Appropriate Lengths Between Phalanges of Multijointed Fingers for Stable Grasping

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Abstract

An appropriate arrangement of finger joints is very important since the stability of grasping an obj
eatly depends on that arrangement. Multijointed fingers can grasp an object with many points of cont
ch of which is pressed against the object as if wrapping up that object. The amount of the wrapped up a
d the form of the finger when an object is grasped are therefore important factors for determining
bility of grasping. We propose the wrapping factor to be used for the evaluation of the stability of grasp
using these factors. We consider twenty eight models for the finger having three joints, and perform
nulation of their ability to grasp various shapes stably. Based on the simulation results, an appropri
rangement of lengths between phalanges for a multijointed finger is presented.

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1. Introduction

Two kinds of end effectors for grasping an object have been developed: One is the gripper and th
s the multijointed finger. Most grippers have simple mechanisms and grasp an object by pinching it si
grippers can only close and open. Although grippers are useful for grasping objects of limited shape a
controlling the pressing force of the fingers against the object would make those grippers more versati
Multijointed fingers exhibit this versatility since they have increased mechanical flexibility and are
grasp objects of a wider variety of shapes and sizes [3,4]. While these are desirable features, th
equirement for grasping objects is that the grip is stable. One way of determining this stability in bot
of end effectors is by measuring the force exerted between the fingers and an object. Asada[2] and C
tudied the problem of achieving a stable grip from this point of view. Multijointed fingers, however, g
object in a complex manner and this complexity makes it difficult to determine the stability of graspin
olely on the force between the fingers and object. We propose another method for assessing the stab
grip in multijointed fingers based on their inherent ability to wrap around an object. In a previous pa
we used the amount of wrapped up area as a guide to assessing the stability of the grip. Howe
considered neither the number of points of contact between the fingers and the object nor the positio
fingers where that contact occurs. Salisbury treated contact configurations for designing a most s
articulated hand (Stanford/JPL Hand), his treatment, however, was limited to mobilities and conne
for acceptable hand mechanisms and did not include stability of grasping [4].

In this paper we examine the role of these additional factors in evaluating the stability of graspin
the number of points of contact between fingers and object depend on the arrangement of the joints
engths between the phalanges, two criteria are important to the stability of grasping: the amount
wrapped up area and the form of the fingers including tactual conditions when the object is grasped. T
taking notice of these two criteria, we will evaluate the stability of grasping by multijointed fingers
three joints. The results are applied to the problem of design of multijointed fingers.

2. Evaluation of Grasping by a Form of Fingers

The size of the fingers is determined depending on the sizes of the objects to be handled
quantifying sizes of fingers and objects, we evaluate the stability of the graspings in the relationships b
the objects and the fingers relatively. We will present the criteria which use the configuration of the
and tactual conditions.

poses, most objects are assumed to be lumps except for pillar-shaped objects. In order to express the he lumps, let the maximum width of an object be W_d, and the minimum width be W_s. When the ob ot considered to be a lump, these are measured in the perpendicular plane to the longitudinal axis of ect.

The structure of the multijointed fingers we will consider is shown in Figure 1. In the figure, ltijointed finger moves in one plane and has k links, L_1, L_2, L_3,...,L_k which are connected to joint J_1 ...,J_k, respectively. The angular values of each joints are denoted by θ_1, θ_2, θ_3,...,θ_k. The horizontal lin bottom is a palm and L_p stands for its length. L_0 is the length of the link which plays an auxiliary grasping an object with the multijointed finger. The angular value of the joint J_0 is expressed by θ_0. m L_p is fixed, but the links L_0, L_i (i=1,2,...,k) rotate about the corresponding joints. The range gular rotation of proximal joints J_0 and J_1 are $0<\theta_0<\pi$ and $0<\theta_1<\pi$, and those for other joints are $0<\theta_i<$ 2,3,...,k). Let us denote the total length of the finger as $L_T (= \sum_{i=1}^{k} L_i)$. It seems reasonable to impose owing three conditions on the relations of L_T, L_p and L_0:

$$(L_p^2+L_0^2)^{1/2} < L_T < L_p+L_0, \tag{1}$$

$$W_d < L_T, \tag{2}$$

$$W_s > 2(L_T - L_p)/3. \tag{3}$$

The first condition states that the total length L_T is longer than the length between the tip of L_0 and nt J_1 when L_1 and the palm make a right angle, and shorter than that when the joint stretches. The t gth of the finger should be longer than the maximum width of an object by the second condition. rd condition is understood by considering the case of k = 3; the minimum size of an object W_s is la n the diameter of the circle which touches the links L_0, L_p, L_2 and L_3(fingertip) w $=\theta_1=\theta_2=\theta_3=\pi/2$.

As the size of the object increases, so the length of the fingers must also increase. Intuitively, the rev st also be true. The length L_0 would be determined therefore depending on the length of L_p. We quar s relationship by using μ which is the ratio of L_T to L_p ($\mu = L_T/L_p$). We will investigate the case when , and $L_0=L_p$. Figure 2 illustrates the size of the finger relative to that of the objects which satisfy quality conditions (1-3). Given the three-jointed finger shown in the lower right, the maximum nimum sizes that can be handled by the finger are illustrated for each shape. The rectangle and ell

.2. Definition of Wrapping Factor

In the previous paper [6], the value $\Theta=\theta_0+\sum_{i=1}^{m}\theta_i$ was used to evaluate the stability of grasping, whe was the maximum number of link where there was a contact between the object and the finger ($m\leq k$). Tl oint of contact in the fingertip was treated in the same way as the point of contact in the middle point of tl nk. Also the position of the point of contact on the link L_0 was not considered.

In order to take these factors into account, we define a new measure named a *wrapping factor* W_r hich can be expressed as follows:

$$W_r=\frac{2\pi-(\theta_l-\theta_r)}{2\pi}. \quad (4)$$

he concept of wrapping factor is illustrated in Figure 3. In this definition, θ_l is the angular displacement e point at which the link L_0 touches the object, and θ_r is the angular displacement of the joint J_1 to the mo stal position at which the finger touches the object. When $\theta_l=\theta_r$, the finger wraps the object complete nd the value W_r becomes equal to 1. At this value the grip is considered to be most stable. The larger tl lue of W_r becomes, the more stable grasping the finger provides.

A finger having large values of L_T and k tends to wrap the finger around the object more than one tur nder the conditions that $k=3$, $2^{1/2}<\mu<2$, and equations (1), (2) and (3) are valid, the maximum value of V $1+\tan^{-1}(L_0/L_p)/2\pi$, which occurs when $\theta_l=\pi-\tan^{-1}(L_0/L_p)$ and $\theta_r=\pi$. If $L_p=L_0$, this maximum value W_r is 1.125.

. Simulation for Finding Appropriate Lengths between Phalanges

In order to find appropriate finger constructions for the stable grasping of objects having various shap nd sizes, we simulate the graspings and evaluate them by using the wrapping factor. Various constructions finger are considered and various objects are grasped by each construction. The results depend not only c nger constructions but also on the size and shape of the objects. Mutual relationships among these facto e investigated.

.1. Control Sequence of Finger

Grasping an object by a finger is realized by the following control sequence. It is important to have tl alm L_p touch the object since this contact enables the finger to grasp the object stably. In our sequence asping, this contact is required. The control sequence is:

1. Stretch die finger so that 6_i.=0 (/= 1,2,...,&). An object is placed on the palm link.

2. Starting with joint J_Q, bend the joints in turn from proximal to distal. Joint J_{i+}j begins to bend when a contact occurs with the object on the link L;, or when the angular displacement of joint J_i reaches its maximum.

3. Finger control ends cither when the final link L^ touches the object or when its angular displacement reaches its maximum while joint J^ bends.

application of these rules to the finger control results in various types of finger configurations. Configuratioi f unstable graspings arc included too. For instance, those graspings shown in Figure 4 are considered i nstablc. The configuration in Figure 4(a) is $\wedge_1 = d_2 = \wedge/2$ [rad], and the object does not touch L_t and L 'igure 4 (b) shows the unstable grasping which occurs when the amount of 0_Q+ J5\^/ is l ess tf*an * f^ Tiis configuration is not stable since the object has a tendency to move out from the palm area. We excluc hese unstable graspings before we calculate the wrapping factor W_f described in Section 2.2.

1.2. Finger Models

The finger we consider has three joints whose rotational axes are all parallel Table 1 shows the twcnj ight models we considered each of which has different combinations of the lengths of L_p L_2 and L_3. Eac umber in the table expresses the proportion of the length of a link to the sum of L_v L_2 and L_3. The! lodels are classified into 5 categories.

1. I-type; distal lengths are larger than those of the proximal,

2. D-type; distal lengths are less than those of the proximal,

3. M-type; middle link (i.e. L_2) is longer than the others,

4. V-typc; middle link is shorter than the others,

5. K-typc; three links are the same length.

'igurc 5 illustrates this classification by segmenting the plane whose horizontal and vertical axes rcpresei iroportions of L_2 and L_3, respectively. This figure makes it easy to see which type a model belongs to.

.3. Dimensions of Objects for Grasping

If we were considering the grasping of objects in three-dimensional space, we would use objects like ıll, a cylinder and a four-cornered pillar. However, since our finger moves in one plane, we can simula ılculations for the stability of the grip reliably by using two-dimensional shapes. For simplicity, we excluc ıomboids and ellipses and restrict ourselves to considering circles, squares and rectangles. The ratio of tl ng side to the short side of the rectangles is set as $3^{1/2}$. Dimensions of the finger are $L_0 = L_p = 80$mm ar $= 1.8$. The radii of the circles are chosen from 25mm to 70mm in increments of 2.5mm. The diagon ngths of the squares and rectangles are from 50mm to 140mm in increments of 10mm. All of these shap ıtisfy the conditions of equations (2) and (3) in Section 2.1. Under these conditions, graspings of circle ıuares and rectangles are simulated.

.4. Simulation Process

This section explains in detail how the simulation of grasping circles is performed. At first, a circle laced at the left side of the palm to touch the link L_p. Then, the auxiliary link L_0 closes to find the angul isplacement θ_0 at which link L_0 touches the circle. When contact is made between the object and link I nk L_1 is driven next, and then L_2 and L_3, according to the rules described in Section 3.1. For stable graspii e impose a tactual condition that the total number of points of contact on L_1, L_2 and L_3 is greater than ıual to two. Figure 6 shows an example of finger configurations satisfying the tactual conditions for circle /hen this condition is satisfied, the wrapping factor W_r is calculated. The grasping is then evaluated by tl ıagnitude of the wrapping factor; that is, the grasping is regarded as a stable grasping when the magnitude reater than a threshold value $(W_r)_t$. In our simulation we set $(W_r)_t = 0.8$.

The same circle is then shifted to the right by $dl = 2$mm along L_p and the next check is performed in t ıme manner. When the contact is made on the tip of L_0, or the tactual conditions are not satisfied, the da re not taken into consideration and we examine the next grasping. When the circle is moved to the right e f the palm, the next circle having a different size is tested. Many circles of different sizes are tested ifferent positions relative to the palm, and the total number of graspings which are regarded as stat raspings are obtained.

For other shapes, simulations of grasping are performed in ways similar to those for circles. The o ifference is that rotations of those figures are also considered by rotating the shapes about their centers /ell as moving the position along the palm L_p. The range of rotation is $\pi/2$ and π for squares and rectangl espectively, and the increment of rotation is $d\rho = 2$ degrees. Finger configurations shown in Figure lustrate the stable tactual conditions for rectangles.

roximal joints to halfway, i.e., *(Kd*$_Q$*<ir/2* and *(KO^ir/2.* Figure 8(a) shows the score of stable graspings ft ircles. In the figure, horizontal and vertical axes arc proportions of L_2 and L_y respectively, and thus eac rid position corresponds to each finger model in Table 1. The size of the circle is proportional to the numb< f stable graspings. The threshold of the stable wrapping factor we used is (W_r ^=0.8. Triple circles indicai ic finger model with the most stable graspings: Double circles indicate the model with the second mo able graspings. Similarly, Figure 8(b) and (c) show the simulated results for the squares and rectangle :spcctivcly. Figure 8(d) shows the result when the score of stable graspings for both squares and rcctangh re combined. The results shown in Figure 8 imply that the most stable finger model for circles an xtangles is the M-type (refer to Figure 5).

Figure 9 shows similar simulation results for the case in which *(K0Q<IT* and *(Kd^ir.* Here the link an ic joint can bend completely, unlike the case of Figure 8 in which the auxiliary link L_Q and the proximal joii an bend only halfway. Notice that the stable graspings are found by different models from those in Figure!

By selecting two models with high stability for both circles and rectangles, those finger constructioi hown in Figure 10 are extracted for stable grasping of various shapes. In the figure, (a) shows the resu rfiere (Vmax$^=$ ^Pmajt$^{= w/2,}$ ^ ShOWS *C FeSUlt WherC ^<Pmflx$^{= w/2}$ and ^Pm<«$^=$ *• ^ shoWS ^ reSU rtiere *{9^*$_{max}$^{zz}^ and (^$_1$)$_{OTflJf}$=w/2, and (d) shows the result where (Vmax$^=$^Pmax$^{=w}$, Thc left finger le auxiliary link used in the simulations. The next two couples from the left to the right correspond to tl ppropriate fingers for circles and rectangles, in this order. Hatched and dotted areas show the most proxim nd the most distal links (L_x and L_3), respectively.

By comparing thc four finger constructions in Figure 10, it is observed that the lengths of L_3 are *m* ery different from each other, but thc lengths of 1^ in (a) arc much smaller than in thc other three. Also, I i (a) and *L^* in (b) are longer than any other three. Figure 8(a) implies that thc M-type model is the mo uitable for grasping circles, squares and rectangles when *fX0*$_o$*<ir/2* and *(KO^ir/2.* However, when tl uxiliary link or thc proximal joint can be bent extensively (that is, thc range of *$*$_0$ and *0*$_x$ is enlarged froi r/2 to *ir* the D-type model is useful for circles as shown in Figure 9 and the V-type for squares an ectangles. In general, when the ranges of motion of 0_Q and *$*$_l$ become large at the same rate, the appropria jngth of L_x becomes larger without changing the lengths of L_y

Simulations have also been carried out with different tactual conditions such those under which tl inger makes contact with the object only on L_3 (except the tip) and only on L_r However, no significai lifference has been observed between the results for these conditions and those for the ones previous scusscd.

. Conclusions

We have proposed the wrapping factor as a criterion for evaluating the stability of grasping 1 ultijointcd fingers. In the simulation of grasping, a multijointcd finger having three joints is used at rclcs, squares and rectangles are considered as possible shapes of an object Positions and orientations esc two-dimensional shapes are changed systematically to examine various graspings. From the simulatio D have found that appropriate finger lengths between phalanges depend on the angular ranges of proxim ints. The results obtained from the simulation would Ijc useful for determining the lengths bctwc< lalangcs of multijointed fingers.

cknowledgements

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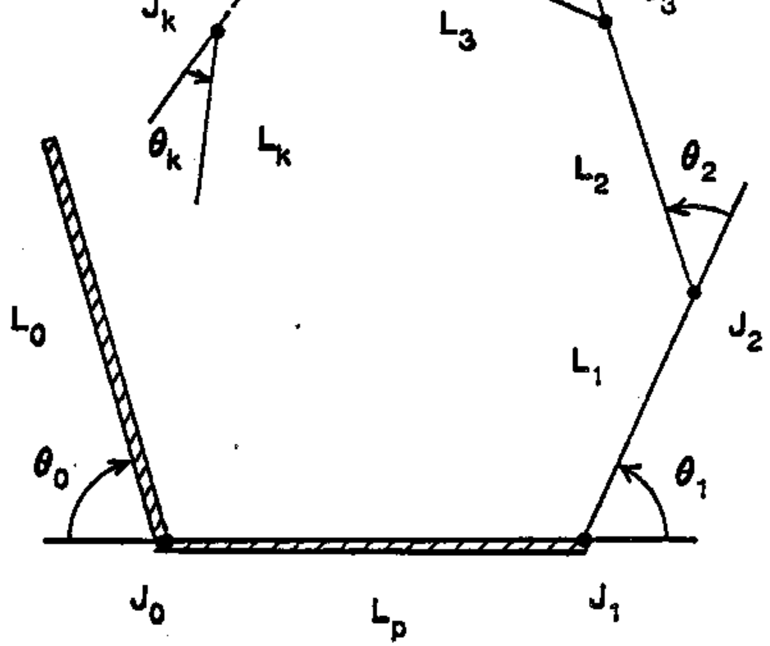


Figure 1: Finger structure.

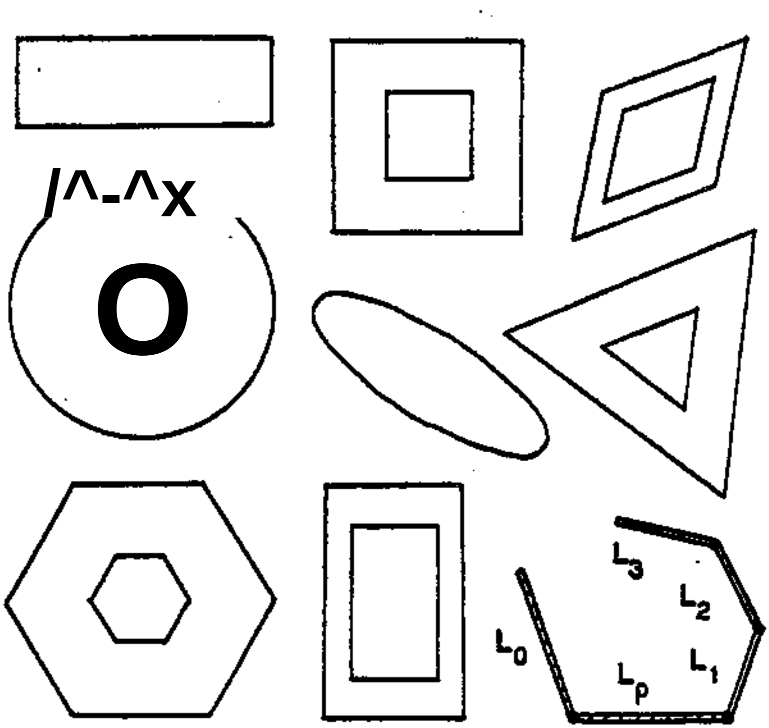


Figure 2: Relationships between the sizes of fingers and objects.

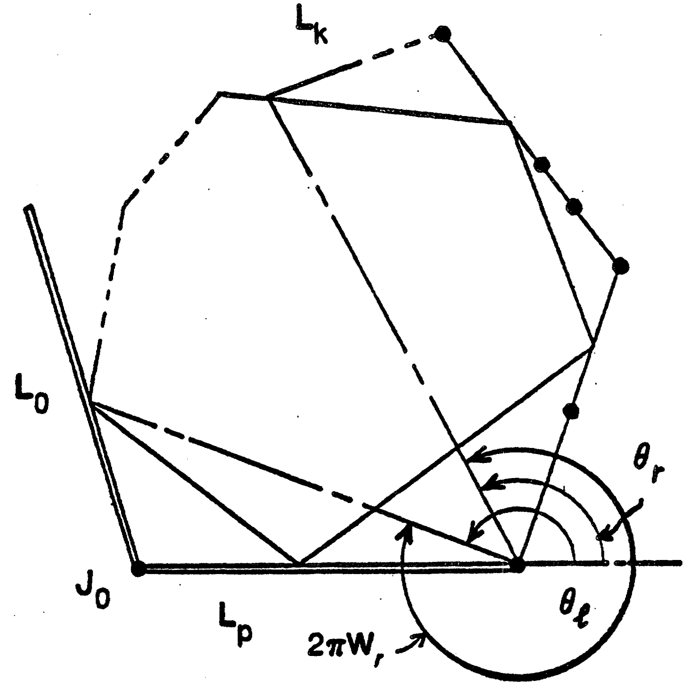


Figure 3: Illustration of the amount of wrap-up.

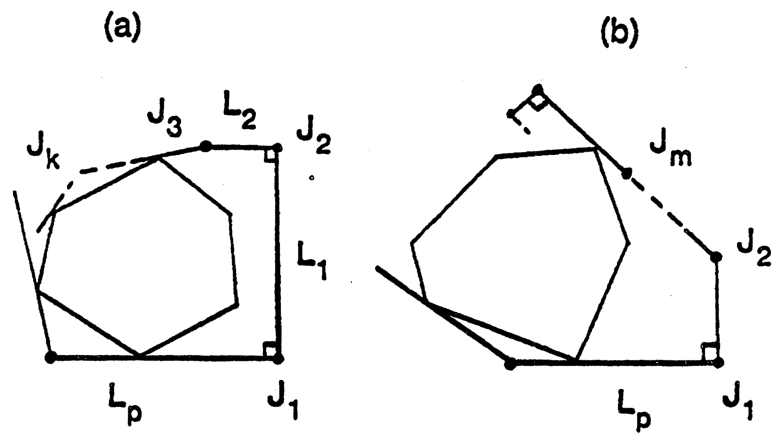


Figure 4: Unstable graspings in general.

TYPE	I	I	I	I	M	M	M	V	I	I	M	M	M	V	V	K	M	M	V	V	D	D	V	D	D	V	D	D
L_1	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	5	5	5	6	6	7
L_2	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	1	2	3	4	1	2	3	1	2	1
L_3	7	6	5	4	3	2	1	6	5	4	3	2	1	5	4	3	2	1	4	3	2	1	3	2	1	2	1	1

Table 1: Finger models.

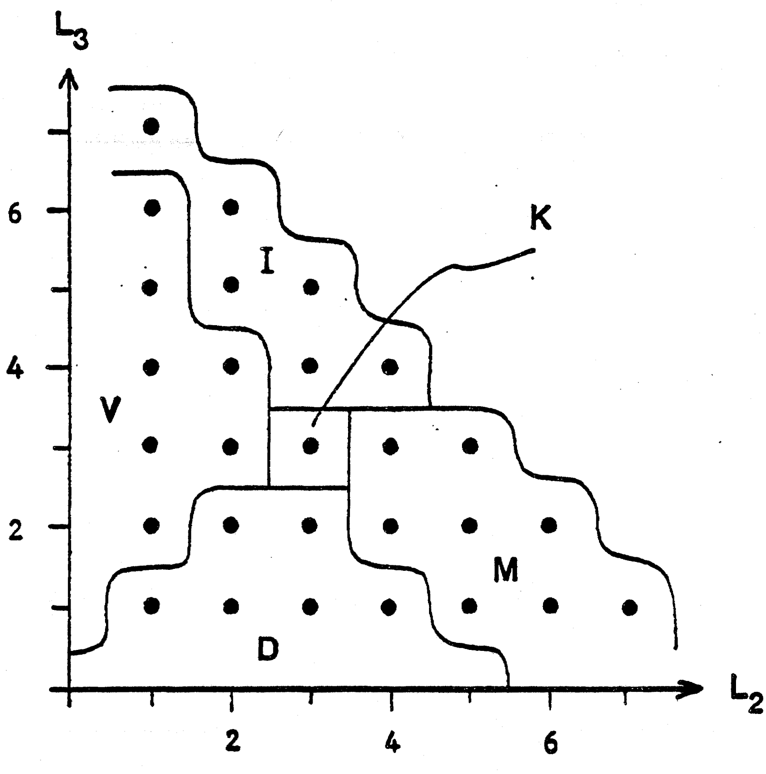


Figure 5: Classification of finger models into five types.

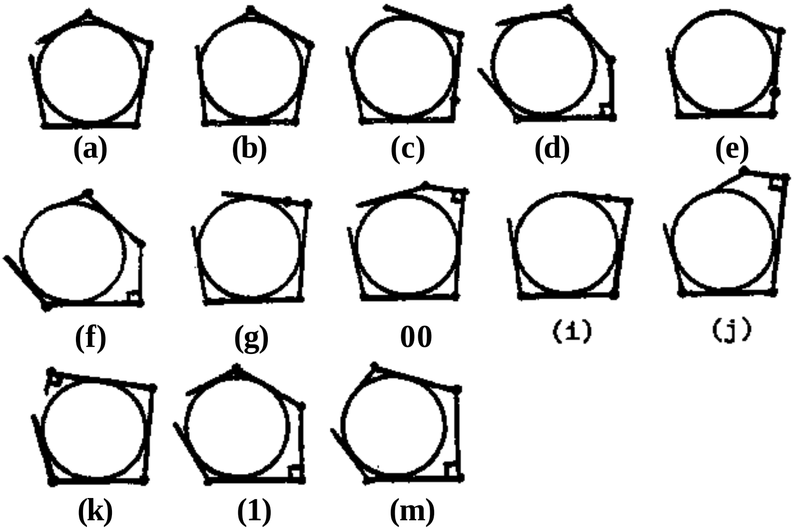
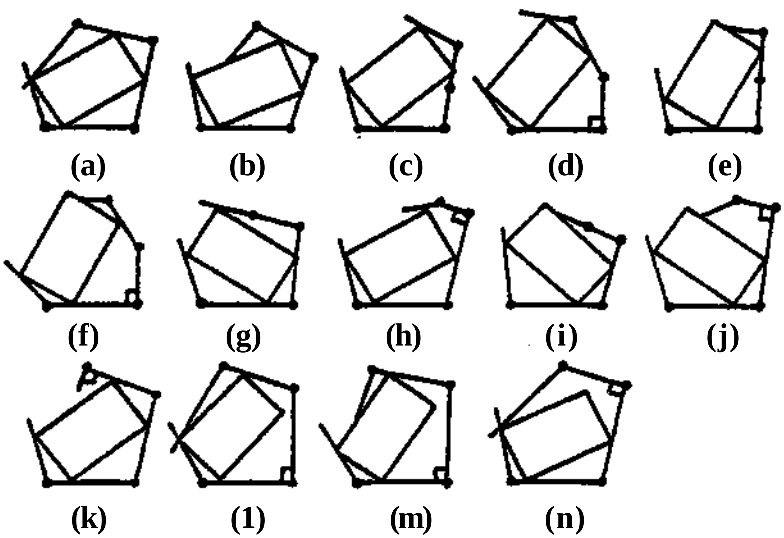
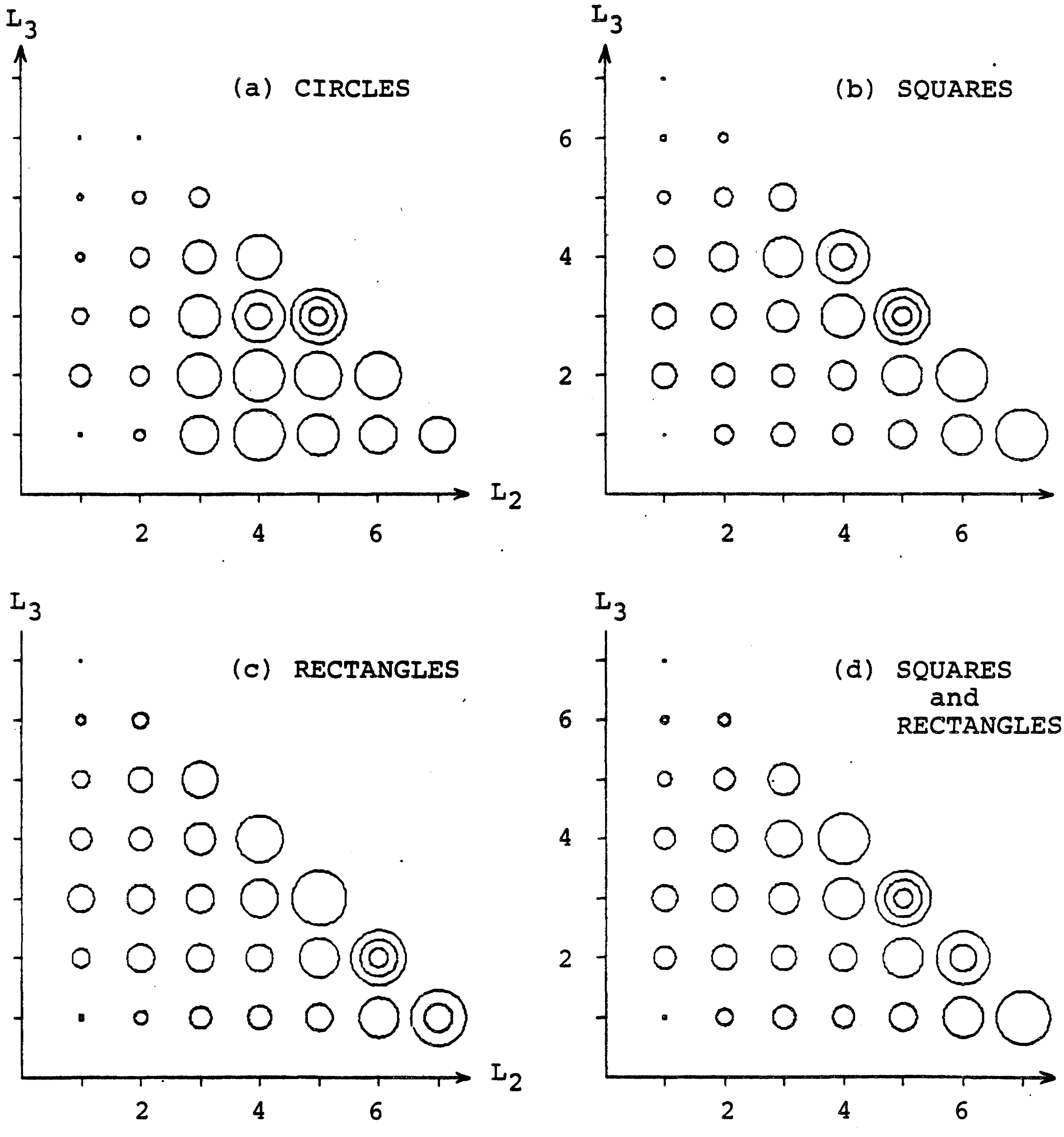
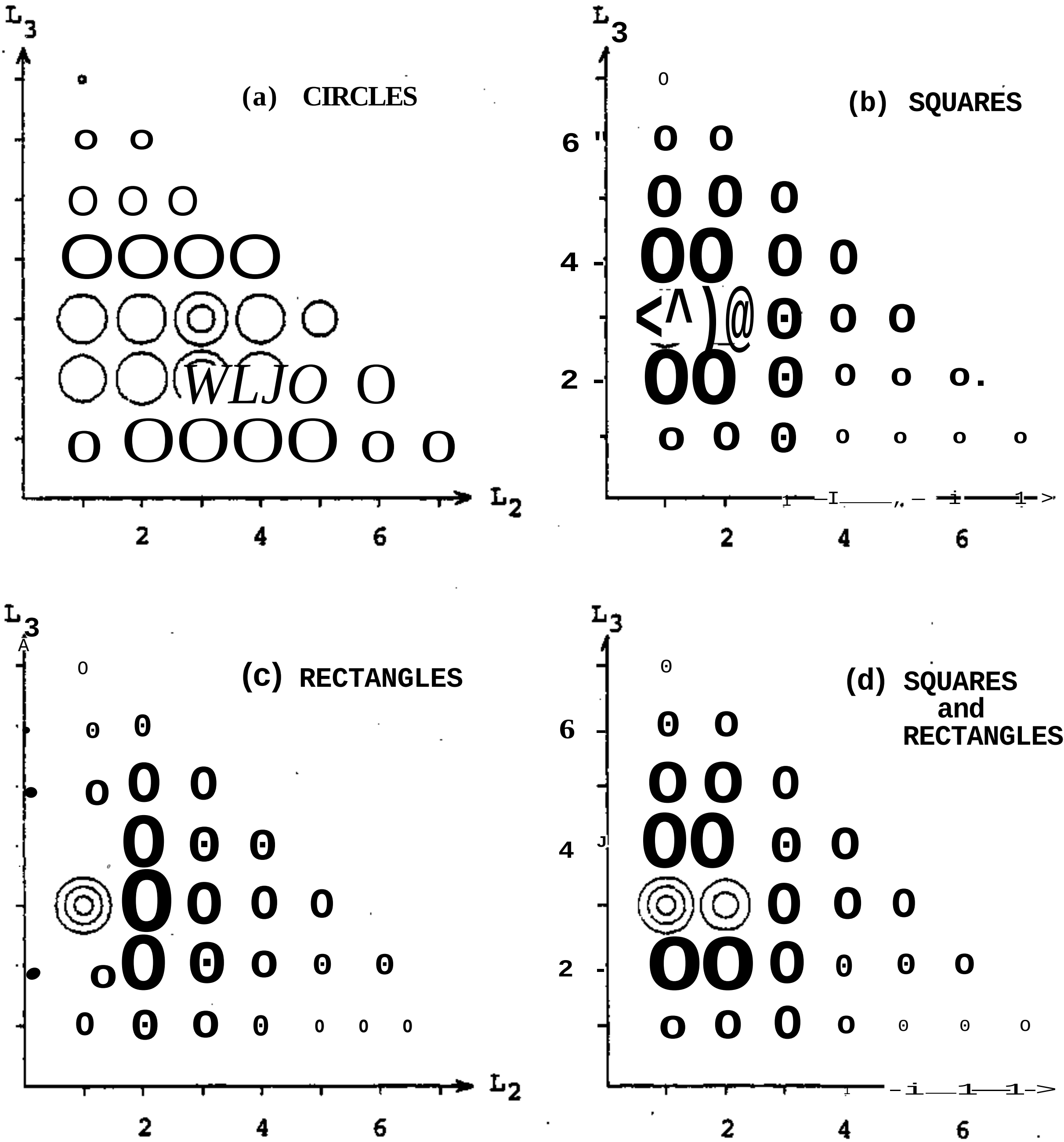


Figure 6: Finger configurations to explain tactual conditions for circles.





L_3
(a) CIRCLES
L_2
2
4
6
L_3
(b) SQUARES
6
4
2
2
4
6
L_3
(c) RECTANGLES
L_2
2
4
6
L_3
(d) SQUARES and RECTANGLES
6
4
2
2
4
6



(a) CIRCLES
(b) SQUARES
(c) RECTANGLES
(d) SQUARES and RECTANGLES
L_3
L_2
2
4
6

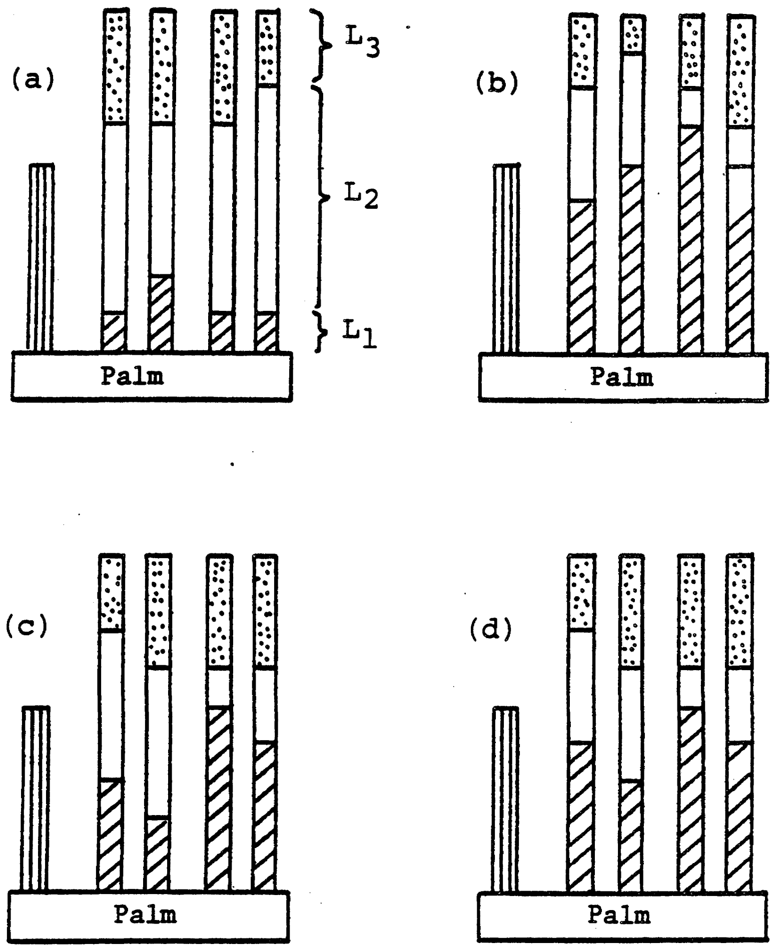


Figure 10: Appropriate finger lengths between phalanges for grasping circles, squares and rectangles.

(a); $(\theta_0)_{max} = (\theta_1)_{max} = \pi/2$,
(b); $(\theta_0)_{max} = \pi/2$ and $(\theta_1)_{max} = \pi$,
(c); $(\theta_0)_{max} = \pi$ and $(\theta_1)_{max} = \pi/2$,
(d); $(\theta_0)_{max} = (\theta_1)_{max} = \pi$.