AN INTFLLTGENT ROBOT WITH COGNITION AND DFCTSION-MAKING ABILITY

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Abstract

An intelligent robot that recognizes and assembles three-dimensional objects is described. The instruction to the robot is fed through a vidicon camera as a three-view plan of the assemblage whose overall spatial configuration is then recognized and decomposed into component parts by a computer.

Another camera looks at the real world for the specific parts required for the assembly and confirms their geometric features. The computer further makes the decisions on the procedure for the manipulation of the parts, and orders the articulated mechanical hand to proceed the assembly sequence.

The information processing is so far restricted to simple polyhedral objects and their co-relationships.

Descriptive terms

Intelligent robot, drawing recognition, assembly drawing, three-view plan, object recognition, three-dimensional objects, polyhedra, decision-making, assembly procedure, computer manipulation.

1. Introduction

In order to complete an integrated automation system, a visual device to take the place of human eyes and a coordinated mechanical svstem which can simulate movements of human hands are necessary. Particularly, in machining and electronic component industries, which mainly handle individual solid materials, automated control of production is extremely difficult, comparing with the situation in some other industries which handle collective fluidic matters.

Little progress has been made of late especially in the techniques of automatic assembly, where numerous component parts are to be put together into a complex unit and of product inspection, which still depends mostly upon visual screening by human eyes. Highly complex cognition ability of human visual system and intricately coordinated maneuverability of human hands have so far rejected in these processes a complete take-over by mechanically oriented systems.

It is obvious, however, that the future industrial production will need more sophisticated automation techniques, and the realization of human visual cognition and handling functions by machines seems to be the only breakthrough of current automation techniques that have already been saturated.

As the conversion of production proceeds from the currently prevalent method of producing a mass of uniform products to a method of producing varied products in small or medium quantities, in response to the increasing diversification of consumers' tastes, the necessity of the new automated techniques will more and more increase. Tt seems obvious in the future production processes that assembly and inspection functions will have to be substituted by versatile systems with some intelligence, to cope with the diversified production lines and the change of products.

There are several attempts to make machines capable of performing visual perception of three-dimensional objects (l),(2),(3) and solving the problems concerning robot behavior (A), (5). Our present work is also one of these attempts intending to develop useful and versatile robot systems in future.

2. Outline of the intelligent robot

The intelligent robot being described below is a prototype system developed to aim at basic researches in building up automated visual cognition and handling functions to be required in the future assembly processes. The robot, named HIVIP, is composed of three nuclear sub-systems; FYF, BRATN and HAND (see Figure 1).

The sub-system FYF is composed of two television cameras. Camera 1 studies the macroscopic instruction given in the form of three-view drawing and recognizes the overall spatial configuration of the object shown in the drawing, as well as the shapes, the number, the mode and order of assembly of the components that make up the object. Camera 2 studies actual component parts separately but arbitrarily placed on an assembly table and confirms the shapes, the locations, the postures and the dimensions of the individual components. When the camera 2 finishes locating the parts, it then finds the specific parts required for each step of assembly sequence, which is automatically programed through the analysis of the drawing by the subsystem BRAIN, a digital computer. When these recognition and decision-making processes are over, the HAND mechanism is activated and starts the assembly process according to the pre-conceived order.

3. Major characteristics

Presently available industrial robots are lacking in intellectual analyzing capabilities to control their movements in response to various conditions of the objects or the circumstantial situation they are subjected to. Furthermore, they are still insufficient in versatility to comprehend human instruction and to adapt themselves to the new jobs.

In general, all the instructions of existing machines have to be fed in microscopic form with one-to-one correspondence to each step of machine movements, as seen in numerically controlled machine tools. The HTVTP, on the other hand, accepts macroscopic instructions given in the form of graphically illustrated plans, thoueh they are still too simple comparing with the actual industrial drawings. When the camera's scrutinization takes in all the information the plans offer, the computer starts planning detailed work procedures required to accomplish the instructed assignment. Capability of studying and understanding macroscopic instructions may be a necessity in future intelligent production system where instant and autonomous response to changes in production procedures is required. The HTVIP seems to be a simple prototype of this future generation robot, as it is capable of studying and understanding the graphic plans even they have never been exposed to before and of taking necess.qrv actions accordingly.

4. Hardware system

The HIVIP is composed as shown in Figures 2 and 3. The two vidicon cameras function as viewing eyes and are operated by a scanning system which closely resembles that of the standard TV system. The image area is divided into 76,800 picture elements; 240 vertical and 320 horizontal. The information of each picture element is transformed into 5-bit (32-level) digital information through an analog-to-digital converter and is transmitted into the process control computer, HITAC 7250, which has 32,768-word 16-bit core memory and operates at 2-microsecond cycle time and 4.5-microsecond add time.

The computer can regulate the TV cameras to block off an area of optional size of the lens view, permitting image information being viewed by the remaining oblong opening of the lens. The computer can also instruct the camera to regulate the 'fineness' of the photographed image by thinning out the matrix of the picture element layout in three modes.

Mode 1 : rough viewing.
Every four picture elements on both vertical and horizontal axes are fed in.
Mode 2 : medium viewing.
Every two picture elements are fed in.
Mode 3 : fine viewing.
All picture elements are fed in.

By reducing the size of the area of the lens view, the camera narrows the eye and focuses on the object, rejecting all unnecessary objects from the field of vision. These visibility control functions, for instance, enable the camera to roughly scan the premises where the objects are positioned; then, when the object's locations are confirmed, the camera narrows its eye by blocking out the lens area viewing unnecessary objects in the premises, leaving open the oblong window to take in the particular object for a closer study, and starts making scrutinizing survey of the shape, the position and the posture of the object.

The visibility control functions can also separate the photo image into two contrasting areas, bright and dark, bordering on a certain threshold instructed by the computer, or can differentiate the image to represent the objects with only their outlines.

The handling mechanism of the HTVTP is an articulated arm with a parallel-jaw type gripping mechanism. Seven degrees of freedom of motion in all are equipped in the handling mechanism which can be controlled simultaneously by seven independent servo-mechanisms. Tn handling control equipment, there are seven data registers, pulse distributors and digital phase modulators that act as digital-to-analog converters and error detectors in the servo-mechanisms. The control signals are compared with the feedback sicnals from synchro-resolver type position detectors in the arm, and are fed into thyristor-driven d.c. servo-motors.

5. Software system

The software of this robot system is controlled by process or non-process monitoring system (PMS, NPMS) of HITAC 7250. Tt is classified into three major proprams; a drawing recognition program, an object recognition program and a handling program.

5.1 Drawing recognition algorithm

The initial instruction to the HTVTP is given in the form of a rough, macroscopic plan showing three sides of the required assemblage (see Figure 4). The plan is, at present, composed only of straight solid lines, accordingly the assemblage must be a polyhedral structure composed only of flat planes.

The robot first scans the plan and recognizes all the lines before making up a list of nodes, branches and loops. From the two-dimensional information thus obtained, the robot, then, checks the co-relationships among them, calculates the spatial points, lines and planes and constructs three-dimensional configuration of the assemblage.

The robot is also capable of suspecting and confirming whether a termination of a line is actuallv a point edge of the assemblage or just a false image looking like a point. The assemblage shown in Figure 4 is made up of a grooved block (an octagonal prism) and two triangular prisms mounted on top. The point A in the front view of the assemblage is a false point created by two crossing lines. The points B, C, D and E shown in the front view are not seen in side and top views. The robot is capable of speculating that the point A might be a false point and the line FA be actually a visible section of a real line FG. It can also imagine the existence of lines indicated only by points such as B, C, D or E.

When it finishes compiling a list of points, lines and planes in three-dimensional space, it then begins to figure out a structural image of the assemblage and in this process, eliminates all unnecessary information. When this is completed, it breaks down the created structural image into independent component parts and begins to examine the way they are assembled together to relay this information to the handling system. In order to break down the assembled image into images of component parts, it employs a principle that a polygonal plane with a certain number of sides is linked with other planes with an equivalent number of arms. When it finds that a line is co-owned by two planes, it classifies the method of the linkage as a tight link and when the line is co-owned by more than two planes, the linkage is termed as a loose link. Thus, the robot disintegrates the set of planes into several subsets or 'shells'. Figure 5 shows the way the assembled planes are disintegrated into a number of shells. After the planes are classified into several groups, the robot put together these open shells to construct closed shells and registers them in the list of parts. The surfaces to be co-owned by two parts are regarded as the contact surfaces when the assembly is carried out. Figure 6 is the example of computer drawings on X-Y plotter after the computer completes the drawing recognition process.

5.2 Object recognition algorithm

The object recognition is performed by utilizing the brightness of light reflection from each surface of the objects on the table. The brightness detected by the vidicon camera is at first transformed into 5-bit digital information and fed into the computer which, in turn, recognizes the positions, postures, shapes and the sizes of the objects. The addition of color identification capability would further make the object recognition easier. This, on the other hand, is not alwavs practical in the actual use, as the unusual coloring of component parts is required in some cases. Since the environmental situation seems to be regulated easily by simplifying the background and adjusting the lighting even in the future actual factory application, the NIVTP is equipped with only brightness identification capability so far and white colored sample objects are used in the demonstration.

The HIVTP can at present be applied to simple polyhedral objects composed of plain surfaces, especially polygonal prisms with the shapes easily processable with milling machines.

The first step of the object recognition algorithm is to spatially differentiate the image taken into the core memory and transform it into a high-contrast image with the edge lines of the objects strongly emphasized. Then, one of the objects in the image is selected by masking all other objects, and the position of each edge line of the object is detected by 'trenching' method and memorized in a list. Figure 7 shows the process of line detection drawn by the line-printer output device. The lines thus detected are sometimes unclear as shown in Figure 8. Therefore the robot rearranges them by carrying out a few procedure such as the elimination of unnecessary twigs. Even when some of the edge lines are missing, the robot is capable of filling them in by correctly analyzing the spatial structure of the object. The information thus obtained finally determines the object's coordinate position on the table and its posture. Above processes are repeated for every object until the recognition of all objects in the image is completed,

5.3 Handling algorithm

When the robot completes the drawing recognition and the object recognition, it then starts thinking the assembly procedure by evaluating the relationships between the parts in the required assembly form. At first the objects on the table are classified into two categories; the necessary and unnecessary objects for the instructed assembly. Tf there are excess parts with the same shape, only the required number of parts at the easier handling positions and postures are selected and regarded as the necessary parts.

Then, the assembly order is determined as the reverse of disintegration order by computing the possible disintegration sequences of the assigned complex into pieces. Tn general, there exists several sequential orders of disintegration as seen in Figure 9. Tn this case, by evaluating the postures of the objects, the most preferable order is selected where the duplicate manipulation of the object by changing the grasping position is not necessary, or minimum in number.

As shown in Figure 10, the robot further selects two parallelling surfaces of the parts for grasping, excluding the contact surfaces of the parts. Then, it determines the paths of the hand, the positions of assembly and the directions of approach by computing the vector sum of the contact surfaces. When these decisions are completed, it then calculates the angular displacement of each joint of the arm and dispatches the determined data to the seven data registers in response to the request from the pulse distributor in the handling control equipment. Thus, the seven different movements of the articulated handling system are regulated independently and driven simultaneously with a continuous-path mode.

When it is judged at this decision-making stage that there is the lack of parts on the table or that the hand mechanism is hard to reach the objects physically, the robot prints out the message on the typewriter, gives up the assembly and waits for a new instruction of the human master.

6. Discussion and conclusion

As described above, the HIVTP is a prototype of the intelligent robot that can understand the macroscopic instruction given in the form of a three-view plan and is capable of making necessary decisions to accomplish the assignment indicated in the plan. The development efforts of this robot have mainly been focused on the exploration of the processing techniques that can deal with the information of co-relationships between three-dimensional objects in contact, as well as the information of individual objects. The drawing recognition capability is especially a unique achievement of this effort and seems to be significant not only in giving a machine an intelligence to understand a macroscopic instruction but also in establishing an important basis of graphic display technique which may develop into a sophisticated computer-aided designing technology.

As the major concern of the present work is the computer algorithms, no special effort has been taken so far on the processor hardware, and the conventional digital control computer has been utilized. The entire software system of the robot, including the operating system software and the working area for visual images, exceeds 400 kilowords of memory, and is stored in 512-kiloword magnetic drum memory as chain jobs. In addition, more than ninety percents of programs are written in FORTRAN of this particular computer whose speed no longer seems to be high enough. These are the main reasons of takinp much computation time as 240 seconds for image processing, 20 seconds for drawing recognition, 50 seconds for each object recognition, 10 seconds for decision-making and 180 seconds for assembly movements on the average.

Tt may be possible in this case to reduce the time to one-tenth or even to one-twentieth by refining the program, yet the development of low-cost processors with totally new concepts, which may have at least the parallel processing capability, seems to be essential for the solution in future industrial application. Thus, our present work rather posed the questions that must be answered in future, and the quantitative and qualitative improvement of recognizable objects is one of the requisites that we should study next for intensifying the problem-solving ability and approaching to the intelligent systems.

References

(1) L.G.Roberts, "Machine Perception of Three-Dimensional Solids", Optical and Electro-optical Information Processing (MTT Press, Cambridge, Massachusetts, 196.5).

(2) G.E.Forsen, "Processing Visual Data with an Automaton Fye", Pictorial Pattern Recognition (Thompson Book Company, Washington, D.C., 1968).

(3) A.Guzman, "Decomposition of a Visual Scene into Three-Dimensional Bodies", Proc. FJCC, p. 291-304, 1968.

(4) J.McCarthy, L.Earnest, D.Reddy & P.Vicens, "A Computer with Hands, Eyes and Ears", Proc. FJCC, p. 329-338, 1968.

(5) N.J.Nilsson, "A Mobile Automaton: An Application of Artificial Intelligence Techniques", Proc. 1st International Joint Conference on Artificial Intelligence, p. 509-520, May 1969.

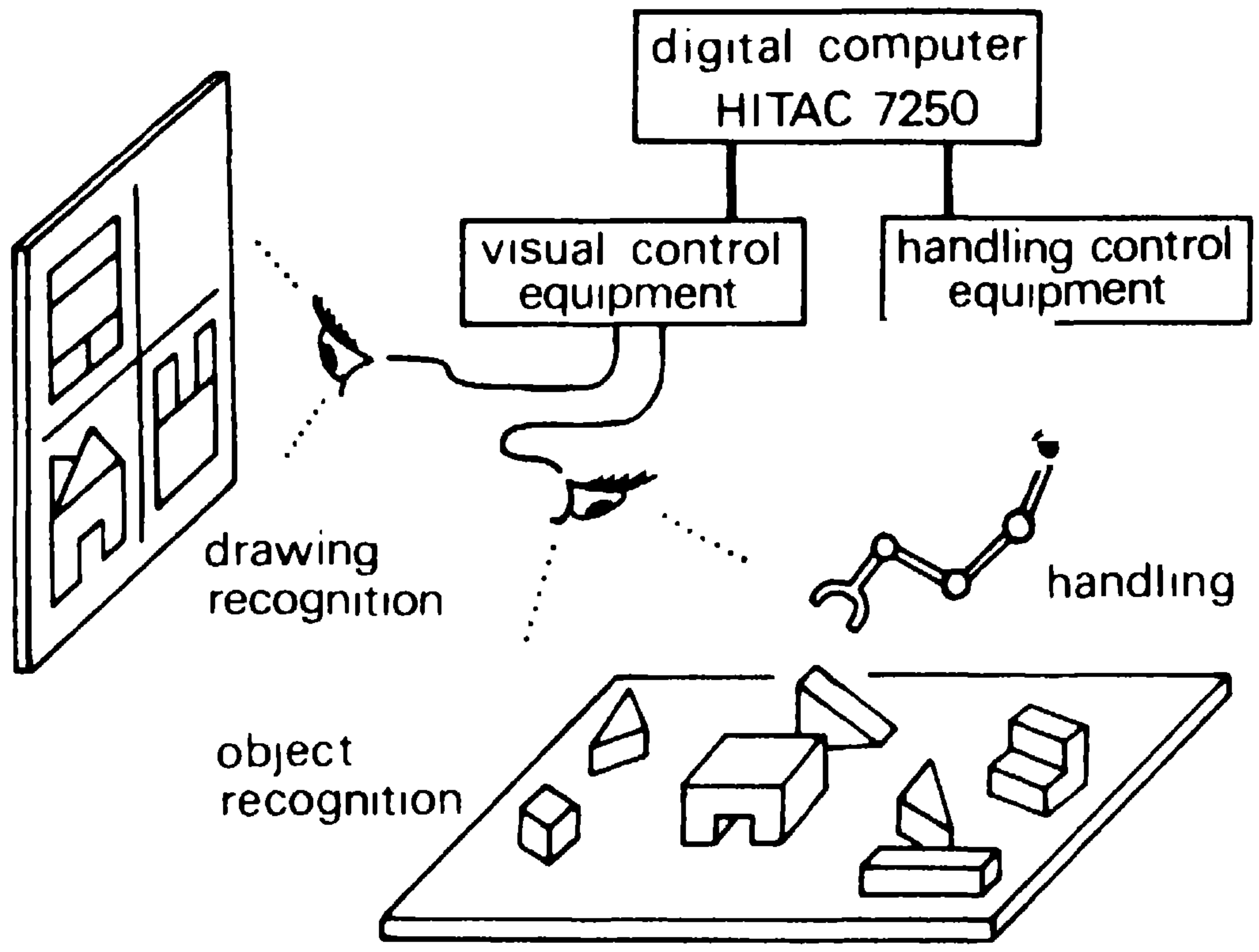


Fig. 1 Outline of the intelligent robot.

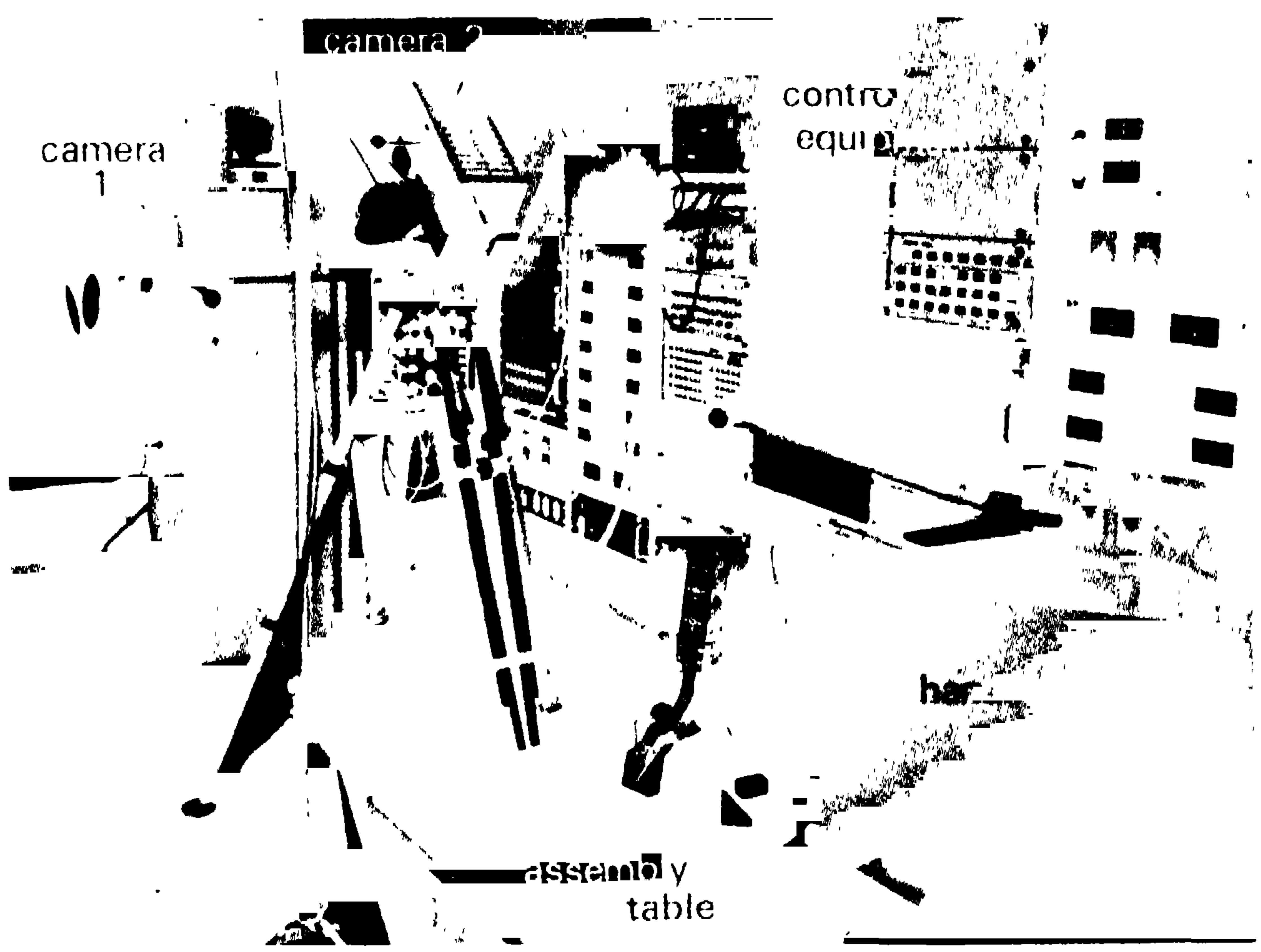


Fig. 2 General view of the intelligent robot.

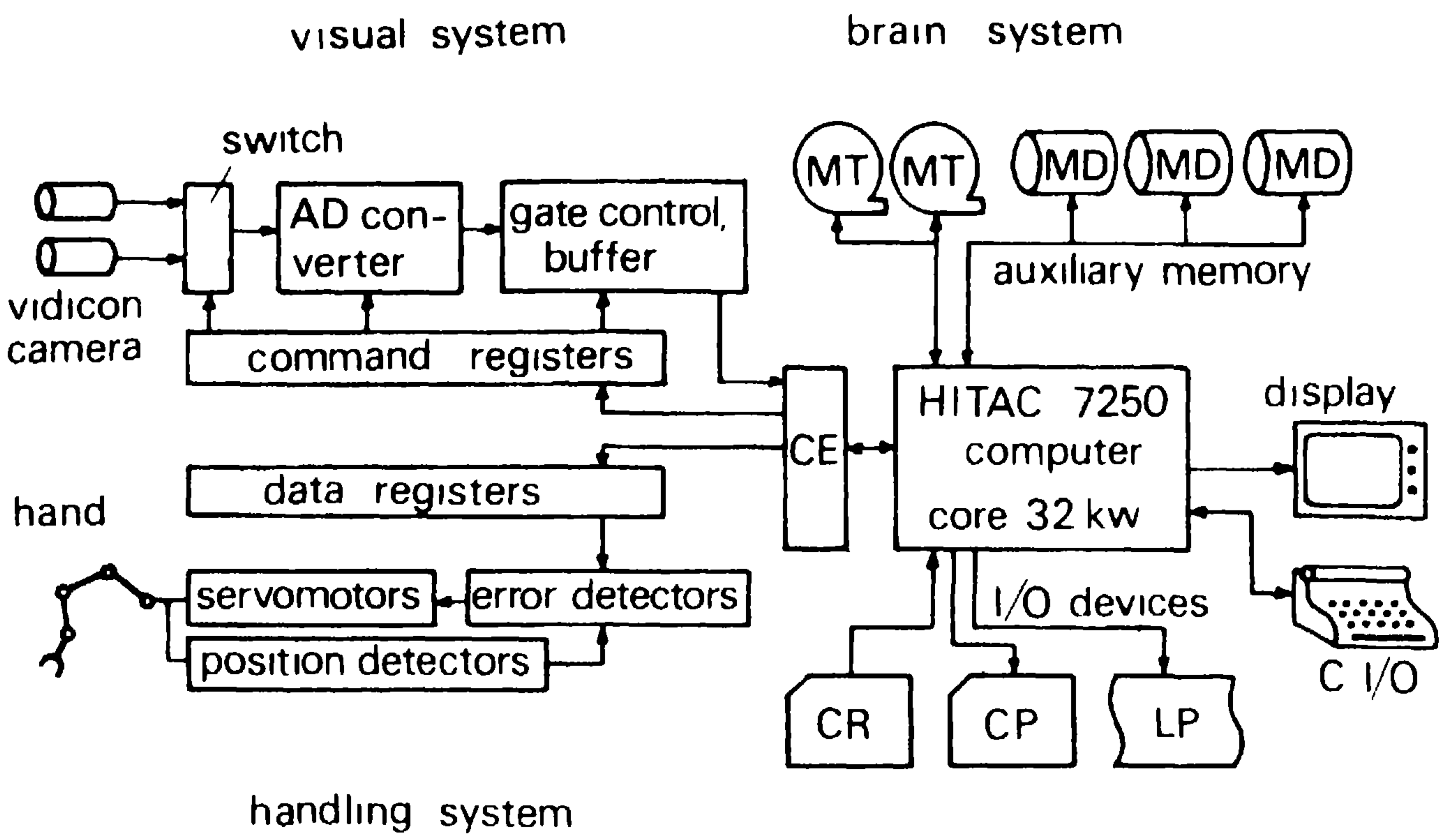


Fig. 3 Hardware system of the intelligent robot.

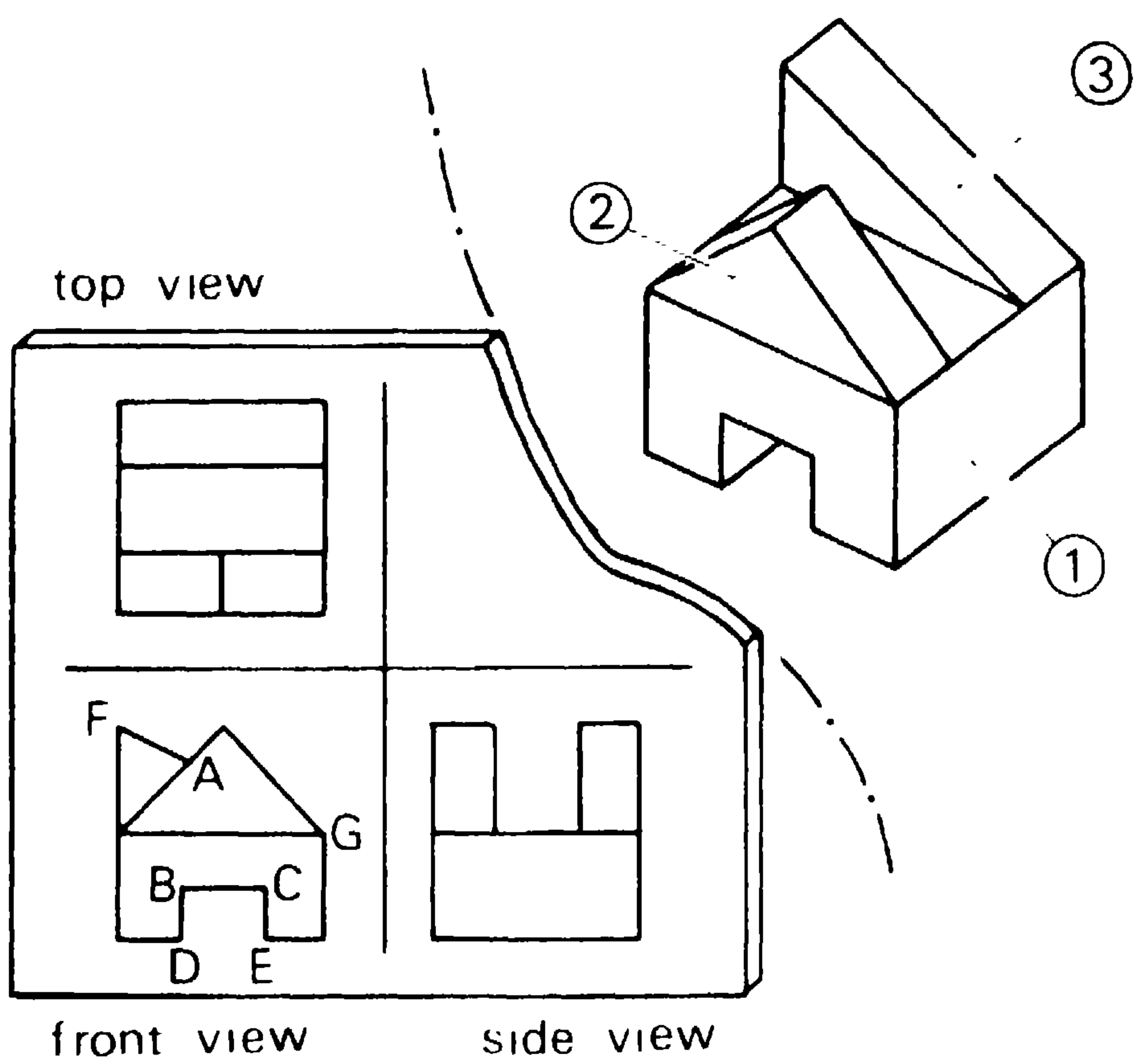


Fig. 4 Example of a three-view drawing and its three-dimensional configuration.

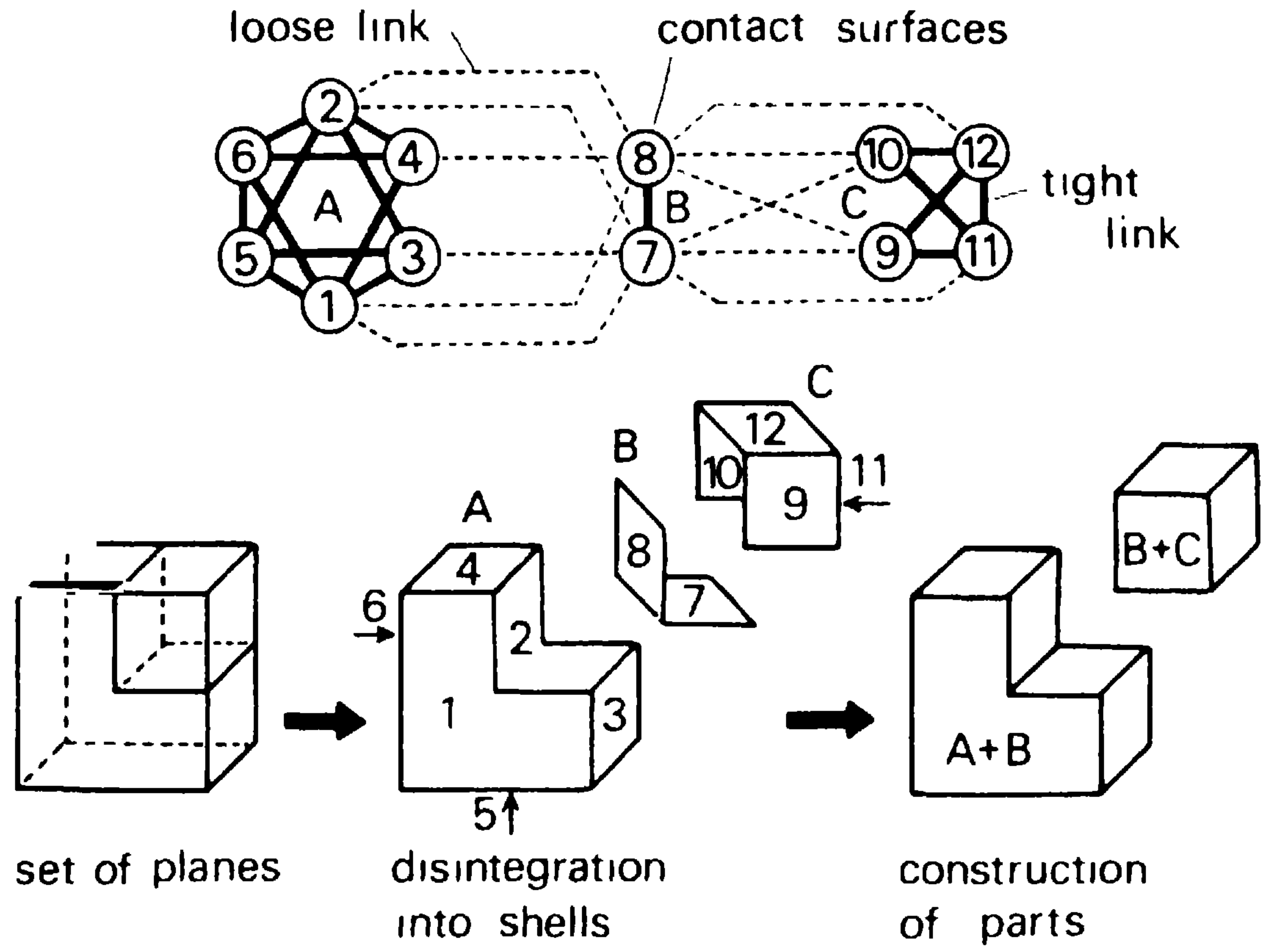
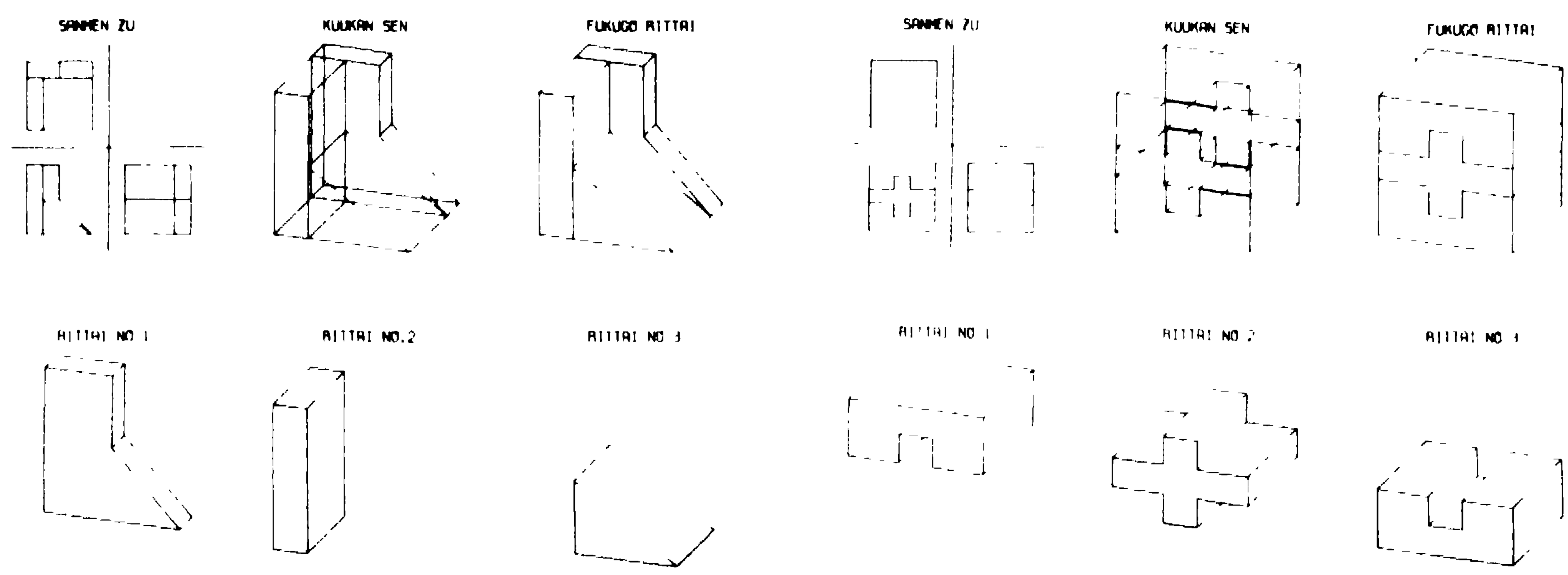


Fig. 5 Recognition process of individual parts from the integrated three-dimensional structure.



Example 1

Example 2

Fig. 6 Examples of results of the drawing recognition.

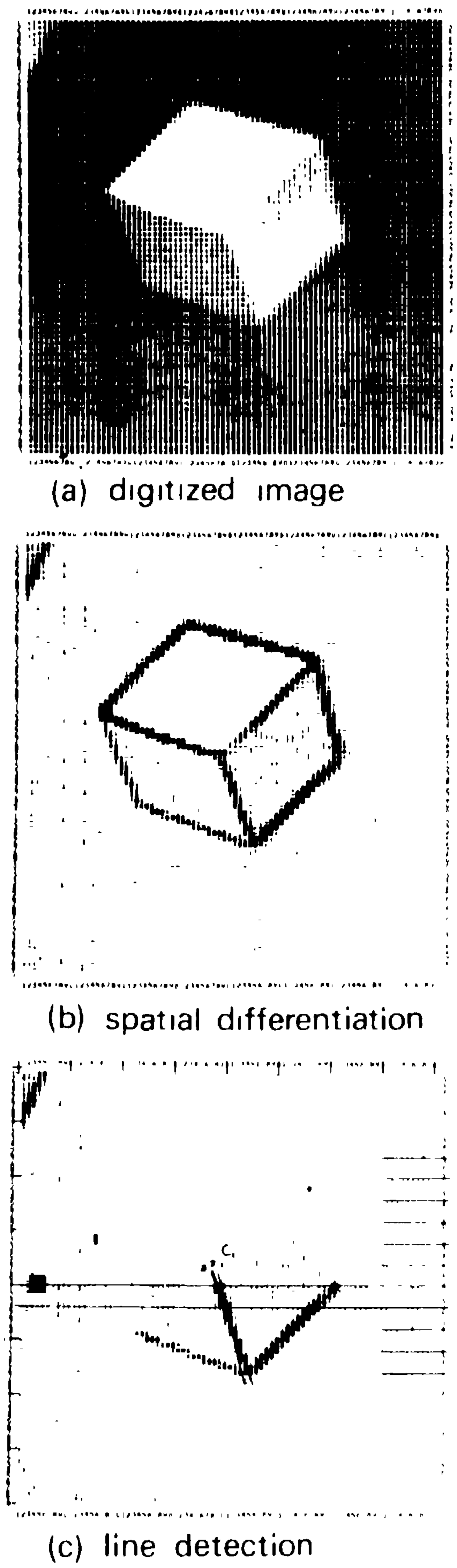


Fig. 7 Image processing and line detection by trenching method.

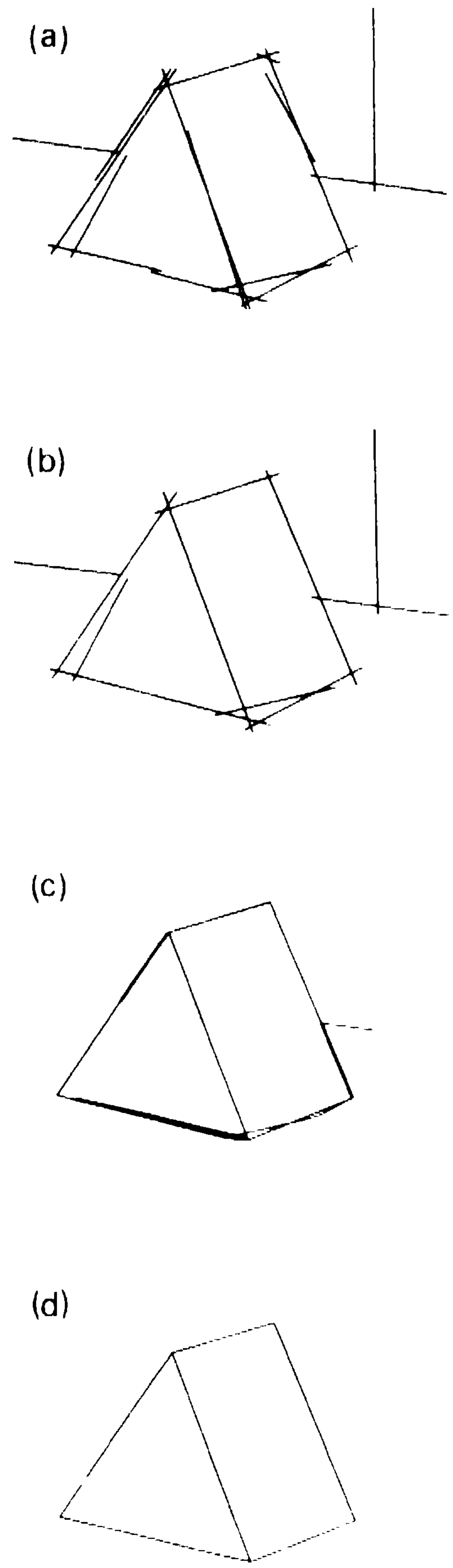


Fig. 8 Rearranging process of detected lines.

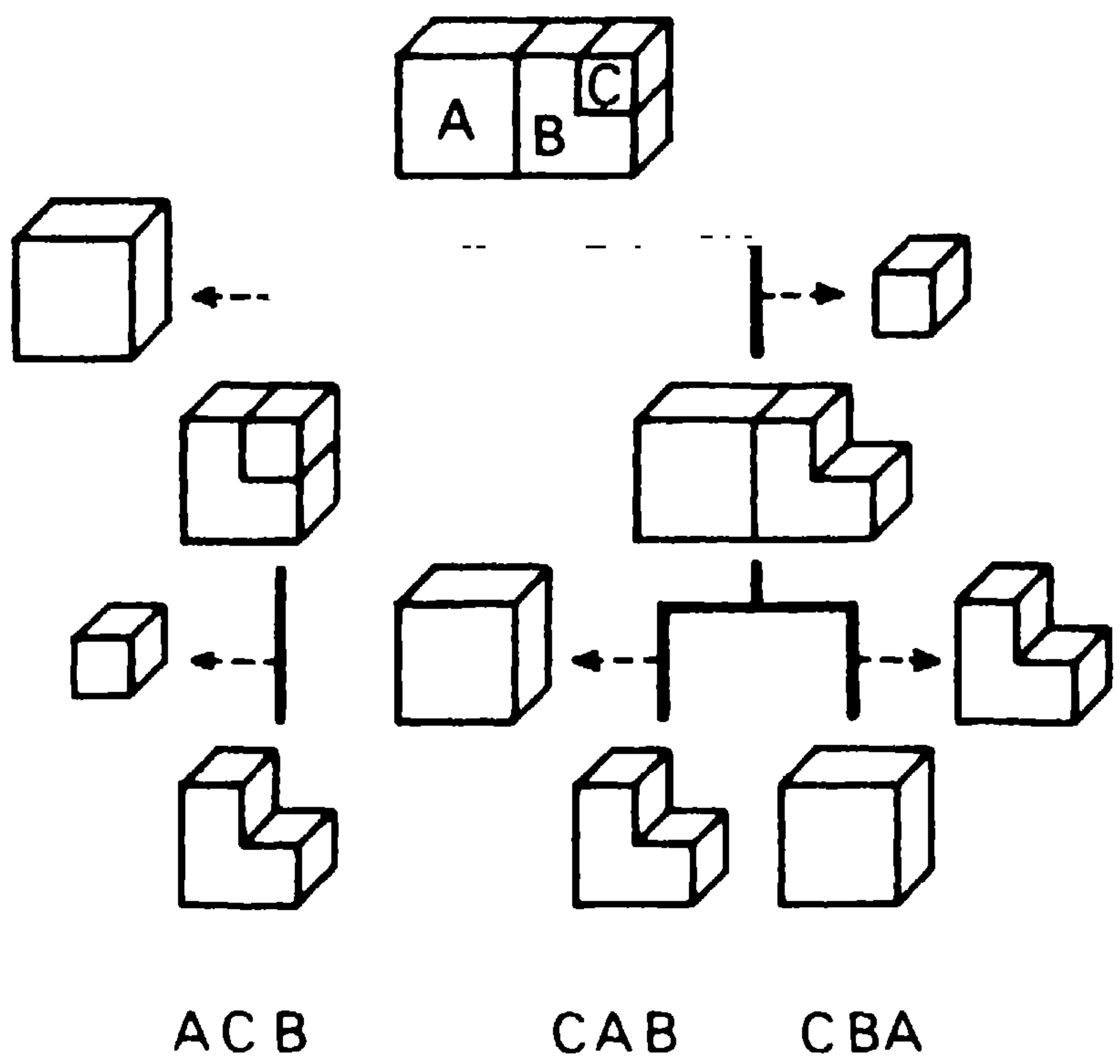


Fig. 9 Example of a disintegration tree for the decision of assembly sequence.

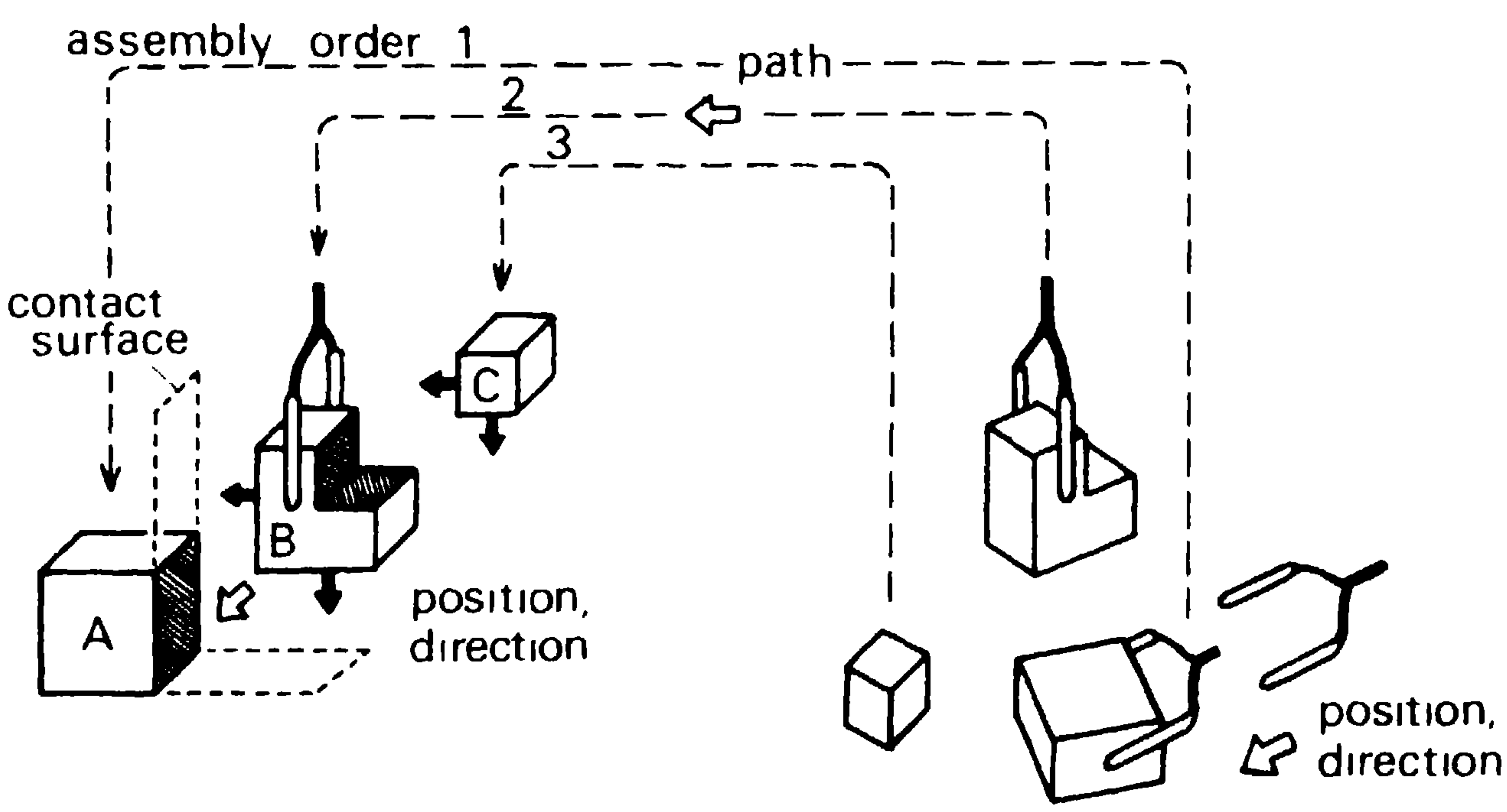


Fig. 10 Decisions on assembly procedure.