SOME ASPECTS OP SENSORY INSTRUMENTATION POR ROBOTS AND MANIPULATORS

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Abstract

Some concepts of the functional organisation of the sensory systems in men and animals are considered, that can serve as a basis for design of artificial sensory systems for robots. The paper describes a human tactile system, a device simulating the tactile function, algorithms for form recognition by sense of touch and the results of the experimrnts with such an artificial tactile system

1. Introduction

In design robot-like devices adaptable to different environments and performing different tasks, we must first of all enable these devices to perceive the information on the external world; in other wirds such devices must possess artificial sensory systems.

The results of sensory systems studies in man and animals allow us to lay down some general principles of organization and functioning for such systems. These principles can serve as a basis for development of hardware analogs of natural aensory systems. Among these principles the followinga should be mentioned.

1. The development of concepts about one's surraundings and one's own state the system usee the Information delivered simultaneously by different senses (hearing, vision, touch, etc.). interacting in perception and processing of this information.

2. Combination of sensory and motor activity, or the ability of sensory systems to perform active search of necessary Information through appropriate motions (looking round, touching, etc.). The capacity of independent motion (eye movements, etc.).

3. Multilevel organization of the sensory data proceasing which permits on the one hand, the lowest level detectors to of recognize the elementary features essential for the recognition of the object and, on the other hand, to discard the useless, nonessential information.

4# A well-defined structural organization of the receptors-receptive fields.

5. The variability within wide limits, of the sensitivity thresholds with the task and the state of the environment (illumination level, noises, etc.).

There is no doubt that for human beings vision is the principal way for perception of the information about the external world. Hearing is essential too, especially in communication (speech recognition). Other sense organs includingtouch, are generally considered to be less important. But this is not quite true especially for touch. Perhaps of the importance of tactile information is under estimated. Because loss of sight or hearing occurs rather frequently, while complete loss of tactile perception is a rare phenomenon and as a rule is accompanied by the loss of motor activity as well. In this situation the motor behavior is out of the question. Because of this inseparability of motor and tactile functions we are inclined to consider the latter as some inherent property and therefore to underestimate its importance.

But in reality, in many situations, especially in performing minute and very precise movements, such as screwing nuts, assemblage of small mechanisms, etc., the sense of touch is very important and cannot be substituted by vision. One can carry out such tasks rather easily even without any visual control.

The foregoing discussion makes it evident that design of manipulators capable of a wide range of functions requires coordinated work of at least three subsystems motor, visual and tactile.

But as a first step it is necessary to work out some approximation of each of these subsystems separately. Since, on the one hand, the motor control and perception of visual information are much more advanced than designing artificial tactile systems and, on the other hand, the latter is no less important, we decided to concentrate our effarts first on the problems of artificial tactile sense and form recognition by tactile perception.

The first objective in design of artificial taotile systems is "sensebilization" of the protheels of extremities. As early ae in the fourties N.A.Bernstein pointed out the importance of the sensibilization of lege prothesiB. Later sensibilization of artificial wrist was suggested by N.Wiener (1) and ofterwards by R.Tomovic (2), These projects had were of theiretical ratheT than practical importance. It was only with design and improvement of manipulators that the artificial tactile systems became a practical proposition.

There are now a number of devices for tactile recognition of the form. These devices fall quite naturally in two groups, devices for the recognition of the shape in the course of a single grasping of the object by manipulator or an artificial wrist, and devices for active tenacious probing of the object by the sensitive element moving along its surface.

The first group includes the projects accomplished at the Tokyo University (3), Waseda University (4), Hitachi Co (5) and some others. Transducers of the "on-off" type were used in all these projects. The experiments show that even with a very limited act of objects (two types only, bars and cylinders) the rate of recognition is not high, and even a slight change in the size of the objects can affect the results very strongly.

Active feeling of the surface was realised by S.Aida and others (6). An artificial finger with four sensory elements of the "on-off" type can move along the surface that is being explored. In the case of the loss of the contact with the surface a special algorithm of search starts.

By changing the coordinates and orientation of the finger one can obtain the information on the shape of the object. The authors of the project develop this system as a part of a symbiotic tactile-visual recognizing system with the visual part playing the main role. This tactile system per se does not seem to be very effective, because it performs only random probing of the surface instead of purposeful search of its most informative elements.

2. Primary Transducers and Organization of the Receptive Field

An effective system incorporating the general principles considered above should, in our opinion, be corroborated by study of published data, and (1) incorporate transducers which can detect the amount of pressure (i.e. of "proportional" type) which are much more informative than the "on-off" type; (2) ensure the functional interaction of the transducers, or provide an artificial receptive field. Thus we can, as it will be shown later, organize purpose-ful rather than random search of the informative elements of the surface.

It is well-known from differential geometry that the local description of the surface element can be given in terms of its curvature in different directions, passing through the given point by finding the so-called principal curvatures. The algorithms, described below, are approximative Implementation of this mathematical method.

For the calculation of the curvature of surface in a given direction it is necessary to have the data at least from three points belonging to this direction. A system of 9 transdurers, organized in a 3 x 3 - matrix estimates the local curvature of the surface in four directions simultaneously. Having this in mind we chose a 3 x 3 matrix consisting of proportional pressure transducers to serve as an elementary receptive field. A special conductive polymer was used as a sensitive element (7).

3. Recognition of Primary Features of Surface Elements

Let

$$X_1, X_2, \ldots, X_9$$

be the data from the transducers of the tactile matrix, applied in a point to the surface in normal direction. Let us introduce the quantities

$$\delta_i = X_5 - \tfrac{1}{2}(X_i + X_{10-i})$$

$$i = 1, 2, 3, 4.$$

These quantities are second differences, or discrete analogs which represents the surface. Therefore they specify the curvature of the surface in four directions. Note that the change of the intensity of pressing the receptive matrix to the surface change the values of X_i proportionally, so the relations among δ_i do not depend on the grasping effort in the artficial wrist or manipulator.

Let us consider the quantities

$$\delta_{min} = \min_i \delta_i \qquad \text{and } \delta_{ort}$$

where δ_{ort} is the value of δ_i in the direction, ortogonal to the direction in which δ_{min} is obtained. We may consider these values as an approximative analog of principal curvatures of the surface in a given point.

Let us refer to the element of the surface as directed if δ_{min} differs essentialy from δ_{ort} . The examples of the directed surfaces are a cylinder, cone, edge, etc. A plane as sphere, etc. are nondirected surfaces. Therefore the value of the difference $\delta_{ort} - \delta_{min}$ give us the first dichotomy for the surfaces: directed and nondirected surfaces. For the directed surfaces, when δ_{min} determines the direction we can tell cylinders from edges using the value of δ_{ort} and we can tell an edge from a curvilinear edge using δ_{min} . In the class of nondirected surfaces we distinguish a plane, sphere and peak ..(vert ex) by the mean curvature, i.e. $\frac{1}{2}\sum \delta_i$

Practically the experiments with recognition were staged only for the convex surfaces* But, if we pay attention not to the absolute values of δ_i alone but to their signs too, we can classify concave and saddle-like surfaces in the same process. The procedure described above is easily programable. But it was of some interest to realise this algorithm (to increase of the speed od response) by a special analog preprocessor. Such a device has been manufactured and tested (8). But the accuracy of the definition of the local types of surfaces was not high in this case. For instance, for the cylinder and sphere it was merely 35-50%. This result was partly due to the tactile matrix, which was not precise enough, but mostly to the low calculation accuracy. Nevertheless we think that the principle of preprocessor detection of the primary features of the surface elements in the process of tactile recognition deserves detailed investigation.

Computer implementation of the same algorithm gave a much higher accuracy. The results of the experiments with classification of the surface using a LOCAL program, for the "Minsk-22" computer are presented in Table 1. The average error for the 6 elements, presented in this Table is about 12%. This accuracy depends mainly on the accuracy of the tactile matrix. Using more precise sensitive elements can improve the reliability of the recognition up to 95-100%.

4. Shape Recognition by Simultaneous Grasp

Experiments with classification of objects with simultaneous grasp by a two-finger manipulator with two tactile matrices of the type described above were staged. Five types of objects of different size were used: cubes, spheres. cylinders, cones and pyramids (9). The orientation of the objects was arbitrary.

Form recognition was carried out by a system of three units. Two of these processed the information from two tactile matrixes with the "LOCAL" program and the third one compared the output signals of these two and classified the objects. A list of all possible objects and their features were introduced in the computer memory beforehand. Experiments with this program which was called the system of passive tactile recognition (SPTR) has demonstrated that this system is sufficient for the classification of simple basically different obiecte. But for the recognition of compo-el objects this system does not work. To obtain more acurate results one needs either more tactile matrices (receptive fields) to grasp the object or an additional algorithm for active search of lacking data (or successive probing of the object).

5. Shape Recognition by Active Touch Motions

The algorithm of the recognition operates in several steps. A list of the objects to be classified and their local features must be introduced in the computer memory beforehand. After the contact of the tactile matrix with the surface of the objects to be recognized, the "LOCAL" program determines the local type of the surface element, The processing of these data leads to a hypothesis on a possible shape of the object; the feature is determined in terms of which the hypothesis should first of all be tested and an instruction is generated which dictates the motion of the tactile matrix, looks like MOVE IN DIRECTION and is displayed* Because the interaction of the manipulator with the tactile system was not completely tasted, the tactile matrix was moved by the experimenter rather than by the manipulator. The tactics of successive touching the surface elements was developed on the knowledge of human way of solving the problem of determining the shape by moving with one finger along the surface of the object.

The above program referred to as a system of active tactile recognition (SATR) was experimentally tested on a limited number of objects such as a sphere, cube, cone cylinder, pyramid of widely different sizes (e.g. cylinder sizes ranged from 15 through 120 mm). The recognition accuracy ranged from 90 through 100%. SATR has confirmed the utility of this tactics whereby characteristic features are actively sought instead of probing the entire surface. Fig. 1 shows the finger path in probing a cylinder and Fig. 2 the computer-generated path.

Conclusion

The experiments carried out in our laboratory show that even with a rather primitive equipment it is possible to make a satisfactory working system of artificial tactile sensing for manipulators. We think that following basic principles may be useful

1.. Using proportional transducers which are more informative than the "on-off" type.

2. Organization of a group of transdusers in a unified sensory system of the tactile matrix.

3. Organization of the process of active search of the most Informative surface elements.

Further sophistication of the system must include the improvement of the tactile matrix, complete automation of of the process of active touch movements, experiments with acre directse objects.

It is very likely that further researches of the interaction of a manipulator tactile system with a motor system and with artificial vision will give rise to new problems in development of artificial tactile systems.

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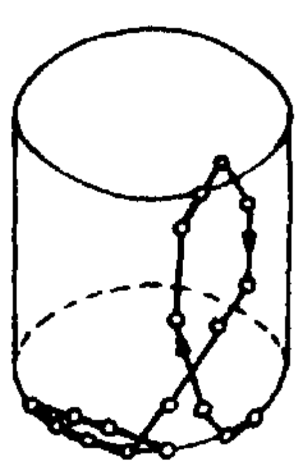
Table 1

Recognition of the local types of the surfaces

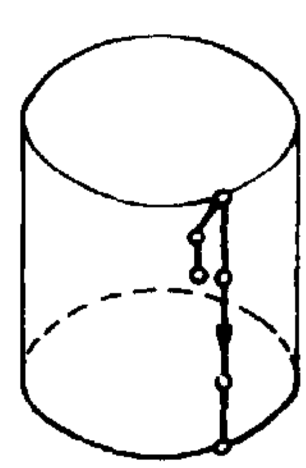
Answer \ Surface	Peak	Sphere	Plane	Cylinder	Edge	Curvilinear edge
Peak	100%	18%				
Sphere		82%		2%		
Plane			84%	6%	2%	
Cylinder			16%	88%	12%	
Edge				4%	80%	8%
Curvilinear edge					6%	92%

Trajectory of the sensor's motion



Human finger

Fig. 1



Tactile matrix

Fig. 2