

COMPUTER CONTROL OF MULTIJOINTED FINGER SYSTEM

Tokuji Okada
Automatic Control Division
Electrotechnical Laboratory
2-6-1 Nagata-cho, Chiyoda-ku
Tokyo 100, Japan

This paper treats computer control of multijointed fingers. First, we discuss optimum operational direction of multijointed fingers. The direction is determined from motional structure of the fingers and is important in the control stage of arm part. Second, general description about software system is presented with primitive programs to control hardware system. These have been implemented on the ETL object-handling system for manual industry. Third, experimental results of nut-turning task are presented which verify the feasibility of manual task by computer control.

1. INTRODUCTION

Multijointed fingers are useful not only for automation of manual industry but also for animal-like assistant robot from the standpoint of human welfares since they are suited to realize flexible motions that give us not fear but familiarity. Further, the fingers provide a research tool for investigation of new modes of servoing, intelligent manipulation, interactive real-time real-world system and AI. Under this philosophy, we treat fingers with complicated structure in our research.

Most of multijointed fingers are not competent for manual task since they are not on a level of programmable manipulation. Hanafusa [1] performed flexible manipulation by using elastic fingers which have coil springs. The ETL object-handling system [3] of which the hardware is overviewed in a reference [2] realizes the flexible manipulation with multijointed fingers.

In this paper, an optimum operational direction of a finger part is discussed with generality. Then, Fundamental ideas for programming manual task are presented with primitive programs about the ETL finger system. Experimental results of nut-turning task by computer control are also shown.

2. OPERATIONAL DIRECTION OF A FINGER PART

Multijointed fingers have an adaptability to grasp an object and handle it from various

direction in general. But it is reasonable to fix an operational direction for a finger part to have much flexibility in handling an object. We consider a volume in which the finger terminal can be located. We call the surface of it an envelope. Shape of the envelope depends on structure of the finger. In most cases, the shape is like an ellipsoid as shown in Fig.1. It is mathematically expressed in the coordinate system (X_p, Y_p, Z_p) that has an origin at the center of the palm plate as

$$\frac{\{(X-x_j)\cos\psi_j - (Z-z_j)\sin\psi_j\}^2}{A_j^2} + \frac{Y^2}{A_j^2} + \frac{\{(X-x_j)\sin\psi_j + (Z-z_j)\cos\psi_j\}^2}{B_j^2} = 1,$$

where j is a subscript related to finger number, $(x_j, 0, z_j)$ denotes the coordinates of the finger root, A_j means effective finger length concerned with bend-in and bend-out joint, and B_j means that concerned with abduct and adduct joint. Mostly, the value of A_j is greater than that of B_j ($A = l_1 + l_2 + l_3 + l_4$, $B = l_2 + l_3 + l_4$).

We have determined an optimum operational direction of a finger part as the direction toward which a common point of multiple envelopes is viewed from the center of the palm plate (In Fig.1, W shows this direction). Even if the finger part is composed of a lot of fingers, the optimum operational direction of the finger part would be fixed on the finger system according to its structure. On the other hand, an object has

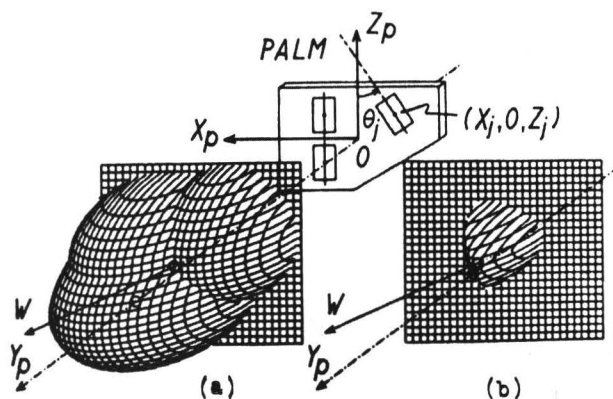


Fig.1 Total envelope related to three fingers

its own optimum operational direction as its property. It can be expressed by an axial line which is peculiar to the object. Therefore, adaptability of the fingers would be created by controlling the arm so that these operational directions might accord with each other.

3. SOFTWARE SYSTEM

3.1 General description

At present, the software system for manual task is on a low level since it is not described in the form like manipulator language or hand language. We consider the symbolic notations [3] that are defined to fundamental motions of a finger are useful to develop the language. Finger operation for manual task would be programmed by applying these motions to a geometric model of an object. The use of sensors is important to make adaptable handling in real-world. As shown in Fig.2, our system has a short-range finding sensor (SRFS) [4] at the palm area for local inspection of the object. This sensor reduces complexity of programming since it augments the capabilities of the system so that it can find and acquire unindexed workpieces and cope with unexpected events in performing object handling and assembly operations. For example, in nut turning, it monitors the fixation between screw and nut, and provides the resulting displacement of a nut along a screw axis. Therefore, fingers' pushing or pulling operation is sensor-controlled according to the amount of its displacement.

3.2 Primitive Programs

Primitive programs control the hardware of the object-handling system. The next program is common to finger part and arm part.

TAFCON(IAF, IFMODE, XAF, YAF, ZAF)

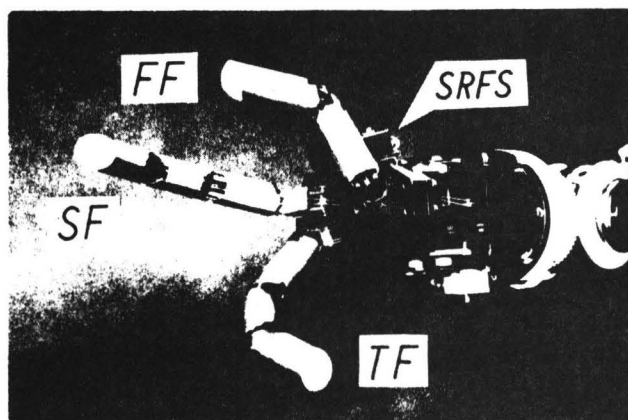


Fig.2 View of finger part

The argument IAF designates the part to be controlled. The meaning of it is

$$IAF = \begin{cases} 0 & ; \text{Arm} \\ 1 & ; \text{First Finger} \\ 2 & ; \text{Second Finger} \\ 3 & ; \text{Third Finger} \end{cases}$$

IFMODE is the argument concerned with the control mode about the finger terminal direction. This is effective when the value of IAF is not equal to zero. When IFMODE takes the value of 1, only the position of a finger terminal is controlled. But when the value of 2 or 3 is assigned to IFMODE, not only the position but also the direction of the finger terminal is controlled. Especially, when the value of 3 is assigned to IFMODE, the direction is controlled to be optimum. (XAF, YAF, ZAF) are the coordinates of the palm point for arm control or the terminal point for finger control in the coordinate system (X, Y, Z) that has an origin at the shoulder joint. When the value of IAF is equal to zero, the next program is used.

ARMSOL(XAF, YAF, ZAF, α , β , γ , IFLAG)

This program calculates an arm solution by using the parameters (α , β , γ) that are concerned with the optimum operational direction of the finger part. The argument IFLAG notifies whether the arm solution is obtained or not.

As far as the fingers are concerned, coordinates (XAF, YAF, ZAF) are the values expressed in the coordinate system (X, Y, Z). In order to obtain the coordinates (XF, YF, ZF) expressed in the coordinate system (XF, YF, ZF) that has an origin at the root of the finger, the next program for coordinates transformation is used:

TRANSF(J, XAF, YAF, ZAF, XF, YF, ZF)

The argument J takes the value equal to that of IAF and designates the finger to be controlled. Control values (P1, P2, P3, P4) for finger joints

are obtained from programs FINSL1, FINSL2 and FINSL3 that are prepared according to the values of IFMODE. The command format to use these programs is written as follows:

FINSLn(J,XF,YF,ZF,P1,P2,P3,P4,IFLAG)

when the value of IFMODE is 2 or 3, the unit vector $V_{fn} (=u_{f1}X+u_{f2}Y+u_{f3}Z)$ which denotes the direction of the finger to be controlled is referred. Finger solution in FINSL2 and FINSL3 are obtained by hill-climbing method and exhausting method, respectively.

4. EXPERIMENTAL MANUAL TASK

Nut-turning task is performed in the experiment. In order to adapt the fingers to the task, arm part is controlled so that the optimum operational direction of the fingers accords with axial line of the screw. Then, each terminal point of the fingers is controlled to move along the contour which is assumed to be circular in mathematical model of the nut. Results of the task are shown in Fig.3. The values of IFMODE in (a) and (b) are equal to 1 and 2, respectively. In (b), both directions of the finger SF and TF are equal to screw axis, namely, $u_{21}=u_{23}=u_{31}=u_{33}=0$ and $u_{22}=u_{32}=1$. Time required to accomplish one cycle of turning for (b) is about 2.3 times long as compared with that for (a) under such condition that the resolution angle of the joint is 2 degrees. Incidentally, the time for the case of IFMODE=3 is about 3.5 times long. The fact shows that the more precisely the finger direction is controlled, the more time it takes. But the time required to obtain control values for the case of IFMODE=2 is not so long as we have supposed. We could hardly find the difference in the results between the cases of IFMODE=2 and IFMODE=3. This means the capability of real-time control of both the position and the orientation of multi-jointed fingers in IFMODE=2. In (a), finger supports the nut with a point. But in (b), it tends to support the nut with a line. The fingers would realize stable operation when the orientation of the fingers are controlled to fit to a surface of an object.

5. CONCLUSIONS

Nut-turning task has been carried out smoothly by computer control without influence of shape and size of the nut. This would show the feasibility of manual tasks by multi-jointed fingers with flexibility.

Each fingertip is assumed to be an ideal point. But in real, it is extended like a ball. Therefore, the extension of the nut should be

considered in fine operation of an object. Further the fingers might be controlled not only in position but also in torque. We have just started to develop intelligent manipulation with cooperated control of these.

REFERENCES

- [1] H.Hanafusa and H.Asada, "A Robot Hand with Elastic Fingers and its Application to Assembly Process." IFAC Symposium, Tokyo, 1977.
- [2] T.Okada and S.Tsuchiya, "On a Versatile Finger System." Proc. 7th ISIR, 1977.
- [3] T.Okada, "Object-Handling System for Manual Industry." IEEE Trans. Vol.SMC-9, No.2, 1979.
- [4] T.Okada, "A Short-Range Finding Sensor for Manipulators." Bull. Electrotech. Lab. Vol.42, No.6, 1978.



Fig.3 Nut-turning task