岡山大農学報 (72), 69−76 (1988)

Detecting Fruit by Visual Feedback on Hand-Eye System (I)

—— Fruit Detecting Experiment Using Anthropomorphic Type Manipulator ——

Naoshi KONDO
(*Laboratory of Agricultural Machinery*)

Received July 1, 1988

Introduction

Many fruit trees are planted in sloping orchards in Japan and almost of fruits are now harvested by human labor. Therefore harvesting operations are hard works. The fruits which are harvested by the shaker are not for fresh marketing, but only for processing. A robot which harvests fruits automatically one by one with its manipulator is more desirable in Japanese condition. When a visual sensor is used as an eye of the robot, it must be simple and cheap, since it is for agricultural use. Besides, it should be able to recognize various colors of fruits.

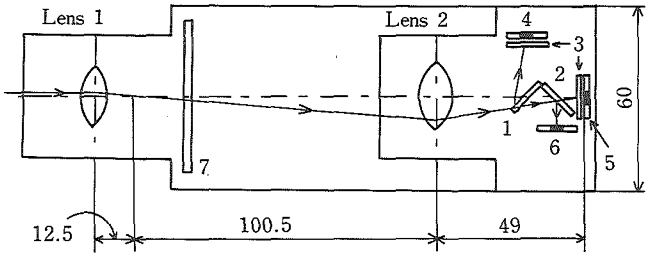
There are two systems to attach the visual sensor to the robot ; visual sensor attached to manipulator[5] or frame independent to manipulator. A method of detecting the three dimensional positions of fruit by means of a stereo-camera using the visual sensor which was attached to the frame was already reported[3]. This method is effective to detect comparatively low plants such as tomato. It is difficult, however, to recognize the fruits of tall trees such as citrus fruits, and to measure the locations of them accurately, because the longer the distance from the visual sensor to the fruits is, the less the picture elements to recognize fruits are.

In this report, the visual sensor was attached near to the hand of the manipulator. This position is effective to get higher accuracy of detecting fruits, because picture elements of fruits increase with coming near to fruits. The fruit detecting experiment for gripping was done by use of an anthropomorphic type manipulator[2] with 5 degrees of freedom.

Experimental Apparatus and Method

1. Visual sensor

Fig. 1. shows an optical system of the visual sensor made as a trial. Two dichroic mirrors (red and blue reflection) and three image sensors[4] which were MOS type and contained 64 (H)×64 (V) photo diodes were used in this visual sensor. Light was decomposed into three color components (red, green, and blue) and the color of an object was decided by mutual ratio of the three colors. Distance from the visual sensor to the object varied widely according to movement of the manipulator. If one lens whose focal length was about 10 mm was used, object focusing was necessary with the movement of manipulator. Besides, the space between the lens and the image sensor, in which mirrors and filters were placed, became small. For these reasons, the lens 1 whose focal length was 12.5 mm, F-number was 1.4 and the lens 2 whose focal length was 25 mm, F-number was 1.4 were used in this device. As the visual sensor was attached to the manipulator, it should be made small and light, 2 mm aluminum plate was used to make the camera box, and its electronic circuits[4] for the image sensors were separated from the visual sensor. The size of the visual sensor was 225 mm in length,



Lensl f_1=12.5mm
F_1=1.4
Lens2 f_2=25mm
F_2=1.4

1 Dichroic mirror (red reflection)
2 Dichroic mirror (blue reflection)
3 N. D. filter (20%)
4~6 Image sensor
7 Filters

Fig. 1. Optical system of visual sensor.

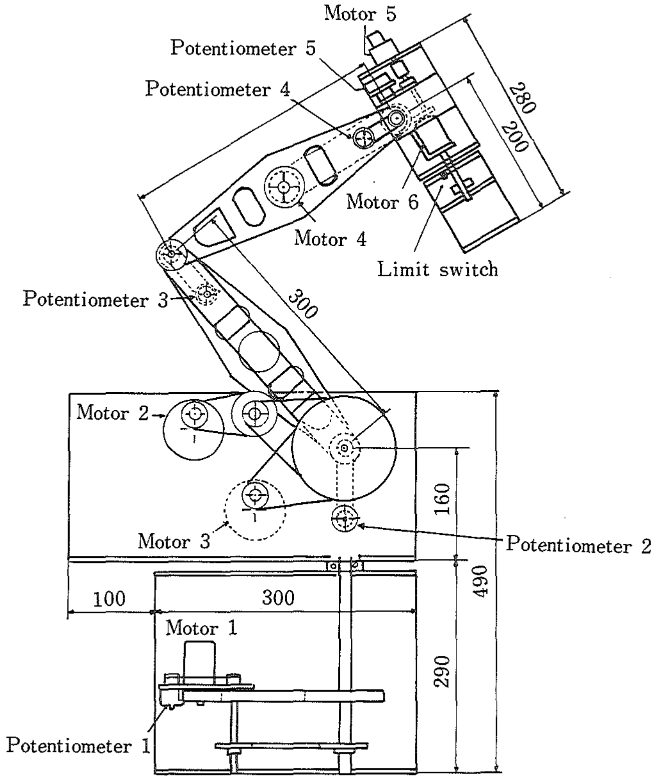


Fig. 2. Anthropomorphic type manipulator.

106 mm in width, and 76 mm in height (when a stand was fitted), and weighed 880 g. Its field angle was about 55°.

In this experiment, considering memory numbers and calculation speed of microcomputer, 32×32 of the picture elements were input to the microcomputer and scanning frequency of the image sensors was about 15 kHz/bit.

Only when picture elements assigned fruit color continued for three in both horizontal and vertical directions in the image, it was regarded as a fruit.

2. Anthropomorphic manipulator

Fig. 2. shows an anthropomorphic type manipulator used in this experiment, which had 5 degrees of freedom. Details of this manipulator is explained in reference[2].

3. Control method

At first, the robot travels along the row of the trees and stops in front of a fruit tree. Secondly, the first image is input at the initial posture of the manipulator of which the visual field of visual sensor is wide. Thirdly, the manipulator approaches the fruits one by one in order of the first image measured fruit locations by the visual sensor, and then harvests them. It is repeated and when all of the fruits in the first image have been harvested, the image of the next region is input in the initial posture of the manipulator again.

As for the manipulator approaching method to a fruit, direction of each fruit and picture element number of fruit (the maximum number of picture elements which recognize a fruit at a line) which are obtained from the first input image are memorized. Next, approximate distance from the visual sensor to the fruit and desired angle of the manipulator are calculated. The manipulator controlled at the desired angle approaches each fruit inputting the images until the picture element number of fruit become over the set value.

(1) Distance from visual sensor to fruit

Relationship between the distance from the visual sensor to a fruit and the picture element number of fruit is inverse proportion as shown in Fig. 3. Therefore, if fruit diameters of the same variety are nearly constant, the picture element number of fruit gives an approximate distance from the visual sensor to the fruit. In this experiment, the distance was obtained assuming that the average of the fruit diameter was 65 mm.

(2) Deviated angle of manipulator

The deviated angle α of the manipulator to a fruit in Fig. 4. is calculated as follows :

$$\alpha = \tan^{-1} \frac{X \cdot \sin \alpha'}{L + X \cdot \cos \alpha'} \qquad \cdots\cdots(1)$$

L ; distance from stationary joint of manipulator to camera lens

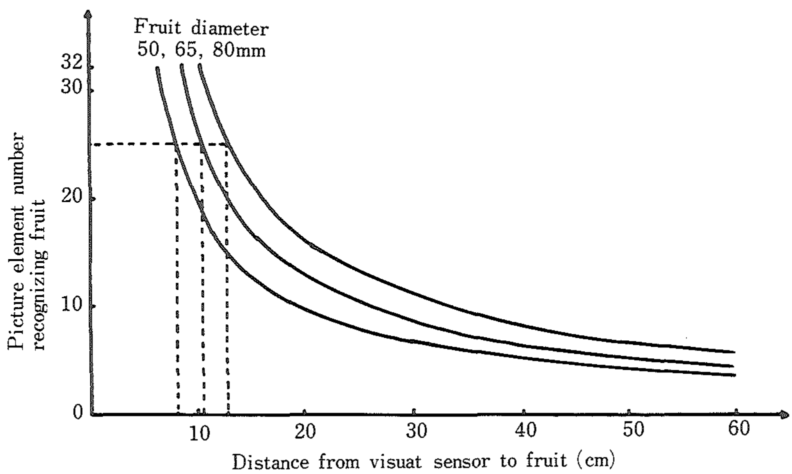


Fig. 3. Relation between picture element number of fruit and distance from visual sensor to fruit.

X ; distance from camera lens to fruit
α' ; direction of fruit obtained from input image

In this experiment, α was approximately calculated by the following equations (2), (3), (4) which were expressed only by arcsine in order to shorten the calculation time in a microcomputer.

$$\alpha = \tan^{-1}\frac{\alpha' \cdot \sin^{-1} 1}{\sin^{-1} 1 + \sin^{-1}(L/X)} \qquad (X > L) \quad \cdots\cdots(2)$$

$$\alpha = \frac{\alpha'}{2} \qquad (X = L) \quad \cdots\cdots(3)$$

$$\alpha = \tan^{-1}\frac{\alpha' \cdot \sin^{-1} 1}{\sin^{-1} 1 + \sin^{-1}(X/L)} \qquad (X < L) \quad \cdots\cdots(4)$$

4. Flowchart of fruit detecting experiment

Fig. 5. shows a flowchart of fruit detecting experiment for gripping a fruit. After the manipulator took at first the initial posture, the first image was input. If the picture element number of fruit was less than the set value, the approximate distance from the visual sensor to a fruit and the deviated angle of the manipulator were calculated. At that time, the moving distance of the manipulator was obtained from the picture element number of fruit, since the image input time and the processing time were about 1 s in all and the anthropomorphic type manipulator which rotating speeds of motors were not controlled was used in the experiment. This moving distance was determined lest the manipulator should approach too near the fruit at a time, assuming that the smallest fruit diameter was 30 mm. Feedback loop was made so as that the image was input again after the manipulator moved for the moving distance. It was repeated until the picture element number of fruit become bigger than the set value. As the fruit was in front of the visual sensor at this time, the position of the hand was rectified to be in front of the fruit, and then the grip was done. If the hand could grip the fruit, the manipulator took the initial posture again, and the flow of the control ended. If it could not grip, it was tried twice, and then the flow ended. In this experiment, the set value of the picture element number of fruit was 24, so that the manipulator might approach to 10 cm before the center of the fruit and the hand might grip when the fruit diameter was 65 mm, which was regarded as the average.

The microcomputer used was New L-Kit 8 made by Fujitsu. Program was written in machine language of 5 k bites, while 6 k bites were used as memory for data.

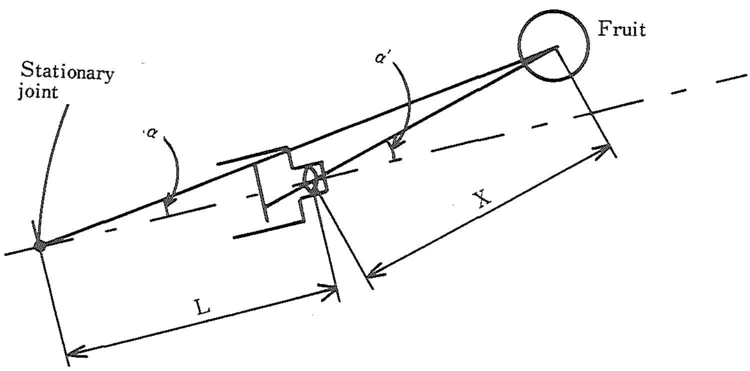


Fig. 4. Direction of fruit and desired angle.

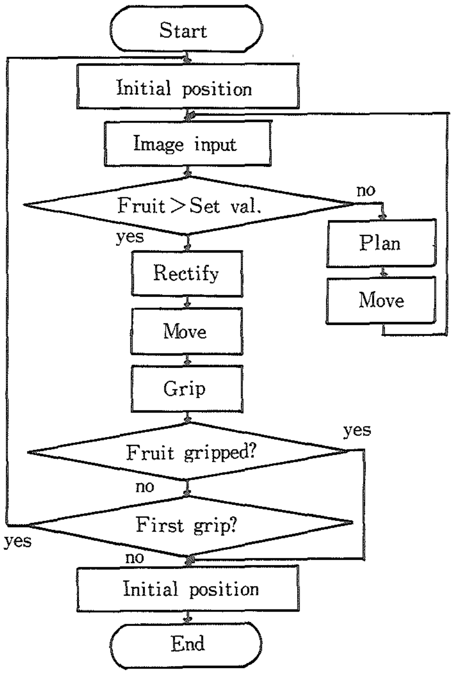


Fig. 5. Flowchart of fruit detecting experiment.

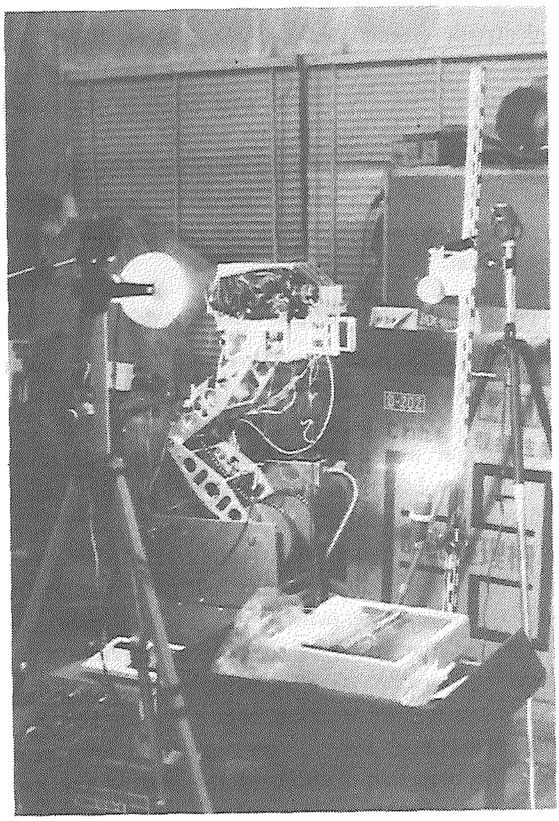


Fig. 6. Experimental apparatus.

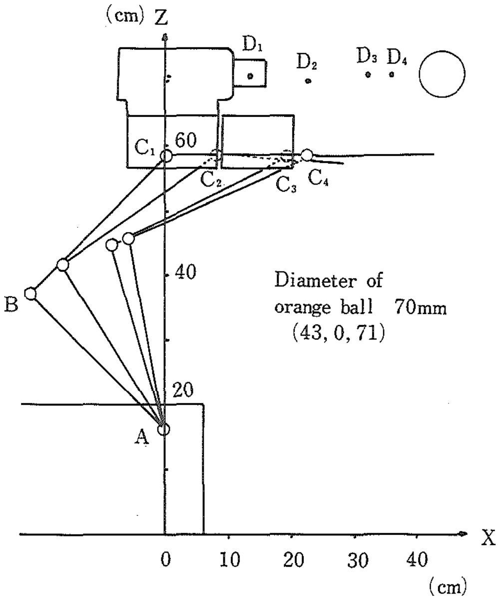


Fig. 7. Experimental result.

5. Experimental method

The experiment was done in room as shown in Fig. 6. The manipulator, the microcomputer, power supplies, etc. were mounted on the traveling device (battery car), and both the visual sensor and its electronic circuits were attached to near the hand of the manipulator. The reason why not only the visual sensor but also its electronic circuits were attached was that the adequate outputs from the image sensors were not obtained, if the length of the cable from the visual sensor to its circuits became more than 30 cm. Total weight of the visual sensor, its circuits and so on was about 3 kg. The gripped objects were wooden balls painted in orange color (they are called orange balls in this report) and they were illuminated properly by color temperature 3200 K lamps. The diameters of the orange balls were 60 mm, 70 mm and 80 mm.

Experimental Results and Consideration

Fig. 7. shows an example of the experimental results. The manipulator was set on the rectangular co-ordinate system, with the direction of the fruit as the X co-ordinate axis, the horizontal direction which was perpendicular to the X-axis as the Y-axis, and the vertical direction as the Z-axis. Origin was positioned at the waist joint. When the manipulator took the initial posture, joint A had the co-ordinates (0, 0, 16), joint B_1 had (−21, 0, 37), joint C_1 had (0, 0, 58.5), and the camera lens 1 D_1 had (13, 0, 71), while the orange ball whose diameter was 70 mm had the co-ordinates (43, 0, 71). The visual sensor should have moved on a straight line ideally, since the orange ball positioned in front of the visual sensor. As shown in Fig. 7, however, the path $D_1 \sim D_4$ of the camera lens 1 did not make a straight line, as the weight of the visual sensor and its circuits was relatively heavy and there was the play of the manipulator. In this example, the manipulator moved three times and after the visual sensor approached to 8 cm before the center of the orange ball, the hand could grip it. When the orange ball did not position in front of the visual sensor, the manipulator often could not approach it because of the play of the manipulator. Therefore, this experiment was done only in the condition that the orange ball was in front of the visual sensor. It was observed from this experiment, that the manipulator approached to 7.5

cm in average before the orange ball when the diameter of the orange ball was 60 mm, 9.5 cm when the diameter was 70 mm, 11 cm when the diameter was 80 mm, and then gripped. It should have approach to 9.6 cm before the orange ball when the diameter was 60 mm, 11.2 cm when 70 mm, 12.8 cm when 80 mm ideally. It was considered that the reasons why the manipulator approached too near the orange ball were that there was the play of the manipulator, that the visual sensor could not recognize the orange ball precisely, and so forth.

From these experimental results, it was observed that the hand was able to grip the orange balls which positioned at 30 cm in front of the visual sensor whose picture element number was 32×32, since the structure of the hand permitted a reasonable error. A characteristic of this method was that the manipulator was able to approach the fruit reliably measuring the fruit location if the fruit was in the visual field of the visual sensor. Defects of it were that the error depended on the fruit diameter arose in the distance from the visual sensor to the fruit, and that it took long time for the manipulator to approach it because of many image inputs if the image input time and the processing time were not reasonably short. It was considered that this method was more advantageous to a telescopic type manipulator than the anthropomorphic type manipulator which moved after the position of the hand and the posture of the manipulator were decided.

Summary

A visual sensor which could recognize fruits was made in order to develop the sight sense of the fruit harvesting robot. This visual sensor was attached to an anthropomorphic type manipulator, and a fruit detecting experiment using a method of visual feedback was done. The results were obtained as follows ;

It was observed that the hand was able to grip the orange balls which positioned at 30 cm in front of the visual sensor. It was given as defects that the error depended on the fruit diameter arose, number of the image input was big, and so on. It was considered that this method was more advantageous to telescopic type manipulator than anthropomorphic type manipulator.

References

1) KAWAMURA, N., N. KONDO: Study on Visual Sensor Attached to Manipulator for Harvesting Fruit, Journal of Currency Branch of the Society of Agricultural Machinery **55**, Japan, 45−48 (1984)
2) KAWAMURA, N., K. NAMIKAWA, T. FUJIURA, M. URA: Study on Agricultural Robot (I), Journal of the Japanese Society of Agricultural Machinery, **46** (3), 353−358 (1984)
3) KAWAMURA, N., K. NAMIKAWA, T. FUJIURA, M. URA: Study on Agricultural Robot (II), Journal of the Japanese Society of Agricultural Machinery, **47** (2), 177−182 (1985)
4) MATSUSHITA ELECTRONICS CORPORATION: Specification Area Image Sensor MEL 64×64.
5) SLAUGHTER, D. C., R. C. HARRELL: Color Vision in Robotic Fruit Harvesting, Transaction of the ASAE **30** (4), 1144−1148 (1987)

ハンドアイシステムにおけるビジュアルフィードバックを用いた果実の検出（I）

―― 関節型マニピュレータを用いた果実検出実験 ――

近藤　直
（農業機械学研究室）

現在我国の果実類における作業はほとんど人力によって行なわれており，その疲労は大きくなっている．そこで農業用ロボットが望まれており，そのロボットの感覚の中で最も大きな割合を占める視覚部を開発することを目的に視覚センサを試作した．すでに報告されているステレオ写真による果実の位置検出法では視覚センサを走行装置に取り付け，一定距離進行方向に視覚センサを平行移動させることによって果実の3次元位置を求めているが，この方法はトマト等のようにほぼ平面内に生育する果実には有効であるものの，柑橘類のように大きな樹冠を形成する果実に対しては，視覚センサから果実までの距離が大きいと果実を認識する画素数が小さくなり，正確な認識，位置測定が困難となる．

そこで本研究では，視覚センサの画素数を有効に生かせる位置，つまり果実を収穫する際に移動するマニピュレータの手先近くに試作した視覚センサを装着することを考えた．そしてビジュアルフィードバック法について自由度5を持つ関節型マニピュレータを用い，果実把握のための位置検出実験を行なうことによって検出精度の検討をした．本実験では対象物は視覚センサの正面にあるとし，視覚センサから対象物までの距離は果実認識画素数より算出した．マニピュレータの目標角度は静止した関節から視覚センサまでの距離，視覚センサから対象物までの距離，及び入力画像より得られる対象物の方向とから求めた．

この実験の結果，視覚センサの正面で距離30 cm程度のところに位置する木球は多少の径の違いはあっても許容誤差を持つハンドの構造のため，画素数32×32でほぼ把握可能であった．この方法は対象物が視覚センサの視野内にあればマニピュレータの動きを利用して確実に接近できるというという特徴があるが，欠点として球径の大小によって求める対象物までの距離に差がでること，画像入力回数が多いため，画像入力，処理に要する時間が長いと接近するのに時間がかかること等があげられた．また，手先の位置と姿勢を決定して移動する人間腕型マニピュレータよりも，直動型マニピュレータに有利な方法であると考えられた．