AutoVM: Automatic Visual / Mechanical Inspection of Packaged Integrated Circuits

Donald J. Christian
Member of Technical Staff

Texas Instruments, Inc.
Corporate Manufacturing Technology Center
Dallas, Texas 75238

Abstract

This paper describes an automatic inspection system for DIP - packaged integrated circuits which uses machine vision.

"VM", or "Visual and Mechanical " inspection, is the final quality control step in the manufacture of integrated circuits. The packaged circuits are typically manually inspected to insure label quality and mechanical integrity. Fatigue severely limits human effectiveness at this task, making manual inspection expensive and unreliable. However, the VM inspection process has recently become even more important to customers because of their adoption of modern manufacturing automation technology. IC defects which are correctable by assembly personnel frequently go undetected by automatic assembly equipment.

The AutoVM machine consists of two television cameras with two associated machine vision systems, and material handling and control mechanisms. ICs in Dual Inline Packages (DIPs) are fed into the machine in standard tube packages, and are automatically unpacked, inspected, sorted, and repackaged into tubes. Rejected ICs are sorted by correctability. After correction, the ICs are reinspected.

AutoVM machines are now in production use at several Texas Instruments production facilities around the world. The machines have been demonstrated to be effective and reliable.

Introduction

The Semiconductor Division of Texas Instruments, Incorporated manufactures thousands of different varieties of integrated circuits (ICs). ICs are a fundamental and essential component of practically every electronic device in the world today, and have made possible the electronic industrial revolution which engulfs us in the 1980's.

Electronics manufacturing and testing is an area in which novel forms of automation have been pioneered. Modern semiconductor fabrication facilities are among the most fully automated factories in the world.

IC testing techniques employed to date have been primarily concerned with electrical and functional performance. AutoVM is among the first to address testing for cosmetic and package flaws.

Cosmetic testing may at first seem a trivial pursuit, and not worthy of a serious and expensive automation effort. But when the label is the only means of differentiating between vastly different objects, as in pharmeceuticals and electronics, then the correctness and legibility of the label has a value equal to that of the product itself. For example, the chemical differences between asprin, vitamin C, and penicillin are significant even though the tablets may be identical to the eye. If the label is not correct, then the product is worthless.

Cosmetic appearance is also important in consumer products which are displayed for sale. Examples of this are alcoholic beverages, perfume, breakfast cereals, automobiles, and soaps. Indeed, appearance is a factor in the sale of most consumer products.

This paper describes an operational system based on modern machine vision techniques which demonstrates the technical and economic feasibility of package inspection for integrated circuits.

Functional Needs for Electronics Package Inspection

The final step in the manufacture of integrated circuits is the inspection of the package to verify the package integrity and the legibility of the label. This step is commonly referred to as "V and M", or Visual and

Mechanical inspection. Manual VM inspection is tedious and requires judgements which are both qualitative and subjective.

The Dual Inline Package, or DIP, is the most popular form of packaging for integrated circuits. Figure 1 shows several ICs in DIP packages. The majority of manufacturing defects for these products are associated with the metal connector leads. The leads are attached to the two long sides of the DIP package in straight rows, like the legs of an insect. There can be as few as four leads, or as many as ninety-six, but the most common numbers are fourteen, sixteen, and eighteen.

Note that several of the leads visible in figure 1 are visibly bent. These bent leads are manufacturing defects. One of the ICs in the picture is placed on a flat metal plate. This plate is a calibrated test fixture used to manually verify the straightness of the leads. Two sets of channels of precise dimension are routed in the surface of the plate. The package to be tested is slid first into in one set of channels to check the lead 'sweep' dimensions, and then the other set of channels to check the 'spread' dimensions.

Problems with the label (also called the symbolization) are the second most common failure mode. Bent leads and bad symbolization together account for most of the non-electrical failures. The AutoVM machine was designed to detect both of these types of flaws, as well as other less common types.

Connector lead failures can be classified into two categories: electrically detectable and mechanically detectable. Electrical testing of the ICs is done at least twice: once after wafer fabrication (at multiprobe) and once after encapsulation and final assembly. The remaining unsorted (nonelectrical) failures must be trapped using nonelectrical methods. A military specification exists, MIL SPEC 883-C, which details U.S. requirements for lead dimensions along with other cosmetic, package, and die specifications.

Lead failures have become more costly to users recently because of their adoption of automatic assembly equipment, particularly 'board stuffing' machines. When an assembly robot attempts to insert an IC with a bent lead, the lead misses its target hole and is further bent. Electrical contact may or may not be made, and mechanical contact is unsatisfactory. This condition, sometimes called 'knuckled under leads', is often difficult or impossible to see. Even when the failure is electrically detectable, it may be overlooked until the electrical test of a larger assembly. In a worst case scenario, an assembly containing a knuckled-under lead is integrated into an end product such as a heart pacemaker or a spacecraft, is tested as 'OK', shipped, and later fails in the field. Diagnosis and repair at this stage is always expensive. Since a typical printed circuit board assembly may contain 2000 leads, bent lead insertion failures are unfortunately familiar to most electronic manufacturers.

IC labels can be smeared, absent, dim, inverted, or simply wrong. No comprehensive quality specification exists for electronic component symbolization. The most commonly used benchmark is "a label must be visible to a person with good vision when held eighteen inches from the eye under good light".

Clearly, a standardized and repeatable means for performing VM inpections would be a welcome quality assurance tool.

Economic Justification for Automatic VM inspection

There are several ways to view the economic justification of automation. No single method gives a complete view of the situation.

Since production equipment involves capital investment and one alternative is an equivalent manual operation with associated wage costs, a direct financial comparison is tempting. The resulting payback period can then be categorized as 'too long' or 'short enough' based simply on the production costs of the two alternatives.

One difficulty with the comparative approach is in the phrase "equivalent manual operation". With automatic inspection techniques such as machine vision, a more detailed and consistent inspection can be sustained than is humanly possible. What are the benefits of such a superhuman inspection ? A heavy burden of testing is eliminated for those customers who need consistent quality. What are the customers willing to pay for this additional service ? An opportunity exists for those who can identify and fill this need.

Some customers are now incorporating 'defect penalty' clauses into purchase contracts. These clauses tie a financial penalty to each defective piece

that the customer returns. The penalty is usually much greater than the value of the piece. This can provide a powerful economic incentive for vendors to capture all defective units before shipment.

Also worth mentioning is the value of the reliability image of the vendor. This comes only from a history of delivering consistent high quality products. Customers are willing to pay a premium for products with "a name you can trust".

AutoVM Machine Requirements and Specifications

In preliminary discussions with potential users, many general performance requirements and expectations were identified. Some of these are listed below.

Overall performance requirements:

- Can be quickly set up for novel and unknown types of material.
- Reprogrammable by nontechnical personnel.
- Immune to variations in the quality of programming.
- Uses a consistent quality specification (MIL SPEC).
- Able to inspect ICs with varying number of pins.
- Cost competitive with current manual inspections.
- Reasonably low false alarm rate. The cost of reworking a truly good IC is relatively low.
- Extremely low failure escape rate. The cost of allowing a truly defective IC to escape is unacceptably high.

Material handling system requirements:

- Input and output ICs from randomly stacked plastic shipping tubes. (automatic unpacking and repacking).
- Automatic clearing of jammed ICs (de-jamming software invoked automatically when needed).
- Automatic display of clear diagnostic messages when a manual assist is required (upon de-jam failure).
- Statistical monitoring of all jams to assist maintenance personnel in "tuning up" individual machines.

Lead Inspector requirements:

- Easily adjustable for a different number of leads per workpiece.
- Measures lead tip position accurate to within 1 mil.
- Detects missing and extra leads.
- Immune to 'normal' contrast and lighting variations.
- Immune to 'normal' position variations of workpieces.
- Immune to nonlinearities in the optical and camera subsystems: both spatial and luminous.
- Detects contamination on the leads (ink, paint, grease, etc.).
- Detects solder blobs and solder chips on the leads.
- Discriminates between reworkable and nonreworkable leads.

Symbol Inspector requirements:

- Inspects letters printed in any character font.
- Inspects arbitrary symbols (such as a map of Texas).
- Adjusts to different printing processes (stamp, roll, soft touch, laser print).
- Immune to 'normal' printing variations.
- Very sensitive to variations in legibility.
- Immune to 'normal' variations in label position and stamping angle.
- Immune to 'normal' variations in illumination and ink color.
- Immune to 'normal' position variations of workpieces.
- Immune to nonlinearities in the optical and camera subsystems: both spatial and luminous.
- High flexibility for unanticipated label variations and combinations.

Theory of Operation

Figure 2 is a photograph of the prototype AutoVM machine. DIP-packaged integrated circuits are loaded and unloaded in standard twenty-inch shipping tubes. Tubes full of uninspected units are randomly dumped into the input tube handler on the left. Tubes filled with inspected and qualified units are removed from the output handler on the right.

ICs are automatically unpacked, singulated, and brought into the inspection station, where they are simultaneously presented to the two television cameras. Video images are input, processed, and analyzed, and the final classification or judgement signals are generated. If all judgements are favorable, then the qualified unit is packed for shipment.

Rejected units are sorted according to failure type and the

correctability of the problem. Three categories of rejects - bad labels, ruined leads, and straightenable leads - are sorted into three reject output ports. Bad labels can be painted over and relabeled for highly valued ICs. Many small- and medium-scale-integrated circuits (commonly called 'jellybeans') are so inexpensive now that relabeling is not economic. Leads which are not severely bent can be automatically straightened and reinspected. Some types of contamination such as lint and flakes can easily be removed; other types are more difficult. ICs with missing or deformed leads are almost always scrapped.

Lead Inspection

The lead inspector camera is presented with a bottom view of the integrated circuit package. An illuminating sheet of light is focused on the ends of the leads, which appear as bright spots in the picture. Figure 3 is a video image taken from this camera. Deformations in both the X-direction (sweep) and the Y-direction (spread) are easily visible from this vantage point. Leads which are too short ('peg' leads) are not illuminated and are classified as missing.

There are two main phases of operation to lead inspection: setup and production. During setup, the inspector is 'trained'. Information about the task to be performed is stored in the computer's memory. Production is the operational inspection of integrated circuits, and consists of registration, measurement, and judgement.

When an IC is presented to the camera, a video image is acquired and the objects of interest (the leads) are identified. Ordinal projection vectors are used to obtain coarse registration information. Connectivity analysis was considered and discarded because of the unpredictable number of objects created by each lead. The X-position of ICs in the inspection station is not repeatable and unfortunately varies more than the inter-pin gap distance. SO the lead images do not appear at a predictable position in the image. To make matters worse, the leads most likely to be bent are the ones on the four corners of the package. This makes the corner leads poor indicators of the overall workpiece position. A final complication appears after several months of operation: mechanical track wear makes two horizontal silver lines close to the leads.

To overcome these problems, the registration software begins in the middle of the image where the certainty is greatest, and works outward toward both ends. Note that there are several points during registration at which the process may be aborted, such as the case when no leads are visible at all.

After an image is registered, measurements of lead position and appearance are made. Lead center position is estimated as the first moment of a local area centered around the expected position. Lead absence is indicated by an exception flag from the moment generator. Unusual variations in the area of a lead are taken as evidence of the presence of contamination.

After lead registration and measurement are successfully completed, the resulting lead positions can be prepared to pre-established nominals, and a final judgement can be made as to the acceptability of the unit. If the deviations are greater than the scrap tolerance, then the unit is judged 'unrecoverably bent'. If a lead is bent but the deviation is within scrap tolerance, then the judgement is 'bent but reworkable'. If all measurements are within MIL SPEC, then the unit is judged 'good'.

Label Inspection

The label inspector camera is given a top view of the DIP package. The workpiece is illuminated with a ring light mounted around the camera lens. Figure 4 is a video image taken from this camera.

As with lead inspection, label inspection has two phases: setup and operation. During setup, the inspector is 'trained' to the label specific for one lot of integrated circuits. Information about each symbol in the label, including position and appearance, is stored in the computer's memory. The operational phase is the production inspection of ICs and, also like lead inspection, consists of registration, measurement, and judgement.

After a video image is acquired, each digit must individually be located and identified. The positions of the digits in the image vary due to print registration drift, and due to the mechanical wanderings of units within the inspection station. Most of the meandering is in the lateral direction (the long axis), and somewhat less in the vertical axis and in rotation.

Individual fine registrations proved to be necessary for each character in the label. After one character's position is known, then the

expected positions of subsequent characters can be more accurately predicted. This prediction is usually accurate enough to constrain the search areas, but not enough to use as the fine registration position.

Once all the digits have been registered, a comparison with the prototype digits can be made. A map of differences between the digits and their prototypes is constructed. Most of the differences identified in the map can be attributed to video quantization effects, noise, and 'normal' variations in the printing process. But when a digit is significantly deformed, one or more "blobs" appear in this difference map, corresponding to the areas of insufficient or excess ink. In figure 5, nore that the blobs are highly spatially correlated and that their images contain significant energy at lower spatial frequencies. Typical noise, on the other hand, has low spatial correlation and very low spatial frequency energy.

To extract the digit deformation signal from the background noise, the difference map of each digit is treated by a nonlinear two-dimensional lowpass filter. The blob areas remaining are measured and a figure of merit representing digit deformation is computed. Figures exceeding a precomputed quality threshold are indications of an illegible digit. Every digit in the label is inspected in this way. A single failed digit is sufficient grounds to reject the entire label.

Figure 6 shows several units which were rejected by the label inspector. Most of the defects are easy to see, and others are more subtle. The top center unit, for example, was rejected because of a gap in the "zero" in the center of the label. This demonstrates the sensitivity of the inspector.

Conclusion

AutoVM, a machine which automatically and visually inspects integrated circuit packages, has been discussed. The machine incorporates two machine vision systems and a control computer.

Many problems arose during development, installation, and pilot operation which were impossible to forsee at the onset of the project. Two vital parts of making an effort such as this succeed are perseverance and a flexibility of approach. Especially valuable is the ability to rigorously question dearest held notions and the tenaciousness to follow the chosen path in the darkest hours. Only with these virtues can the onslaught of unforseen problems be survived.

Making AutoVM work was a task involving many people in Texas Instruments' Semiconductor Group, Process Automation Center, and Corporate Manufacturing Technology Center. I would like to thank Tony Adams, Joe Antao, Eldon Bennett, Pat Humm, Ward McClure, Sam Narasimhan, Mike Stachowicz, Yee Hsun U, Gary Wilson, and others too numerous to mention, for their support and contributions toward making AutoVM a practical success.

About the author:

Don holds a MS in electrical engineering from Southern Methodist Univ., Dallas, and a BS in computer and information science from Ohio State Univ, Columbus. He is a member of the MVA, the AVA, and a senior member of the IEEE. He has been known to play the electric guitar quite loudly.

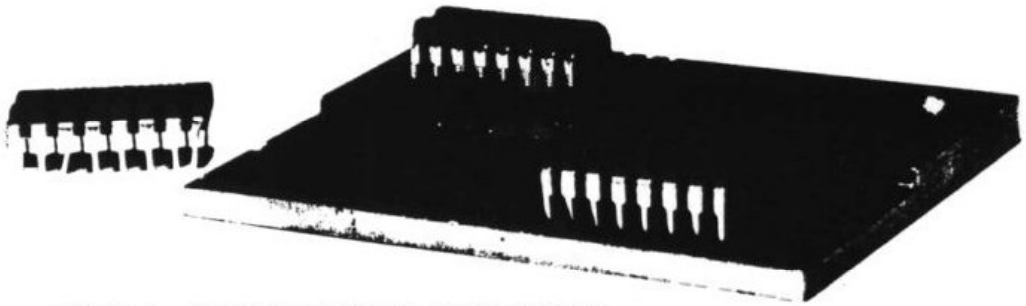

Figure 1. Integrated Circuits in DIP packages.

The metal gage block is used to measure lead straightness.

Figure 2. AutoVM Machine

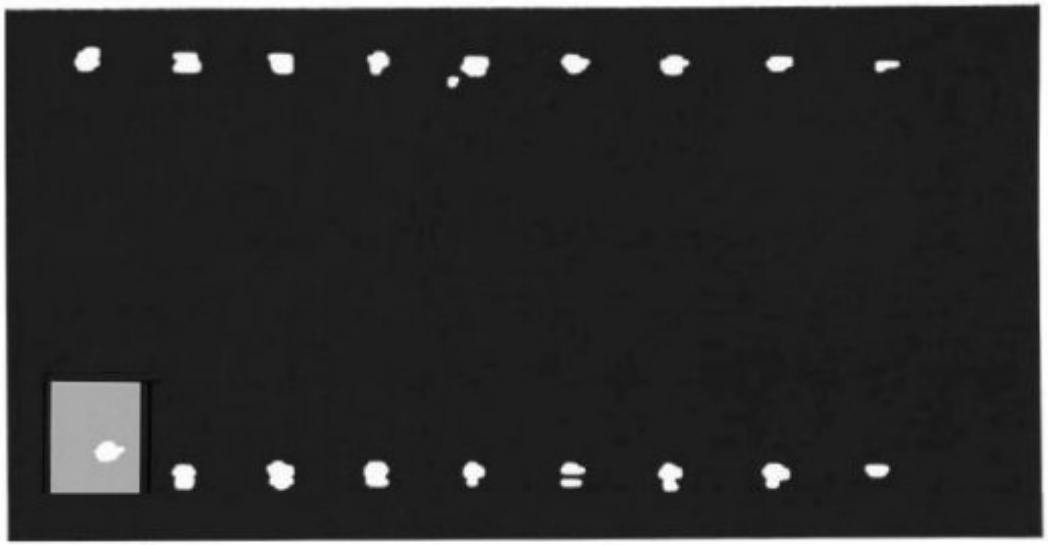

Figure 3. Lead Inspector View
The leftmost lower lead is flagged as "bent".

Figure 4. Label Inspector View

Figure 5. Label Difference Map
Mostly noise, but one blob indicates a legibility defect.

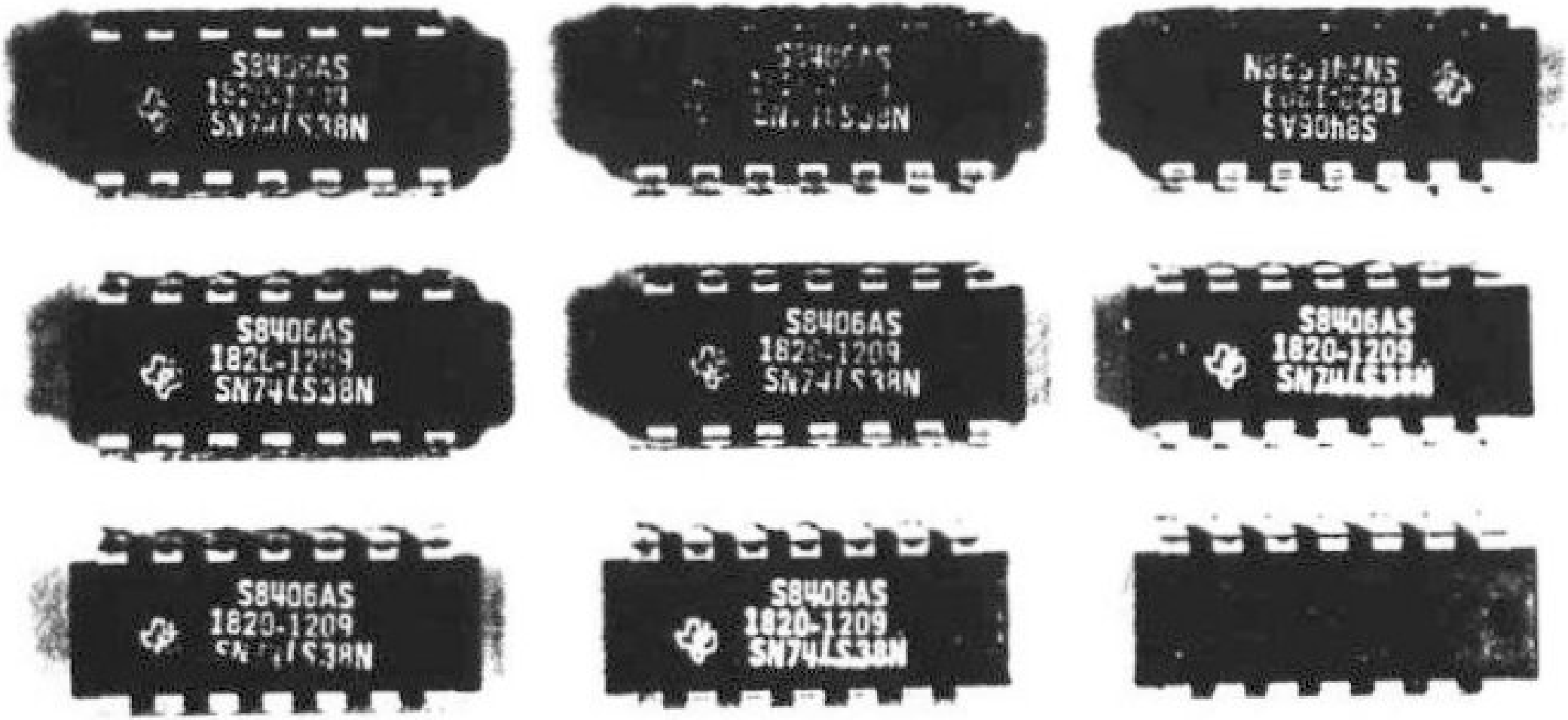

Figure 6. Label defects, sorted by AutoVM.
Some legibility problems are less obvious.