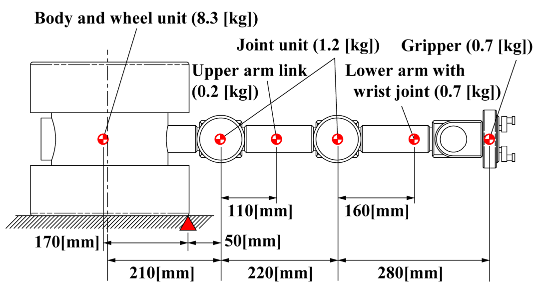


Fig.6. Weight distribution of the Souki-II

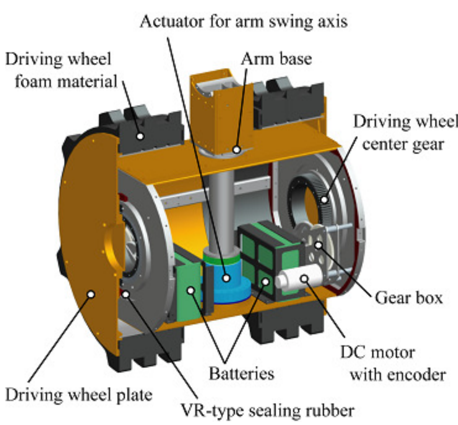


Fig. 7. Body mechanism

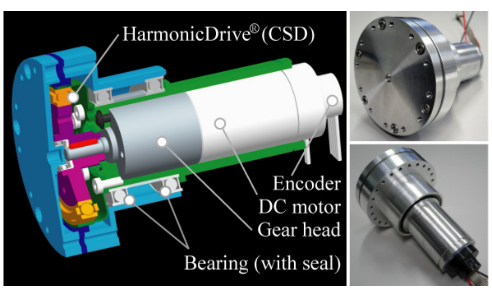


Fig. 8. Introduced actuator unit

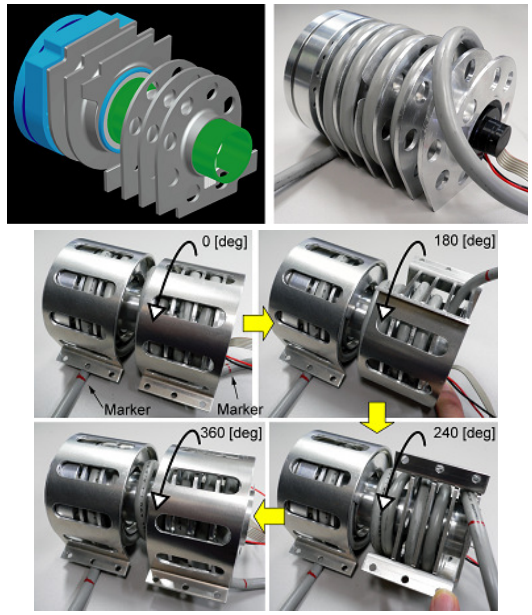


Fig. 9. Spiral grooved wire guide around joint actuator

III-2 Actuator unit

The actuator unit is in the arm joints and consists of a motor and reduction structure. This unit simplifies the design of the arm link allowing for maintenance to be concentrated on only these parts. Additionally, the whole arm is protected against dust and water. A joint actuator unit has many advantages.

The actuator unit is shown in Fig.8. This unit consists of a DC motor of output power 23.2W, drive voltage 24[V], harmonic drive with reduction ratio 594, and total no load rotation 60 rpm, total weight 560g. Two shielded deep groove bearings are attached around the gear head.

The result of a torque performance examination of the actuator unit is shown in Fig.10. The error bars show the maximum and minimum number of three measurements. The linear approximate equation in the graph is calculated by the least square method which passes through the no-load current 0.46[A]. From the specification of DC motor and Fig.6 the maximum torque of this unit is about 8.5[Nm] and more torque can be output in a short term use. As a result, Souki-II can be take posture easily as shown in Fig.6.

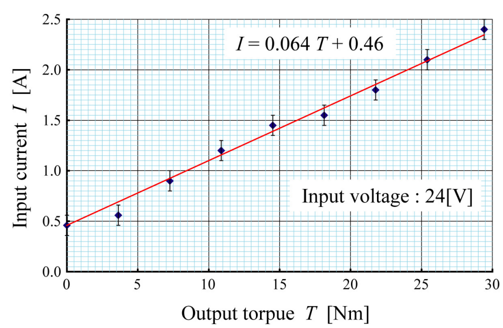


Fig. 10. results of actuator experiments

III-3 Joint mechanism of wiring

Actuator units were attached to every joint, hence, and we need lots of electric wires. However, as the revolution axis of the actuator has no hole, we can not install the wire inside the joint and the wires have to be attached outside. Such wires sometimes cause trouble, so we introduced a new joint structure for the Souki-II. It is to attach a cover member with a spiral groove on it as shown in Fig.9. When the joint rotates in the directing of coiling, the diameter of the surrounding wire becomes smaller, and when the joint rotates in the opposite direction, the diameter becomes bigger. By this way, this mechanism absorbs changes of the length. As the wire rotates several times, the bending rate of the wire is small securing long life. Furthermore, the cover member with the spiral groove acts as a radiation fin for the actuator and as well as a heat sink.

Fig.9 also shows the proposed wiring mechanism of the joint. With reference to this figure, the left side is fixed whilst the right part is rotated clockwise. You can see the change in the diameter of the wire.

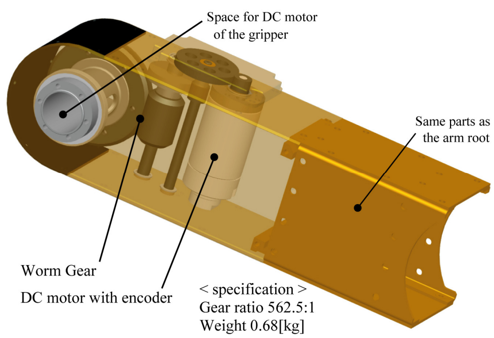


Fig. 11. Wrist mechanism of Suki-II

III-4 Arm mechanism

The wrist structure is shown in Fig.11. In order to reduce the weight and introduce no back-drivability, we selected a worm gear mechanism. The twist structure has a reduction ratio of 562.5 and weight of 0.7[kg].

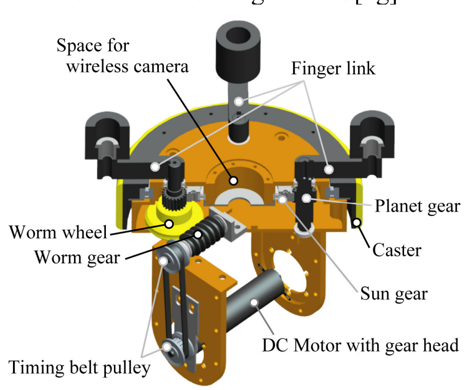


Fig. 12. Gripper mechanism

III-5 Gripper/Docking mechanism

The gripper is designed as in Fig.12. Rotation of the DC motor is transmitted via the worm gear to drive the sun gear and the sun gear drives four axes where finger links are connected eccentrically. We also attached a docking tab on the body of Souki-II to be gripped by the gripper. Once these parts have connected, both units are completely fixed because the gripper uses a worm gear which is irreversible. The adjustment of position between two Souki-IIs is made by the arm rotation axis.

III-6 Prototype of Souki-II Experiments

Two prototypes of Souki-II were made (see Fig.13). Their specification is as follows;

- -Total weight: 12.3[kg]
- -Fully extended length: 920[mm]
- -Each arm link measurements:
  229(L)[mm] x 53(W)[mm] x 64(D)[mm]
- -Body measurements:
  ϕ 320[mm] x 228[mm]

Fig. 13. Total view of the Souki-II

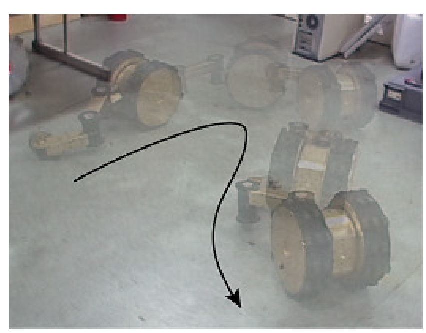


Fig. 14. Steering control of the Souki-II

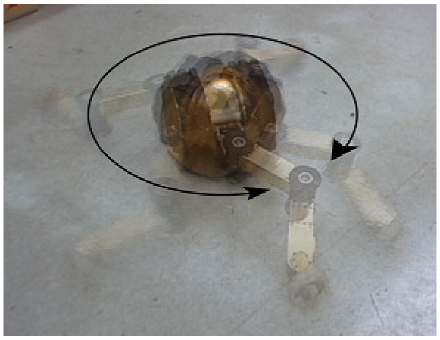


Fig. 15. On-the-spot rotation of Souki-II

Souki-II was made to move on flat ground to confirm basic ability of motion. By changing the angle of the passive wheel, steering of Souki-II was easily achieved on flat ground (Fig.14). By using counter rotation of the two main wheels, on the spot steering was also possible (Fig.15). In the experiment using a step of 150[mm] as shown in Fig.16, Souki-II successfully traversed it by using its arm to support the reaction force.

Manipulation tests were also carried out. When Souki-II was in its working mode, it could successfully grip objects from a small stone of diameter 20[mm] to a ring of diameter is 78[mm] as shown in Fig.12

A mode changing test was carried out to test the transition between the moving and working modes (Fig.17) and to confirm that it is possible to change the mode without an impact shock.

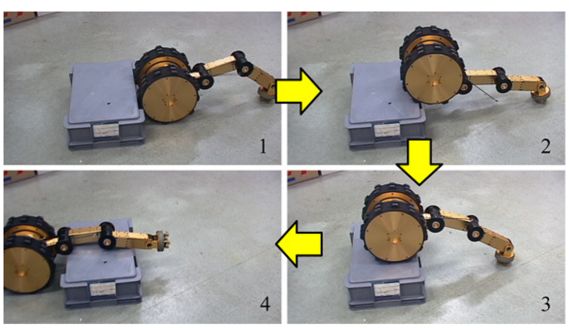


Fig. 16. Obstacle overcome motion (150[mm] step)

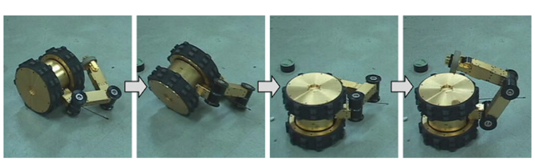


Fig. 17. Mode change from wheel to manipulation mode

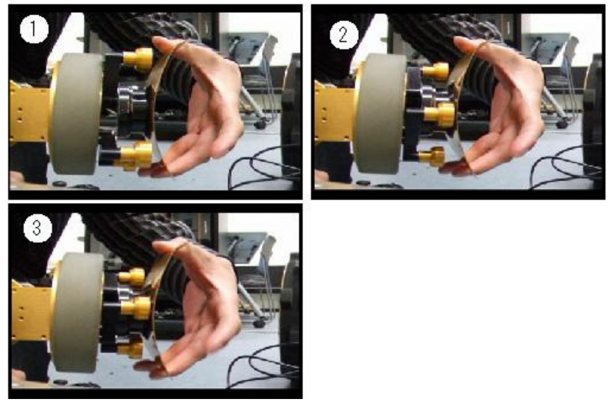


Fig. 18. Experiment to grasp the docking tab

IV. Co-operative work of Souki-II

In this section, the experiment of docking two Souki-IIs is described.

The partial docking test is shown in Fig 18. The gripper shape and the docking tab on the body are matched and connected strongly enough. The results of this test confirmed that docking can be achieved strongly enough.

The sequence of the docking behavior (Fig.19) and movement while docking were also examined (Fig.20). It was confirmed that after docking, Souki-II can easily steer by rotating the arm rotation axis as shown in Fig.18. Whilst two Souki-IIs have an angle about the movement direction of each other, they curve but it is better to control the speed of each wheel.

A step traversing test was also made for the connected Souki-II. A single Souki-II could not traverse over a step of 180[mm] in height, however, once two of the Souki-II are connected, it could traverse this step easily as shown in Fig.21. Whilst traversing over the step, the trailing Souki-II is pushing the front one helping to increase fraction between the wheel and the step.

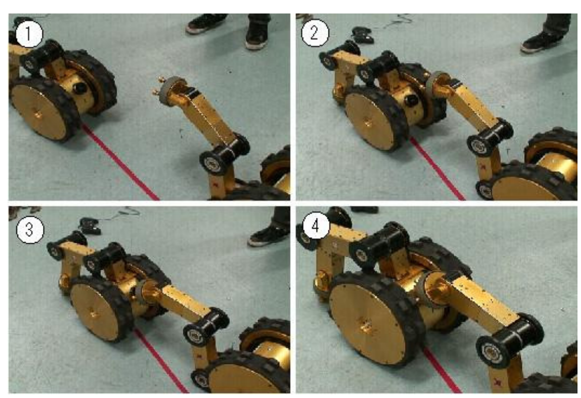
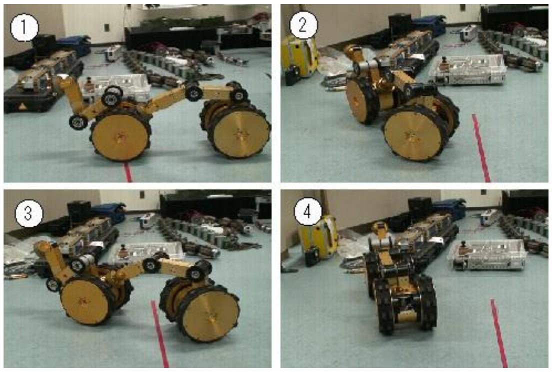


Fig. 19. Docking behavior



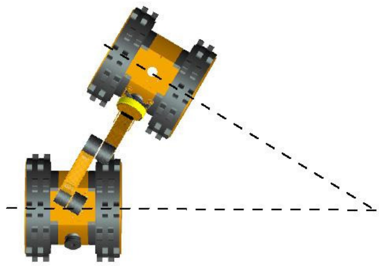


Fig.20. Steering while docking

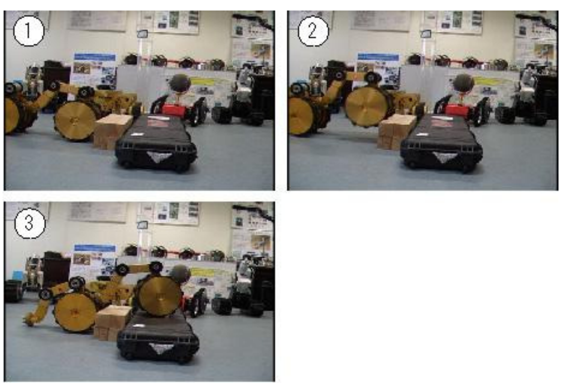


Fig.21. Traverse 180[mm] step while docking

V. Conclusion and future work

We developed the arm-wheel hybrid robot “Souki-II” as an improved model of the former model “Uni-Rover”. The Souki-II showed its specific feature of changing its mode from wheeled locomotion to a manipulation mode. It also had the feature of connecting to another unit by using docking gears and connected Souryu-II showed high terrain adaptability.

Experiments using the prototype models were successful but we need more study to improve the mobility and introduce autonomous operation.

To improve the motion in connected mode, appropriate position and force control should be considered. For the autonomous control of the docking, we will need camera and target beacon control. Furthermore, an algorithm for automated docking should also be developed.

With these additional studies, the arm-wheel hybrid robot “Souki-II” will be adapted for use in many applications.

VI. Acknowledgment

This research is supported by the grant-in-aid for the 21st Century COE (Center of Excellence) Program “Innovation of Creative Engineering through Development of Advanced Robotics” by The Ministry of Education, Culture, Sports, Science and Technology of Japan.

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