SHORT NOTE

A Problem in Computer Vision:

Orienting Silicon Integrated Circuit Chips
for Lead Bonding

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Will computers that see and understand what they see revolutionize industry by automating the part orientation and part inspection processes? Predictions have been made and hedged, yet very little has been done so far. There are two reasons:

* Computing power still costs too much.
* Our understanding of real images is too feeble.

We believe these obstacles are eroding quickly. There is now every indication that difficult operations can be automated soon with dramatic productivity increases. For one thing, powerful computers are available now on single integrated circuit chips. At the same time new ideas have emerged that will enable machines to fill jobs that are too tedious or dangerous to attract human labor. Already one machine in the field is reading handwritten ZIP codes [1]. Another is visually inspecting printed-circuit cards for etching defects at faster than human speed and better than human reliability [2].

To illustrate what can be done, we describe a working program that visually determines the position and orientation of tiny silicon chips, a necessary prerequisite to establishing electrical contact between the chips and the leads protruding from the premolded plastic or ceramic packages enclosing them. Human operators perform this task for every transistor and integrated circuit made today by peering through a microscope or viewing a TV enlargement.

How Integrated Circuits are Made

The photographs in Figs. 1a and 1b show typical integrated circuits (IC) lead-bonded into dual inline packages (DIP) and hybrid circuits. Many individual integrated circuits are fabricated together on a single 2- or 3-in. wafer as in Fig. 2. As if it were a sheet of glass, the wafer is scribed with a diamond tool or laser beam and then split up into individual circuits ready for installation in the stan-
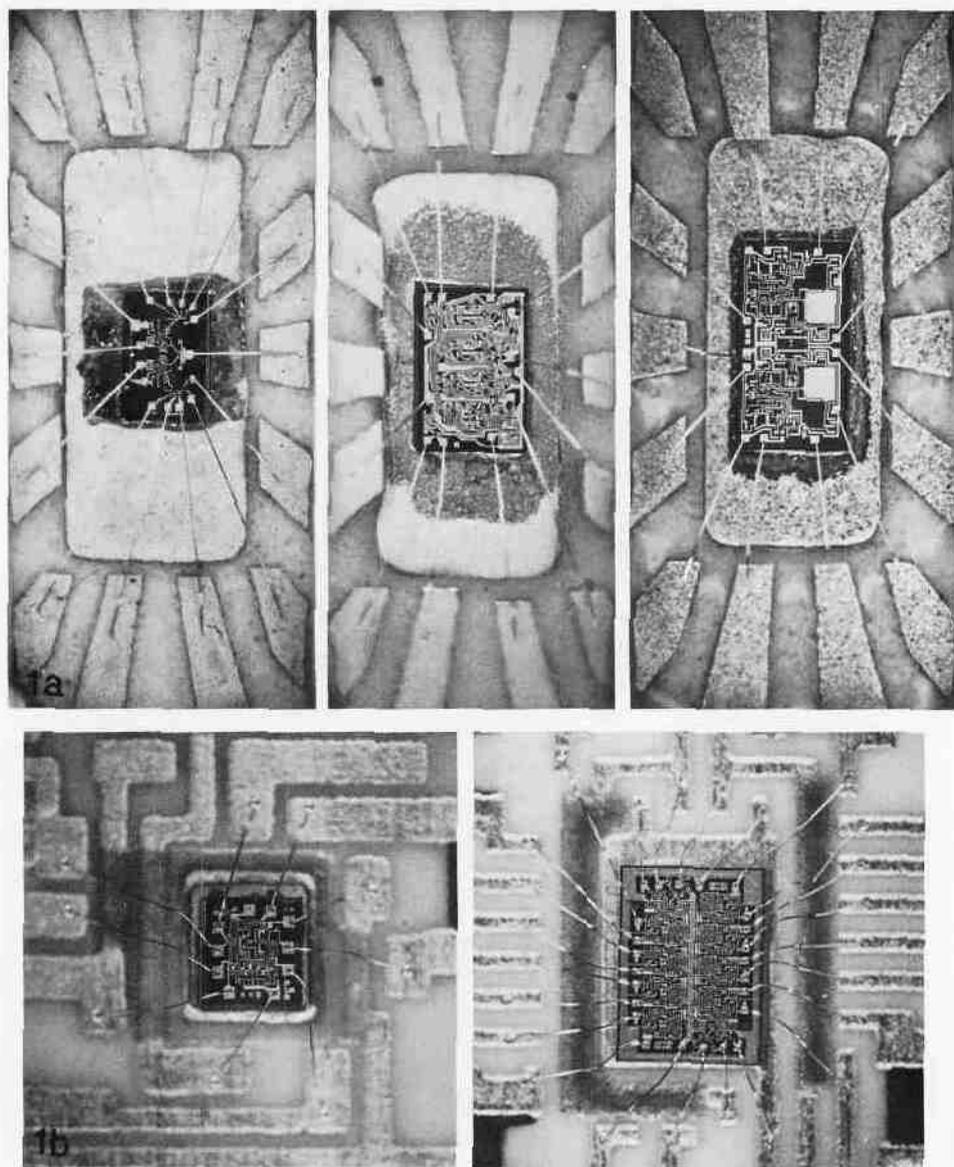
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FIG. 1.(a) Typical integrated circuit chips lead-bonded into fourteen-pin dual-inline-packages using 1-mil aluminium wire. (b) Typical integrated circuit chips lead-bonded into hybrid circuits using 1-mil gold wire.

dard packages. Tiny probe electrodes are applied to each chip in turn to see if it works. Defective chips are marked with an ink spot.

After a chip is bonded to the substrate by eutectic or plastic means, automatic equipment can attach gold or aluminium wires from pads on the chip to the much larger conductors that extend out of the package. Unfortunately the target pads are not registered precisely with the lines of cleavage and the chips slip a bit as they are laid down, thus losing precise alignment. Consequently the position and
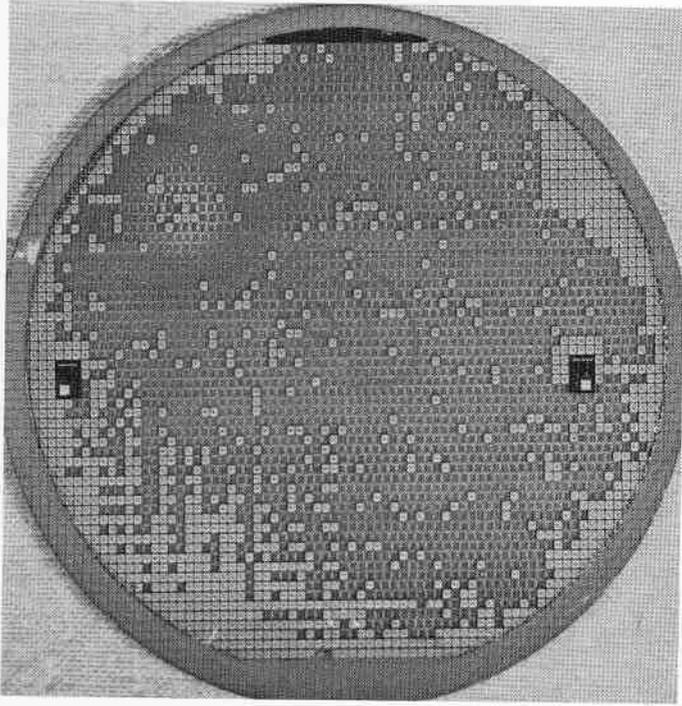
FIG. 2. Standard 3" wafer (only defective chips have been left behind on it).
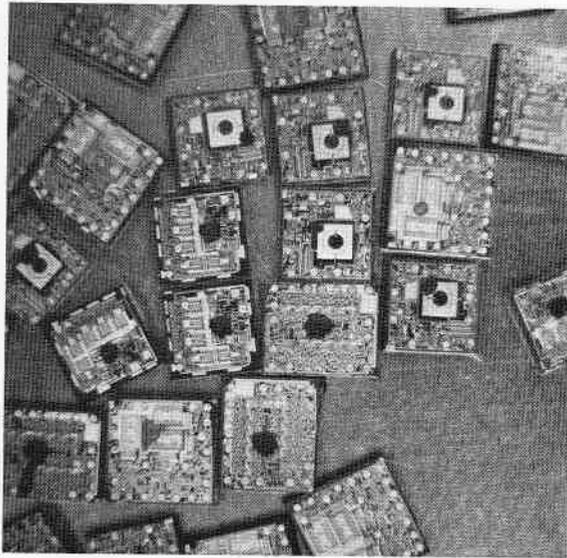

FIG. 3. Chips with reinforced pads for lead-frame attachment (they happen to be defective ones marked with ink spots).

orientation of the chip must be determined accurately before the automatic equipment takes over. Typically the human operator moves cross hairs to the target centers using a joy stick.

Newer techniques limit the problem somewhat by using IC chips with beam-leads or reinforced gold-ball contacts as shown in Fig. 3. These can be bonded directly to either lead-frames, as in Fig. 4a or film-carriers, as in Fig. 4b. The greater expense of this process is warranted only because it simplifies the manual alignment operation. Since the frame bears a prong for each pad, only one alignment operation is needed for each chip, rather than one for each pad connected to. Another, more recent approach, makes use of program-controlled bonding sequences activated after an initial manual alignment. Machines using this technique are referred to as "automatic" lead-bonders.

Still, alignment remains the only operation not yet automated. The cost of this is difficult to separate from other steps, but it ranges from perhaps 3 cents for simple chips mass-produced abroad to 30 cents for complicated chips made domestically. Assembly and packaging account for over half the cost of manufacture of integrated circuits and the bonding operation consumes over one-half of the cost of labor in their assembly.
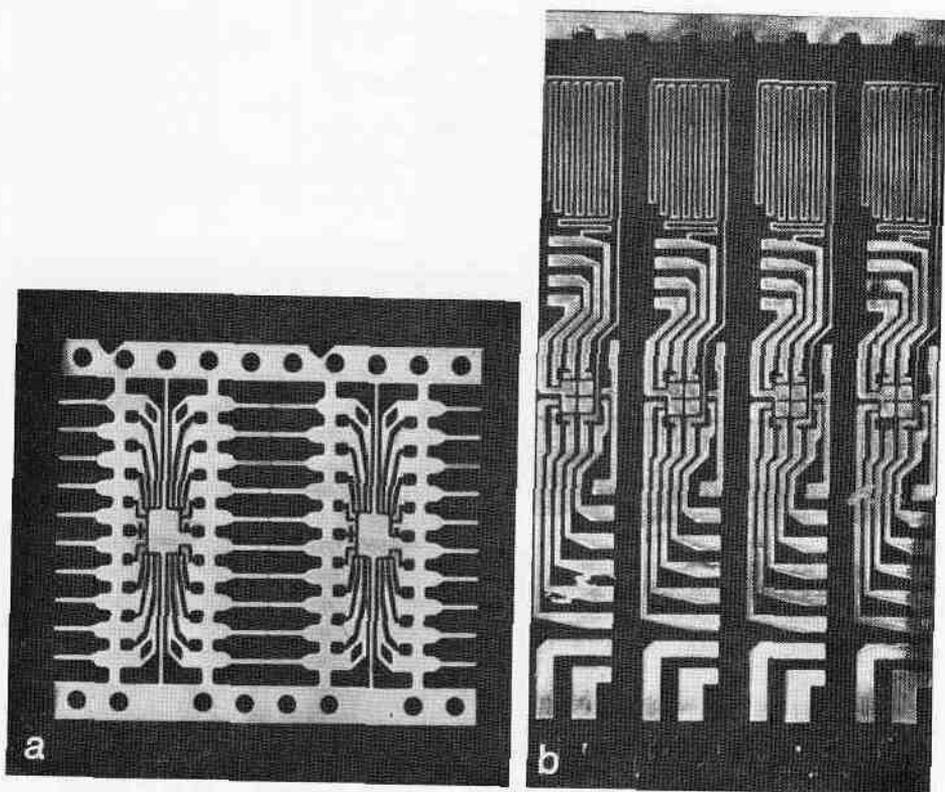

FIG. 4.(a) Lead-frame strip of 10-mil-thick gold-plated brass. (b) Flexible film-carrier strip.
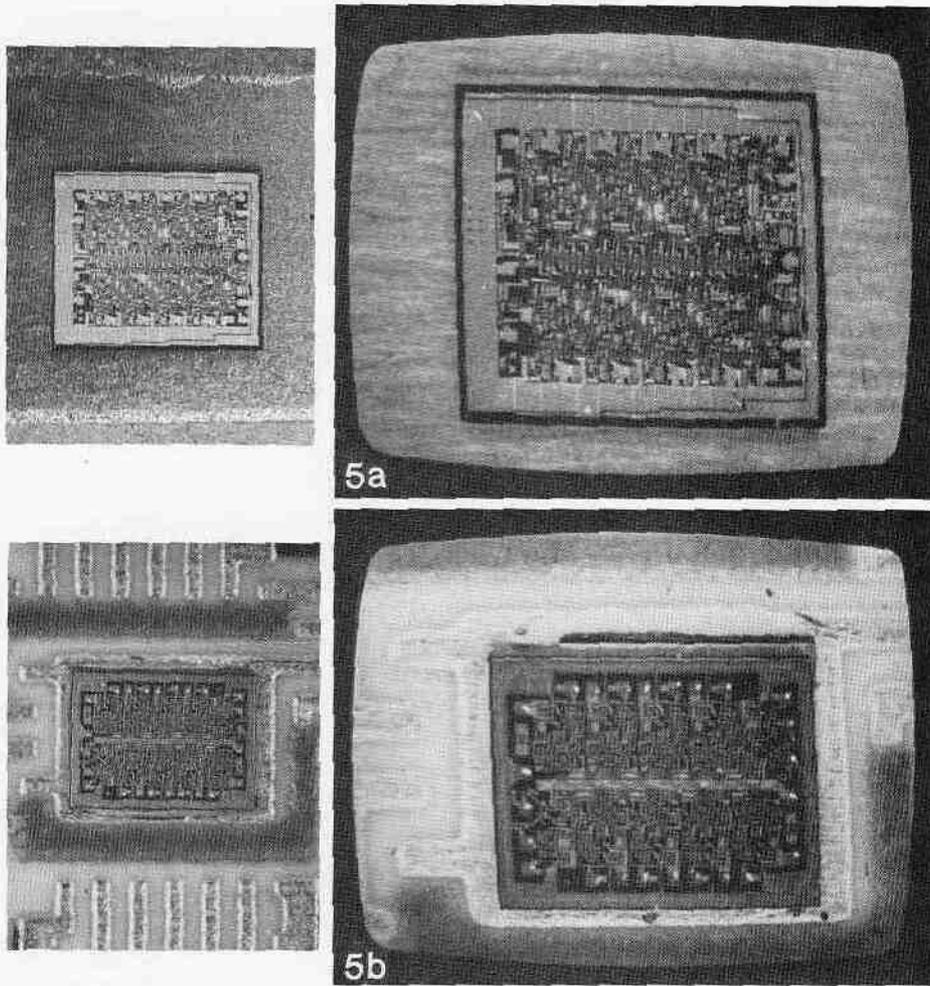
FIG. 5.(a) Micrograph and photo of TV monitor image of integrated circuit chip with bright aluminium border. Note dark gap in the border. (b) Micrograph and photo of TV monitor image of integrated circuit chip with bright aluminium border. Note highlights on pads caused by probing electrodes.

A Border Simplifies Processing

Quick processing of complicated objects usually requires exploitation of special properties that make complete image analysis unnecessary. Sometimes slight redesign helps. In particular, addition of an aluminium border to integrated circuit chips considerably simplifies the orientation task. By happy accident some of the newer Schottky TTL chips now appear with such borders anyway, as seen in Figs. 5a and 5b. Since some chip area is sacrificed, generalizing our method may be desirable when handling chips which do not need borders for other reasons.
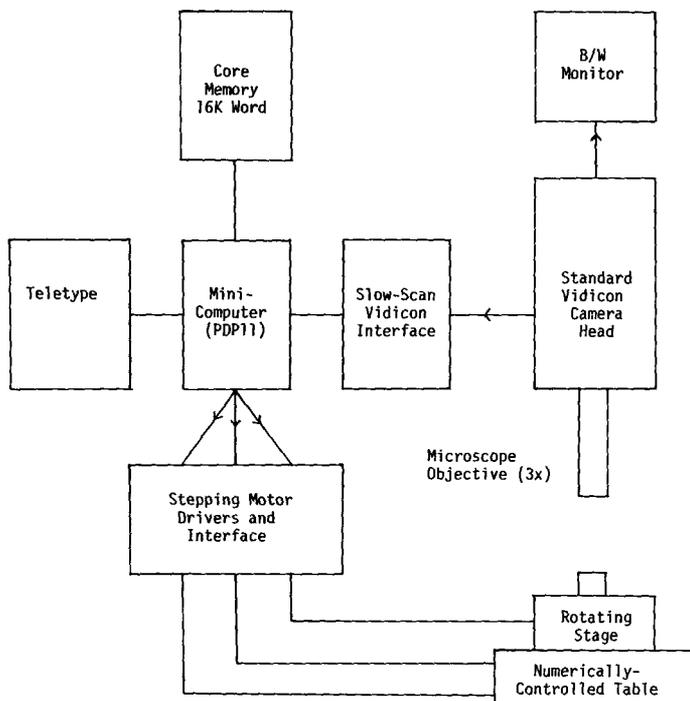
FIG. 6. Block-diagram of system used for laboratory demonstration of automatic positioning and orienting of integrated circuit chips using visual input.

The Image Can Be Processed Quickly by Inexpensive Equipment

Figure 6 is a diagram of the system used. All modules are standard items; nothing is exotic. Since the overall system was designed for flexible study of a broad range of applied problems, the sophistication and cost far exceed what is necessary. We estimate that a system costing $15,000 would do the job easily now, with further reduction likely as the cost of mini- and microcomputers continues down. (In fact there is a nice positive feedback loop at work since lead-bonding is a substantial component of the cost of the integrated circuits inside the necessary processing equipment.) In addition, part of the equipment could be shared among a number of work stations.

Inexpensive or not, no slow technique would be of much interest to industry. It is therefore fortunate that the visual processing can be done in less than 0.25 sec. To do so requires some work, however. The mismatch of TV vidicon speed and computer speed is the first problem to face. Since a binary approximation of the image cannot do the job, several bits of analog to digital conversion are needed. But multiple gray level conversion at video speed requires talented and expensive A to D hardware as well as fancy memory buffering.

Picking off and converting one point per horizontal scan is the easy solution. Using this technique, intensities from one vertical line of points can be collected for each complete set of horizontal scans. The entire image can be acquired by
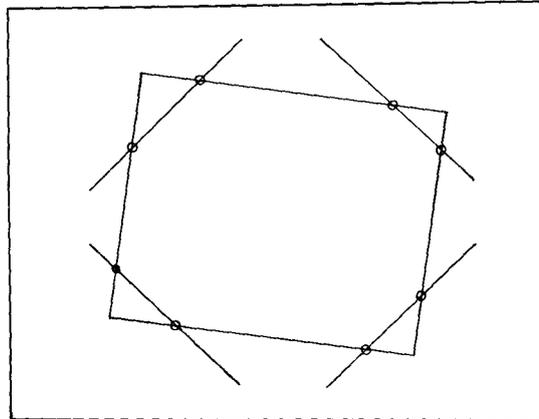
FIG. 7. The four diagonal scan lines superimposed on a sketch of the image of an integrated circuit chip. Circles mark the eight edge points found by the program.

increasing the time between initiation of horizonal scan and sampling, thus stepping the vertical line of sampled points across the image. About 17 sec are required to record a complete image of 480 by 512 pixels this way. Fortunately, however, the chip orienting program need not look at a complete image. In fact the points indicated in Fig. 7 are quite adequate and they are obtainable from four picture frames in 0.066 sec. The four diagonal lines intersect the chip frontiers at eight points. Finding them enables measurements of pad position accurate to 0.5 mil, given that initial errors are within approximately

$$\Delta x < 15 \text{ mil}, \qquad \Delta y < 10 \text{ mil}, \qquad \Delta\theta < 25°.$$

Initial placement ordinarily falls within these limits. If the chip is further away from the expected position, nothing is lost beyond the time required for an extra pass of the process following coarse adjustment by the first try. There is a trade-off between accuracy and tolerance for large positioning errors, controlled by the placement of the four diagonal scan lines. The positional accuracy of 0.5 mil is quite satisfactory since the target pads are typically 4–10 mil on a side and the connecting wires are from 1 to 3 mil in diameter.

The Image Is Not Binary

Surprises await the person that thinks IC images are trivial. In fact they are complicated enough to be interesting but not so complicated as to require great sophistication. Under proper uniform lighting conditions, the silicon material itself is relatively dark and the metalization lighter and not very grainy, but transitions between dark and light are not strictly steplike. The intensity profiles exhibit local irregularities rather than steady change because the edges of IC chips are ragged and sloped like those of mesas. Specular reflection points riddle these edges foiling reliance on simple thresholding. To do the job therefore requires built-in knowledge about edge profile processing. Figure 8a illustrates these important steps:
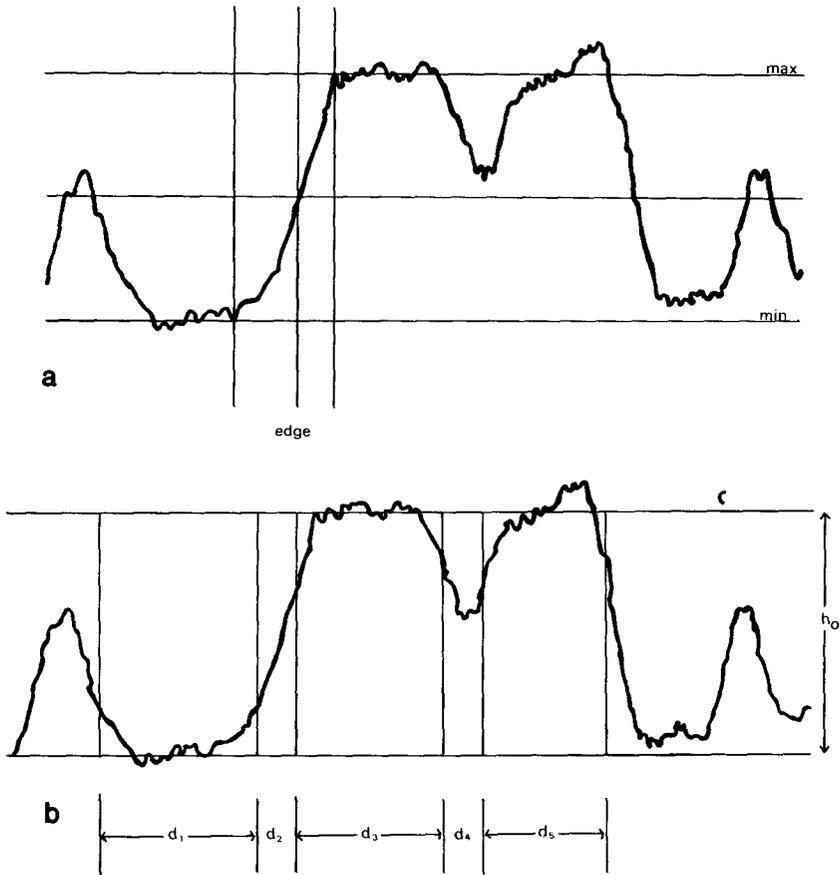
FIG. 8.(a) Illustration of the intensity profile and measurements taken to determine a hypothesized edge position. (b) Illustration of the intensity profile and some of the measurements taken to verify a hypothesized edge position.

    * Search forward looking for the chip's aluminium border. The first sign is a rapid rise in intensity extending over several pixels.

    * Next move further ahead looking for the maximum intensity.

    * Search backward to find the minimum.

    * Calculate (max + min)/2 and find where the waveform crosses this threshold. This is the hypothesized edge of the IC.

The minimum and maximum points tend to be in the midst of plateaus from which they differ only slightly in intensity value. Consequently a small amount of noise somewhere on a plateau can move an extremum considerably. For this reason, averaging between the places where the minimum and maximum are found is not a good way to find the edge. Using the threshhold idea is a standard way to avoid the problem.

Signal noise, dust, and scratches cause occasional miscalculation of an inter-

section point. This rarely interferes with correct positioning, however, because once the boundary is identified as above, built-in verification steps ensure that the result is sound. These include checks on the difference between maximum and minimum, the width of the light and dark plateaus, the width of the transition, and so on, as illustrated by the measurements indicated in Fig. 8b. A failure initiates further profile analysis and if this too fails, the chip is moved a short distance in the best-guess direction and rescanned. Geometrical tests are also performed to ensure that the eight transition points found do indeed lie on a rectangle and that the rectangle has the correct dimensions.

Notice that individual intensity patterns may deviate considerably from the expected shape. Some, for example, may have an abrupt depression in the high-intensity plateau caused by a normal gap in the border material. Others have sharp pinnacles where conchoidal fractures cause specular reflections. Template matching schemes are hard pressed by such problems because it is hard to supply them with specific knowledge about particular anomalies. Thankfully, building knowledge into procedures is immensely easier.

Altogether the approach resembles Shirai's treatment of scene analysis in the world of blocks and wedges, long a favorite of workers in artifiicial intelligence [3]. Indeed Shirai's feature point program is a generally important source of ideas with which everyone in image understanding should be familiar.

Calibration Is Easy

The program needs the relationship between pixels and the step size of the positioning table. There are several factors which influence this: Pixel size varies with each vidicon tube; the pixel size differs in x and y; there is some relative rotation between the camera and the table; and the x and y axes in the camera are not exactly orthogonal. The following linear transformation accounts for these factors.

$$\begin{vmatrix} x_v \\ y_v \end{vmatrix} = \begin{vmatrix} a & b \\ c & d \end{vmatrix} \begin{vmatrix} x_t \\ y_t \end{vmatrix},$$

where x_v and y_v are pixel units and x_t and y_t are table step units. Matrix elements $a,b,c,$ and d are easily obtained by observing the displacement in the vidicon which results from stepping a standard IC through known calibration points. The inverse matrix then gives correct table movement for observed offsets. Refinement of this calibration process aimed at compensating for nonlinear distortion in the vidicon camera would increase accuracy, although further improvement does not seem necessary at the moment.

An Industrial Revolution Is Needed

We believe this application and others like it are the vanguard of a new kind of productivity technology, one oriented toward facing difficult industrial vision and manipulation tasks squarely. Past solutions always involved using people or costly, inflexible special purpose automation. But people are moving increasingly toward the service sector and away from the boredom of the assembly line. Many of the things they do are difficult to automate because special purpose au-

tomation costs too much or cannot work. Thus the need for progress in vision-based productivity technology is acute.

Even in the electronics industry, well known for its aggressive posture with respect to new ideas, there are many other examples of expensive, manual assembly, inspection, and repair operations. Here are just a few:

Inspection of printed circuit cards. When a large circuit board comes out of the etching bath it is likely to have many crack and bridging defects. These must be found and corrected before component insertion. Later on the board must be inspected again after wave soldering, again with many hand corrections necessary. The Japanese have made some progress on this problem [2].

Assembly of electronic circuits. Not all components can be handled by automatic insertion machines. Visual inspection is required in any case. Large or odd-shaped components such as transformers and components with floppy leads present special problems.

Repair of assembled modules. With larger board areas the yield of working circuits is low. The "new" computer is actually a repaired computer debugged by an expensive, trained technician.

Eventually machine vision is likely to increase productivity in such diverse activities as undersea and underground mining, farming chores, surveillance of dangerous machines, package sorting, custodial care, planetary exploration, and the manufacture of shoes, clothes, and other consumer goods. Everyone knows that these are tough problems to hand over to flexible computer-based systems. Until now the technology has not been adequate and computation costs have not been low enough to move machines with these capabilities out of the laboratory and into the manufacturing process. The great strides that have been made in automating continuous processes like oil refining and paper making, or in discrete parts manufacturing for that matter, have yet to be matched in situations requiring mechanical assembly or human quality visual inspection. It is time to catch up.

ACKNOWLEDGMENTS

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