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Harvesting Robot Based on Physical Properties of Grapevine

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Abstract
Grapevine in usually planted in adopting a trellis training system in Japan. It is considered that this training system is more suitable for robot harvesting than the other training systems, since the bunches which hang down from the trellis are exposed and can be easily detected and harvested. Before developing a robot, it is necessary to investigate the physical properties of the grape plant. Accordingly, a harvesting robot was developed experimentally to harvest individual bunches. The robot consisted of a 5 DOF manipulator, an end-effector which could grasp and cut rachis and could push a bunch, a visual sensor in which a TV camera and optical filters were used, and a crawler type traveling device. Based on the experimental results, is was observed that the robot could perform harvesting operations satisfactorily, because the design was based on the physical properties of the grape plant for the development of the robot.

Discipline: Agricultural engineering/Horticulture
Additional key words: sensors, feedback control, trellis training system

Introduction

Studies have been carried out on robots which harvested tomatoes, cucumbers, and citrus fruits in greenhouses or in the field[1–6] in Japan. The conventional plant training systems did not enable man or the robot to detect all the fruits, since they grew almost on a vertical plane or in a spherical orbit so that the leaves and the stems were hiding many fruits in the plant training systems. It was reported that the possibility of using a robot to harvest grape was also studied in France and that it was difficult for the robot to harvest all the fruits under field conditions wherein grapes were planted on rows 1.2 m high and 0.5 m wide[7]. In contrast to the European training method, grapes, kiwi fruits and pears are planted in adopting a trellis training system in Japan, so that only the fruits hang down from the trellis. It is considered that this training system is suitable for robot harvesting, but requires hard work for manual harvest.

In this report, basic studies were carried out to develop a grape-harvesting robot. At first, three-dimensional positions of grape bunches were determined, and a polar coordinate manipulator with 5 degrees of freedom was manufactured as a trial. Secondly, physical properties of rachis, fruits and bunches were investigated, and an end-effector which could hold and cut rachis and push bunches was constructed as a trial. Thirdly, spectral reflectance of grape plant was measured, and suitable wavelengths were selected for visual sensor. Experiments to identify the bunch in the image inputted using optical filters and a TV camera and to detect the bunch position were carried out. Finally, an experiment to harvest the grape bunch with the robot which was mounted on a crawler-type travelling device was conducted.

Materials and methods

1) Cultivation method

Fig. 1 shows the positions of grape bunches and tree spread on the horizontal plane in the trellis training system applied in Okayama University. The height from the ground to the trellis was 170 cm. The variety of grape was Muscat of Alexandria, and the plant training systems of most varieties were similar to those used in the western part of Japan. It is considered that this training system is suitable for robot harvesting, because it is easy to detect the bunches and to have an access to them, although manual harvest is laborious.

2) *Manipulator*

The basic mechanism of the manipulator was investigated according to the position of the bunches, assuming that the robot travelled along the main scaffold. It appeared to be preferable that the mechanism included a prismatic joint so that the manipulator could work with high speed by using

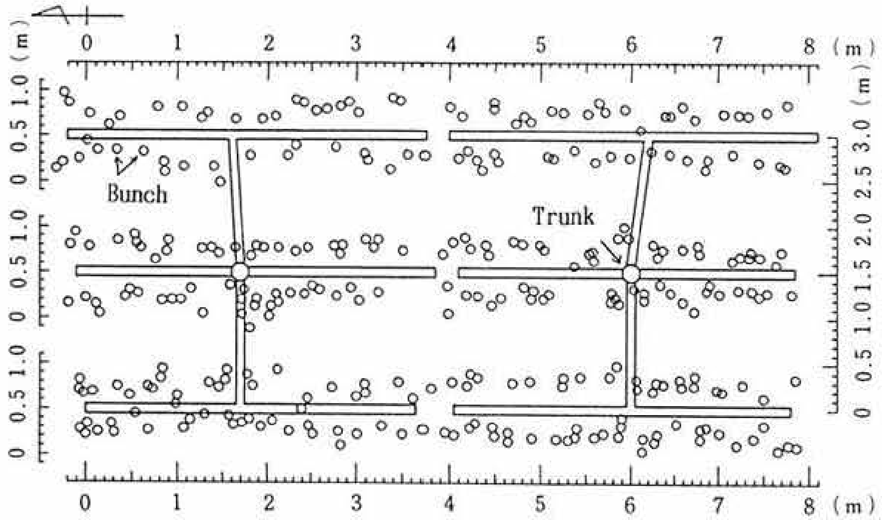


Fig. 1. Position of bunch

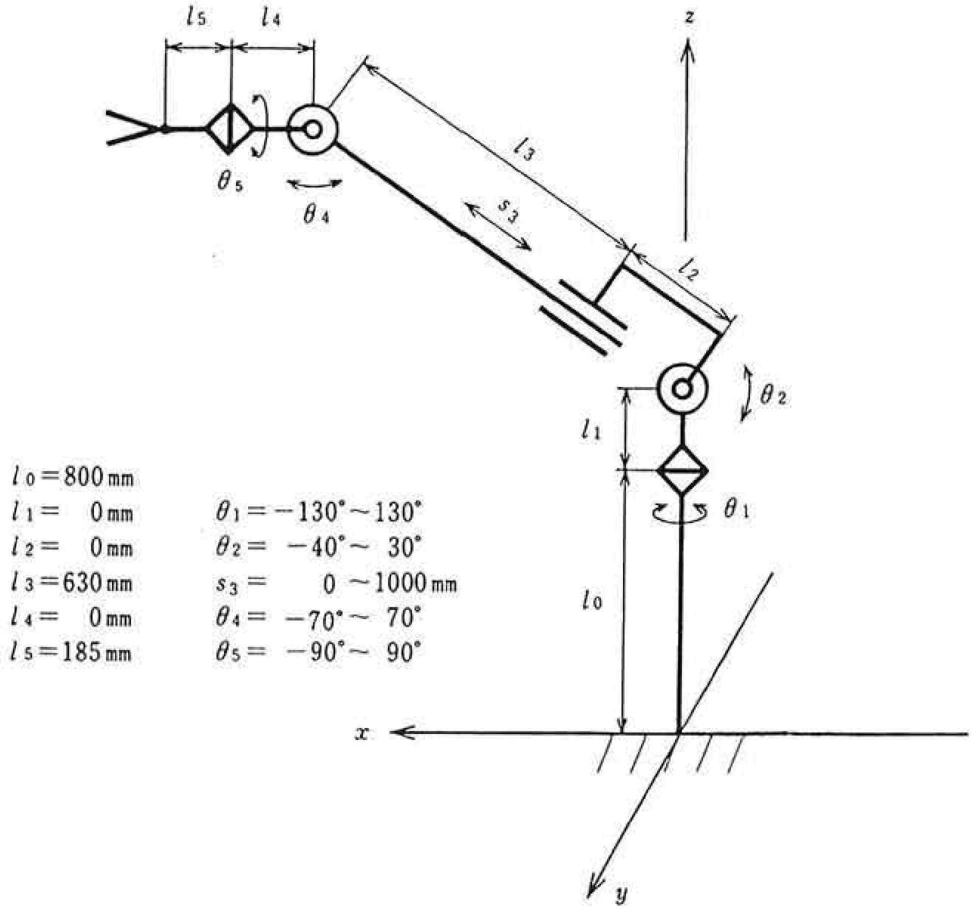


Fig. 2. Basic mechanism of manipulator with 5 degrees of freedom

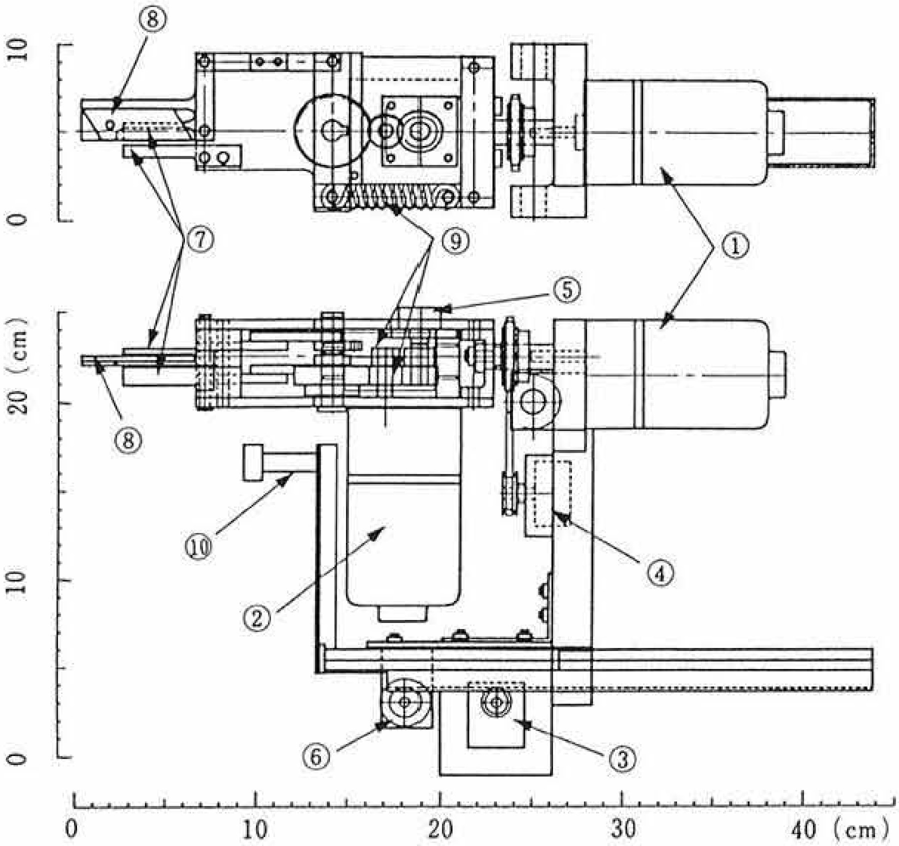
a simple control method, since there were few obstacles under the trellis. However a cartesian coordinate or cylindrical coordinate manipulator may collide with the trellis, when the robot travelled and when the manipulator end moved horizontally at the height of the trellis. Therefore, the polar coordinate manipulator shown in Fig. 2 was selected.

This manipulator had 5 degrees of freedom including 1 prismatic joint and 4 rotational joints. These joints were controlled at various speeds. The length of the arm was 1.6 m, and the stroke was 1 m. The manipulator end could move horizontally below the trellis at a constant speed.

3) *End-effector for harvesting grape*

An end-effector to grasp and cut a rachis was designed so that grape bunches would not shatter and the white powder which enhanced the marketing value would not be removed when the end-effector grasped the rachis tightly at harvest time. Before manufacturing, the relationship between the grasping force and frictional resistance and the relationship between the cross-sectional area and cutting resistance were investigated. Accordingly, the grasping force and the cutting force of the rachis for the end-effector were determined. The results indicated that the grasping force was 10 N and the cutting force was 100 N.

The end-effector manufactured as a trial based on these results is shown in Fig. 3. In addition to the functions of grasping and cutting the rachis, a function of pushing of bunch was added to this end-effector, to enable the end-effector to grasp a very short rachis also at harvest time, to reduce the swinging of the bunch at the time of carrying, and to orient the bunch at the time of release. The cutter ⑧ and finger ⑦ were driven by one DC motor ② and two springs ⑨, and the pushing device ⑩ moved straight by using a DC motor ③, rack and pinion.



① Motor for wrist joint,
② Motor for grasping and cutting,
③ Motor for pushing,
④ Potentiometer for wrist joint,
⑤ Potentiometer for grasping and cutting,
⑥ Potentiometer for pushing,
⑦ Finger for grasping rachis,
⑧ Cutter for cutting rachis,
⑨ Springs for grasping,
⑩ Pushing device.

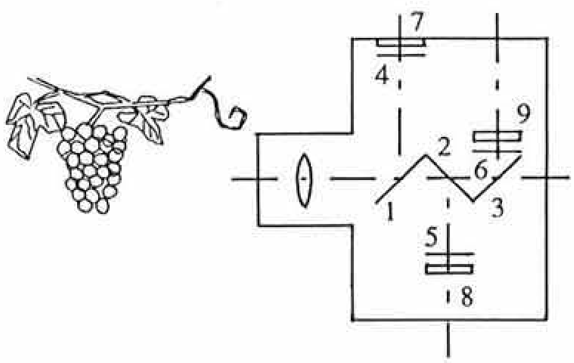
Fig. 3. Grape-harvesting hand

4) Visual sensor

(1) Discrimination

A visual sensor which consisted of several image sensors and optical filters was assumed, as shown in Fig. 4, to discriminate between grapevine plants. Light penetrating through the lens was divided by half mirrors (1,2) and a mirror (3), and images appeared on the image sensors (7–9) after passing through the optical filters (4–6), since the images of the parts of grapevine plant were obtained by calculating the output from the image sensors.

Fig. 5 shows the spectral reflectance of Muscat of Alexandria whose fruit color is white-green. It was observed that the color could be determined from the reflectance in the visible region and that the difference among the reflectances indicated the plant parts in the near-infrared region.



1, 2: Half mirror,
3: Mirror,
4–6: Optical filter,
7–9: Image sensor.

Fig. 4. Optical system of visual sensor

By the addition of R, G, B filters, interference filters of 500, 550, 670, 850 and 970 nm were selected from this figure to discriminate the parts of the grapevine plant. The discriminating experiment was carried out by using the filters and a visual sensor whose sensitivity was in the wavelength range of 400 to 1,200 nm.

When a bunch of Muscat of Alexandria was discriminated from leaves and twigs using R, G filters, discrimination was difficult because the fruit color was similar to that of the leaves and the green twig based on the experimental results. However when 550 and 850 nm interference filters were used, discrimination was possible, because the reflectance of the fruit was different from that of leaf or green twig in the near infrared region. As for Delaware and Campbell Early whose fruit colors were different from those of leaves and twigs, it was easy to discriminate them even using R, G, B filters.

(2) Position detection

In this study, the visual sensor was attached near the end-effector. This position was effective to obtain a higher accuracy for the detection of fruits, because the picture element number for the recognition of the bunch increased when the end-effector came near the bunch. Experiments to detect a fruit with the movement of the manipulator toward the bunch were conducted using the average diameter of bunch, and two picture element numbers for the recognition of the bunch while the visual sensor moved toward the bunch. If the bunch diameters of the same variety are nearly constant, the picture element number for the recognition of the bunch

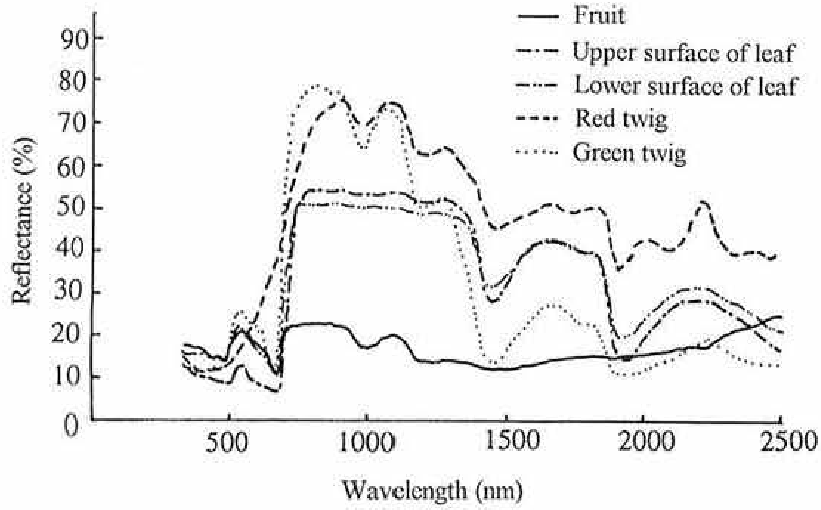
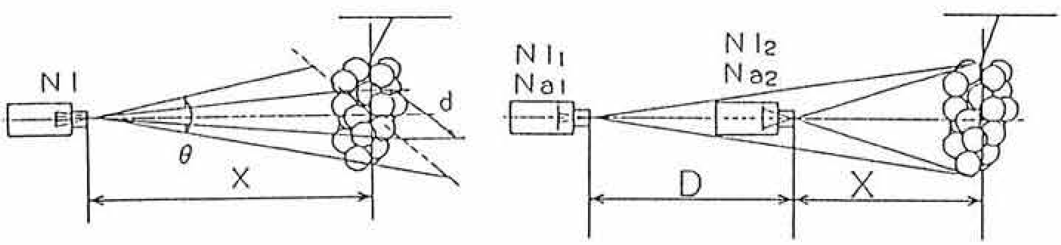


Fig. 5. Spectral reflectance of grape plant

gives an approximate distance from the visual sensor to the bunch that is expressed in equation (1) in Fig. 6. When the whole bunch is observed in the image, the distance is calculated from the picture element numbers for the recognition of the bunch as indicated in equation (3). The use of equation (2) enables to detect the distance when the part of bunch or rachis is observed in the image.

Based on the experimental results for the detection of the positions of bunch and rachis, it was observed that an error remained even at the position at which the distance from the visual sensor to the object was small, when equation (1) was used, because the diameter of the bunch which was used this time was smaller than the average diameter. When equations (2) and (3) were used, the error was about −20 mm at 300 mm distance. When the rachis was detected by using equation (2), the error was larger, because



$$X = \frac{d \cdot N}{2 \cdot Nl \cdot \tan\frac{\theta}{2}} \quad \cdots\cdots\cdots (1)$$

$$X = \frac{D \cdot Nl_1}{Nl_2 - Nl_1} \quad \cdots\cdots (2)$$

$$X = \frac{D \cdot \sqrt{Na_1}}{\sqrt{Na_2} - \sqrt{Na_1}} \quad \cdots\cdots (3)$$

X : Distance from visual sensor to bunch
d : Average diameter of bunch
N : Picture element number of visual sensor on a line
Nl : Picture element number for recognizing a bunch on a line
θ : Visual angle
D : Visual sensor moving distance
Na: Picture element number for recognizing a bunch in an area

Fig. 6. Methods for detecting position

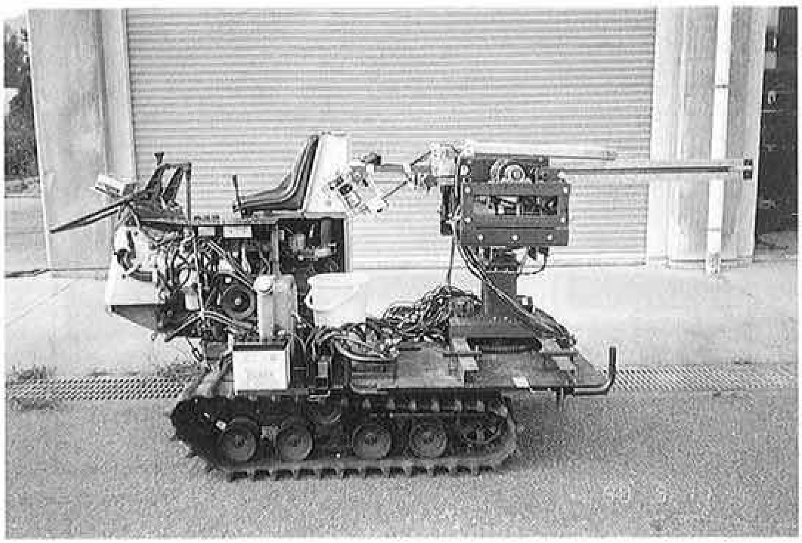


Plate 1. Grape-harvesting robot

the picture element number for the recognition of the rachis was too small for accurate detection.

5) Travelling device

Plate 1 shows the grape-harvesting robot with the travelling device. The travelling device had crawlers, because the field was not tilled and the robot was relatively heavy. The width of the crawler was 360 mm, and the ground contact length was 1,010 mm. The width of the travelling device was 1,400 mm, the length was 2,300 mm, and the height from ground to the plate on which the robot was mounted was 420 mm. The travelling speed of the device could be changed from 0 to 2 m/s. In the experiment, the device was steered manually, and the engine stopped when the robot operated.

The harvest experiment was conducted by using the robot on the travelling device in the laboratory and in the field.

Results and discussion

It was apparent that the end-effector was able to grasp and cut the rachis successfully, since the structure of the end-effector allowed a reasonable error, although the detection error of the visual sensor was about 20 mm. The pushing device also worked effectively except for a rachis that was too short. Fig. 7 shows an example of the experimental results for harvest. However it took a long time for visual feedback control to recognize objects, and it was considered that the CCD camera needed automatic exposure in the field. The photo-electric sensor was effective in the field.

It was confirmed that grapevine in the trellis training system in Japan could be more easily detected by the robot and bunches of grapes could be more easily harvested than in other training systems. It was considered that the training of other fruit trees should be reassessed for the development of robots for agricultural use.

Conclusion

It was observed that the robot could harvest fruits under optimum conditions based on the experimental results, but that it took a long time for the visual sensor to detect obstacles, and that it required automatic exposure in the field, etc. Therefore, the visual sensor should be used in association with another sensor to define the three-dimensional shape of the object.

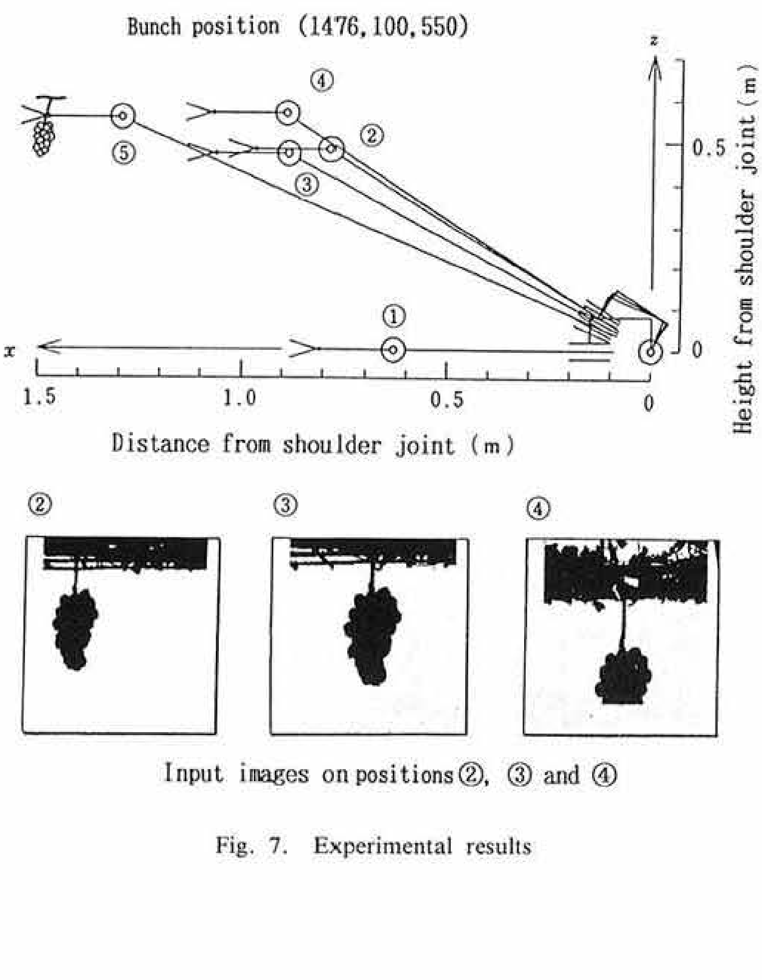


Fig. 7. Experimental results

The trellis training system of grapevine is suitable for robot harvesting. Engineers and horticulturists should cooperate to reconsider the cultivation methods for the development of other agricultural robots.

References

1) Amaha, K. et al. (1989): Development of a robotic hand for harvesting cucumber fruits. *J. Agric. Met.*, **45**, 93-97 [In Japanese with English summary].
2) Fujiura, T. et al. (1990): Fruit harvesting robot for orchard. *J. Jpn. Soc. Agric. Machin.*, **52**, 35-42.
3) Kawamura, N. et al. (1984): Study on agricultural robot (Part 1). *J. Jpn. Soc. Agric. Machin.*, **46**, 353-358 [In Japanese with English summary].
4) Kawamura, N. et al. (1985): Study on agricultural robot (Part 2). *J. Jpn. Soc. Agric. Machin.*, **47**, 237-241 [In Japanese with English summary].
5) Kondo, N. et al. (1992): Request to cultivation method from tomato harvesting robot. *Acta Hortic.*, **319**, 567-572.
6) Kondo, N. et al. (1991): Studies on agricultural robot with 8 degrees of freedom. *J. Jpn. Soc. Agric. Machin.*, **53**, 49-57 [In Japanese with English summary].
7) Sittichareonchai, A. et al. (1989): A robot to harvest grape. ASAE Paper, No.897084.

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