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Research on the strategy of advancing harvest efficiency of fruit harvest robot in the oscillation conditions

Huiliang Shen, Dean Zhao, Wei Ji, Yu Chen, Jidong Lv
School of Electrical and Information Engineering, Jiangsu University
Zhenjiang, China
e-mail: shenhuiliang716@hotmail.com, dazhao@ujs.edu.cn

Abstract—**Take the fruit harvest robot experimental platform as background to research on the strategy of advancing harvest efficiency. Sample continuous and real-time fruit image by image processing, preprocess to detect the objective fruit, and then create an image coordinate system. Calculate oscillation frequency of the objective fruit with curve fitting of sample value. At the same time, get the depth of the objective fruit with visual and calculate the movement time of the Direct-acing joint to achieve the control of the end effector. The research will reduce the locating time, advance harvest efficiency of the harvest robot when spherical fruits like apple are oscillating.**

Keywords-image processing; harvest robot; harvest efficiency; curve fitting; FFT

I. INTRODUCTION

When apples and other Spherical fruits are harvested, first, each module of the robot should be initialized, and the robotic arm should be in the right distance to fruit trees; then, video camera captures the image information of the objective fruit, the position information of objective fruit will be obtained by recognition and location with image processing software[1]; In the end, the grabbing of fruit and separation between fruit and branch are completed by the action of each joint driven by robot control computer. However, when the fruit and branch are separated, regardless the fruit is cut off or twisted off from fruit trees will cause the oscillation; In addition, the natural wind also leads to oscillations, which will make recognition and location time get much longer, thereby lengthen the total time of fruit harvest, effect the harvest efficiency of the robot.

In the research of advancing harvest efficiency of fruit harvest robot, put forward to predict fruit position by calculating fruit oscillation frequency with image processing, calculate movement time of the end effector[1,2], achieve harvest in oscillation conditions, eliminate time waiting for stop of oscillation, reduce the locating time, thereby reduce the total time of harvest, advance harvest efficiency.

II. FRUIT HARVEST ROBOT WORKING PRINCIPLE

In this study, take fruit harvest robot developed independently in our laboratory as experimental platform. The structure of robot arm is PRRRP (Figure 1) [3], and the first degree of freedom has the arm lifted, the middle three degrees of freedom are the rotational degrees of freedom which will make the end effector move towards any direction in the work space, the fifth freedom is the stretching degrees of freedom (the prismatic joints), according to the robot control commands, the end effector moves to the position of the objective fruit to realize fruit harvest. The lifting of the robot arm is completed by the pump, the rotary joints and prismatic joints are driven by servo motor.

Figure 1. Mechanical structure of harvest robot

Harvest robot system consists of mechanical body, the video signal acquisition and processing systems, control system and man-machine interface. At work, the robot capture the target image with cameras installed by way of eye-in-hand. Then, three-dimensional coordinate space information of objective fruit will be obtained by image processing and be entered in the host computer which will calculate the optimal trajectory of the robot and send to the controller to drive each joint move orderly, make the end effector move to the position of the objective fruit to achieve harvest.

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III. CALCULATION OF OBJECTIVE FRUIT OSCILLATION FREQUENCY

The objective fruit does approximate periodic motion in space, which can be discussed in two cases, not perpendicular to the image plane and perpendicular to the image plane. When the oscillation of objective fruit is not perpendicular to the image plane, the trajectory of the projection in image coordinates is still the approximate periodic motion in any direction (Figure 2); When the movement of objective fruit is perpendicular to the image plane, horizontal and vertical coordinates do not change significantly in the image coordinate system, which can be treated as static situation, and it is just small probability events. Therefore, this research is for the situation that objective fruit is not perpendicular to the image plane.

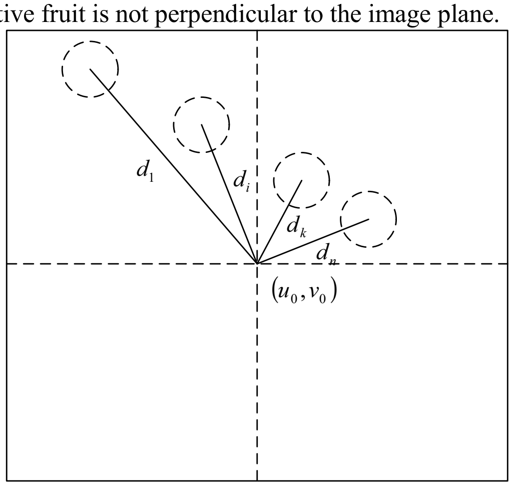

Figure 2. Trajectory of objective fruit projection

The distance d_i from the centroid of objective fruit to image center and the transient position of objective fruit are one-one correspondence, so the change frequency of d is the oscillation frequency of objective fruit.

Sample real-time video, establish d-t Cartesian coordinate system taking the distance d from the centroid of objective fruit to image center as the vertical axis and the image sampling interval of time t as abscissa. Non-linear cycle curve and function will be obtained by fitting curve to (d_i, t). Then f the change frequency of d is obtained by Fourier transform, which is also the oscillation frequency of the objective fruit, so the oscillation cycle $T = \frac{1}{f}$.

The oscillation frequency f is obtained by fast Fourier transform algorithm: Discrete Fourier Transform (DFT) is the basic tool for spectrum analysis, but the calculation is time-consuming, so its application is limited, the research uses the fast Fourier transform (FFT).

IV. CONTROL OF THE END EFFECTOR

The depth of objective fruit s is measured by visual, the velocity of the end effector v is given by the program, then the movement time of the end effector $t_s = \frac{s}{v}$.

Suppose t_0 is a moment of a d_k, let

$$nT = t_s + \Delta t \ (\Delta t < \mathrm{T}) \tag{1}$$

$$\Delta t = nT - t_s \tag{2}$$

Δt is waiting time for supplement. Then at $t_0 + \Delta t$, the end effector runs out and after t_s will grab the fruit , just after the n-cycle in the position of another d_k.

According to $\begin{cases} \Delta t = nT - t_s \\ 0 < \Delta t < T \end{cases}$,

$$\frac{t_s}{T} < n < \frac{t_s}{T} + 1 \tag{3}$$

V. EXPERIMENTAL PROGRAM

Experimental flow chart is shown in Figure 3:

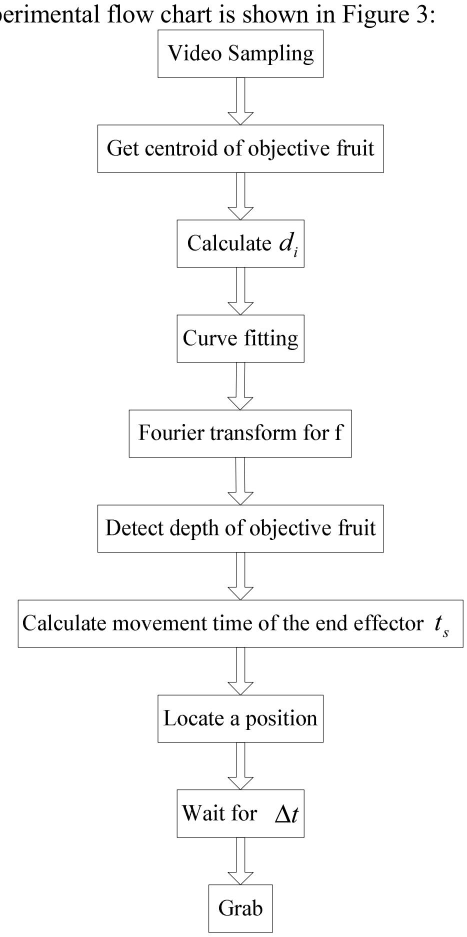

Figure 3. Flow chart of experiment

A. *The establishment of the image plane[4,5]*

Images collected by camera are generally inputted into the computer in the form of a standard television signal, stored as an array of $M \times N$ in the computer, which is M rows N columns. And the value of each element of the array (often referred to as pixels) is the brightness of image points (or known as gray), for example, 320×240 shows that the image is constituted by 320×240 pixels.

Defined the Cartesian coordinate system u-v in the image, the coordinates of each pixel (u, v) are columns and rows of the pixels in the array, so (u, v) are coordinates of the image coordinate system in pixels. Usually, the point of intersection of camera optical axis and the image plane is center of the image (sometimes there will be some deviation because of the camera), so, in the previous example, coordinates of the center of the image are (160,120).

B. *Curve fitting and Fourier transform*

Sample real-time video with a frame rate of 25fps, detect the objective fruit in sampling images and gain two-dimensional coordinates of fruit centroid.

The experimental data of the distance d_i from the centroid of objective fruit to image center of 25 images shown in TABLE I (time interval t = 0.04s).

TABLE I. EXPERIMENTAL DATA

Distance	Value(pixels)	Distance	Value(pixels)
d_1	53.3	d_{14}	43.1
d_2	50.2	d_{15}	43.1
d_3	44.8	d_{16}	46.6
d_4	42.6	d_{17}	52.0
d_5	43.5	d_{18}	52.8
d_6	49.7	d_{19}	48.4
d_7	58.2	d_{20}	43.5
d_8	67.1	d_{21}	42.6
d_9	70.6	d_{22}	45.3
d_{10}	69.3	d_{23}	52.0
d_{11}	64.0	d_{24}	61.7
d_{12}	55.5	d_{25}	68.8
d_{13}	47.5		

Establish Cartesian coordinate system d-t. The image of curve fitting in MATLAB is shown in Figure 4[6].

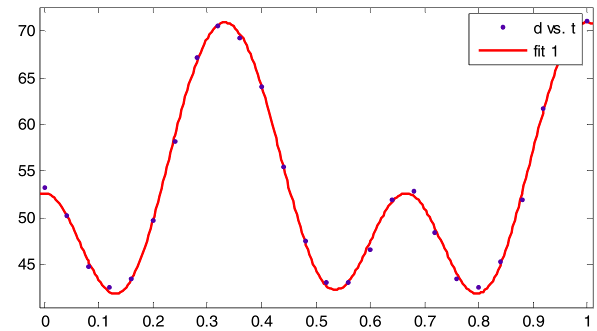

Figure 4. Fitting curve in MATLAB

Curve fitting function:

d=53.04-9.945*cos(t*9.429)-0.1197*sin(t*9.429)+8.752*cos(2*t*9.429)-0.3066*sin(2*t*9.429) (4)

The image of the function after fast Fourier transform is shown in Figure 5[6].

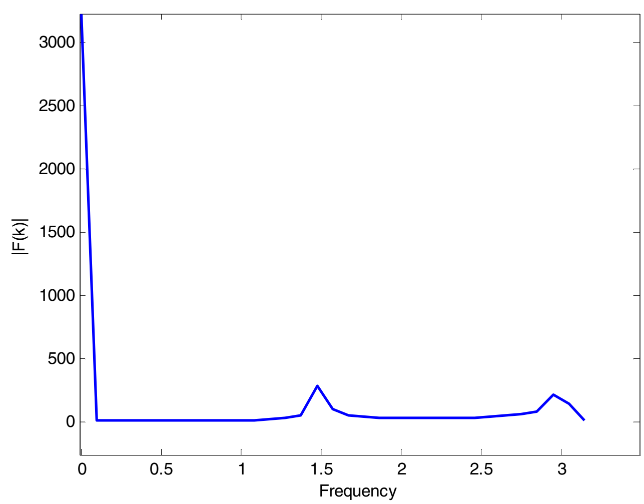

Figure 5. Simulation graph of Fourier transform

The oscillation frequency of the objective fruit f = 1.5Hz.And cycle T is about 0.67s.

Measured by visual, s = 0.6m, the speed of the end effector v is given by the controller, v = 0.2m / s,

$$t_s = \frac{s}{v} = 3\text{s}$$

According to (3), 4.48<n<5.48,

n=5

$$\Delta t = nT - t_s = 0.35\text{s}$$

In laboratory conditions, in the apple harvest experiment based on the fruit harvest robot experimental platform, total time t harvesting a single static apple is about 10s, which is divided into two parts: the locating time t_l 3-5s, grabbing time t_z 5-7s (total time of the end effector running out, grabbing and retracting in situ, t_z is about $2t_s$), $t = t_l + t_z$;

Before improvements, after the removal of a fruit, the other fruit on the branches oscillate because of the force on removal, the total time of harvest gets longer because re-positioning requires for stop of oscillation. This time dues to flexibility of branches, hardness of the stems and other factors, in which grabbing time t_z keeps constant (5-7s), locating time t_l net increases 10-20s or even much longer for waiting for stop of oscillation, $t_l^{'}$ increases to 18-30s. The total time of apple harvest in oscillation conditions $t^{'} = t_l^{'} + t_z$ is about 35s;

After improvements, grabbing time t_z still keeps constant (5-7s), locating time $t_l^{''}$ is 8-10s, which increases slightly relative to the static situation because of procession of more sample pictures and waiting time for supplement Δt. Then, the total time of apple harvest in oscillation conditions $t^{''} = t_l^{''} + t_z$ is about 15s, which has realized the purpose of eliminating time waiting for stop of oscillation, advancing harvest efficiency when the fruit is oscillating.

VI. CONCLUSION

When the fruit harvest robot harvests fruit in oscillation conditions, the locating time includes time waiting for stop of oscillation, which is a long time. This research gains oscillation frequency by curve fitting and Fourier transform to video samples, with calculating movement time of the end of effector. Realize the grabbing of the objective fruit, eliminating time waiting for stop of oscillation, advancing harvest efficiency in oscillation conditions. Despite the end effector has a certain fault tolerance because of a larger grabbing range, which relatively reduces accuracy of the time, several issues still need further study:

(1) The cyclicity of the oscillation path of the objective fruit may be not obvious in the wild environment;

(2) When the objective fruit is just making a circular motion around the image center in the image plane, the value of d is constant, the model does not hold.

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