PRACTICAL ASPECTS OF REAL-TIME AUTOMATED SECURITY PRINTING INSPECTION

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Reducing theory to practice, the most important element in the application of advanced technologies, is not a reduction process at all.

Reducing theory to practice is, in fact, a process of expansion. It involves an expanded awareness of the real world environment in which an advanced technology system must operate. When viewed this way, a solution to a problem takes on an entirely new dimension.

The purpose of this paper, therefore, is to examine certain aspects of real-world security printing environments as compared to various techniques in advanced vision technologies. After completing this examination of commercial and process considerations, suitable technologies will be discussed.

To clarify the title of this paper:

- **"Practical Aspects"** implies reducing theory to practice, however applying advanced technologies is, in fact, an expansion process not a reduction practice.
  This expansion process into the real world quantitatively requires orders of magnitude more complex than theoretical domain and often, qualitatively adds new dimensions to the task.
- **"Real Time"** refers to on-line inspection of webs, sheets or notes at speeds of 400 to 800 feet per minute.
- **"Automated"** refers to the complete replacement of human inspectors. The practical aspects of automated

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inspection of security printing can be grouped into three categories:

1. Process considerations of the printing and converting process itself,
2. Commercial Considerations dealing with returns on investment,

and

3. the Suitable Advanced Technologies that are concentric to these other considerations.

As a first step in reviewing Process and Commercial Considerations, an examination must be made of a list of possible automated inspection objects categorized under two headings:

- Single Color Intaglio Inspection Objectives
  and
- Additional Inspection Objectives of Combined Intaglio and Offset Printed Documents.

In reviewing these lists, security printers must decide if any of these objectives could be deleted, should cost become a limiting factor. Another obvious questions is, "Has any key objective been omitted?"

Far less obvious is the question of degree. As we look at the various types of anomalies in Print Quality it is clear that all notes will have some kind of anomaly. Since printed notes can be both good and imperfect, certainly the "objectives lists" should not include shutting the operation down at the first sign of imperfection.

The issue of "Good but Different" is a central issue to this paper and to reducing theory to practice.

In examining these lists, called the "inspection objectives list", Security Printers should pick out the objectives they are most concerned with and make note of those particular objectives. From time to time, reference will be made to these objectives lists as the focus of real-time inspection systems and as the principle criteria for inspection system performance. Some of the items on the list would be:

SINGLE COLOR INTAGLIO INSPECTION OBJECTIVES

- Verification of denomination
- Verification of printing presence
- Verification of printing registration on each side and front-to-back
- Detection of excess ink caused by sly wipes, bleeding, etc.
- Detection of excessive "mashing" causing poor print quality
- Detection of insufficient ink darkness
- Detection of excessive "flaking" of ink
- Detection of creases in the paper
- Detection of sheet misorientation
- Detection of "set-off"
- Detection of multiple sheet feed

ADDITIONAL INSPECTION OBJECTIVES
FOR INTAGLIO AND OFFSET PRINTED DOCUMENTS

- Detection of simultan to simultan registration variances
- Detection of simultan to intaglio registration variances
- Detection of front intaglio to back intaglio misregister
- Detection of missing simultan ink
- Detection of faded simultan ink

PROCESS CONSIDERATIONS

Outlined below are several process considerations that impact the selection of suitable technology for security print inspection:

- Substrate Characteristics
  - Color Variation
  - Tightness
  - Security Features
- Offset/Litho or Gravure Ink Color Variation
- Registration on Press
  - Intaglio, front and back
  - Intaglio to simultan
  - Simultan to simultan
  - Flare variation
  - Bounce (sheet press)
- Sheet and Web Handling in Converting Operation
- Point of Inspection in Processes
  - On-press
  - Off-press
  - Single note Q.A.

SUBSTRATE CHARACTERISTICS

For the purposes of this paper, the color is measured in 256 grey level (black and white) shades as would be described in an 8-bit format. These shades are called Grey Scale Values (GSV).

GSV deals with reflected light intensity as opposed to color hues. Consequently, subtle shades of white can vary in intensity as much as differing pastel colors with the same reflected light brightness. Another consideration is that simultan type inks may vary in shade 10-20 GSV and that some shades are less than 10-20 GSV in color from the base sheet. These variances are all out of a possible 256 GSV.

The complexity of the problem comes into clear focus when one realizes that unprinted currency paper itself can vary up to 10-20 GSV in color. Add to this security features such as threads, fibers, watermarks, and planchettes and the problem becomes even more interesting.

Another substrate concern is associated with the tightness of the sheet, which is a function of furnish fiber length, formation and floculation size, and internal bond strength as measured by Burst and Mullen tests. This affects the degree of flare, complicating registration inspection objectives.

OFFSET/LITHO INK COLOR VARIATION

As previously mentioned, compounding the grey scale color issue is color variation in the ink itself. This color variation can also vary 5 - 20 GSV for each simultan color.

REGISTRATION

Registration verification on Giori presses must account for 1/4 mm to 1/2mm bounce effects, substrate flare caused by 70 to 80 ton hydraulic forces, as well as inherent causes of simultan to simultan registration variances and simultan to intaglio mis-register.

Since some slight misregister is not only acceptable, but impossible to totally eliminate -- particularly on the trailing end of sheets on sheet fed press -- suitable vision systems must have higher order image processing capabilities in order to avoid rejecting unilaterally any subtle deviation from perfect registration. This is referred to as the "good but different' problem that must be handled by the technologies selected for this application.

In the Technology section of this paper the bandwidth, or data processing throughput, required for these higher order image processing vision systems is discussed.

CONVERTING EFFECTS

Note that sheet (both full and half sheet) and web handling characteristics are concerned with stretch, flare, rotation, web speed variations and flutter (depth of field) variations. These variations at speeds of tens of thousands of impressions per hour create a special burden on inspection systems since good notes can be in- correctly interpreted at reject unless the inspection system can account for these subtle handling influences.

High speed TTL logic hardware that has been developed by Integrated Automation for other applications to handle these kinds of influences in real-time will be discussed briefly in the Technology section of this paper.

POINT OF INSPECTION IN OPERATIONS

There are a number of locations in their operations that Security Printers have selected to conduct automated inspection.

Often the point of inspection is tied to the inspection objectives.

- Inspecting on (a Giori) press will maximize spoilage reduction and could lead eventually to closed-loop control of the press.
- Inspecting both sides of a sheet simultaneously off-press on a mechanical trimming or sorting system affords economies in capital and space utilization. Such a system is close enough to the press to provide timely feedback to the press operations.
- Inspection of single bills before or after numbering operations such as currency overprint equipment (COPE) provides maximum quality assurance, including the opportunity for detection of defects caused by handling, including OCR based inspection, and other functional types of verification

Inspection system architectures must provide the flexibility to adapt to the various functional objectives of inspecting in different point in Security Printing operations.

TECHNOLOGY SECTION

NOTE: Certain proprietary information has been omitted for this paper which is intended for general distribution.

Specific questions may be forwarded to:

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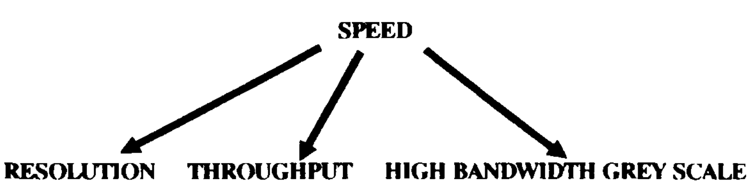
In considering images created by computer driven algorithms detecting intaglio and simultan print defects it must be remembered that it takes 10 to 15 minutes for the computer to capture and image process a result. In the real-time world of security printing 10 to 15 minute processes are not acceptable. Millisecond processes are acceptable. Acceptable processing times are from ten to one hundred milliseconds per note depending on web or sheet speeds, web or sheet widths, the number of notes across the web, and the resolution of the vision system inspecting the notes. All other technical issues are a subset of speed. Speed is the central issue in addressing suitable technologies.

KEY TECHNICAL ISSUES



Speed is measured in dimensions of **bandwidth.** Bandwidth of imaging systems such as Artificial vision examination of printing in real-time should not be confused with the bandwidth associated with radio transmission frequency.

Bandwidths are a measure of data transmission rates in image processing sys- tems. Bandwidths are usually expressed in terms of millions of picture elements (megapixels) per second (MPPS).

Bandwidths of the necessary magnitude to replace human inspectors in actualizing the objectives outlined in the objectives list exist today in both printed circuit boards, inspection systems, and in the semiconductor industry.

By utilizing this high bandwidth TTL hardware incorporating highly pipelined parallel morphology, it is possible to achieve the security printing automated inspection objectives as described in the objectives lists.

TYPES OF FLAWS

For the purpose of this paper, defects have been classified into four categories. They are:

- Gross/Critical
- Major
- Minor
- Fine

The classifications are intended to rate visual offensiveness. Obviously, the location of the anomaly on a note face greatly influences this "rating". A small defect on the vignette of a note face or one affecting the type text is more sensitive and offensive than a larger defect in a less sensitive area.

COMPUTER VISION, MACHINE VISION AND ARTIFICIAL VISION

Some examples of high bandwidth image processing visions systems follow. The term image processing is used in this context to mean analyzing the images that have been collected by upstream image capture hardware.

Bare Printed Circuit Boards (PCBs) and populated PCBs require similar bandwidths as security printing to inspect. The computer driven algorithms to detect 250 surface mounted devices (SMDs), resistors and capacitors on a particular board took about 17 minutes to process by computer. However, by dropping these computer-driven algorithms into TTL hardware, the inspection time was reduced from 17 minutes to 2.4 seconds, thereby enabling the vision system to work on-line in a high-speed automated PCB component placement operation.

Inspecting semiconductor wafers and dies requires similar bandwidths. The pixel size in these cases may be as small as 1/2 micron by 1/2 micron or roughly the wavelength of light. This diffraction limit image capture application, along with the bare and populated PCB applications use template matching on golden image comparison approaches.

For purposes of this paper, the computer driven vision algorithms are referred to as "computer vision", the TTL hardware equivalent of the computer vision algorithms as "machine vision" and higher order image processing, which is designed to replace human inspectors as "Artificial vision".

SUITABLE TECHNOLOGIES

For better understanding of this paper, the following definitions are presented:

Escape Rates:	Represent the percent of documents that leaves your operations as undetected off-quality notes or potential collector's items.
Over-Kill Rates:	Represent the percent of good notes that are considered defective by an inspection system.
Bandwidth:	A measure of performance of vision systems that quantifies the rates of data transmission. Band- width is to artificial vision systems as horsepower is to automobiles.

In the case of 2-D template matching systems, acceptable rates in the overkill have always been the most difficult to achieve because of the vary high bandwidth requirements. The 2-D template matching technique will be compared to another 2-D image processing technique: object tracking.

2-D template matching is a vision technique used for high bandwidth applications involving printing of all kinds:

- Printed Circuit Boards
- Some forms of OCR
- The semiconductor industry's photo-lithography process

This vision technique is sometimes called Golden Image Comparison. It utilizes very elegant subtraction-type processes which lend themselves well to print inspection applications. This technique, however, is vulnerable to "good but different" overkill problems. In order to alleviate the "good but different" overkill condition, the same pixel captured in the image capture hardware must often be processed up to 8 to 20 times in the image processing hardware.

This image processing bandwidth requirement is referred to as higher-order image processing or, in some cases, second-level image processing.

Another 2-D approach to machine vision is object tracking. Object tracking is par- ticularly useful when there is no well-defined "template" or golden image to reference. Some examples of these systems are:

- Papermaking (unprinted substrates)
- Steel and Aluminum rolling mills
- Nonwoven material medical gowns
and
- Disposable sanitary products (as an example of object racking in an "almost" artificial vision application)

In the case of two piece high speed aluminum can manufacturing 10 cans per second (36,000 per hour), flaws in the base metal will cause catastrophic jams in the can forming machinery. An object tracking system (OTS) is used to inspect the aluminum and prevent defective materials from being sent to the can making and filling operations.

The block diagram on the following page shows the environment in which the OTS is used. Ingots are formed under the "Hall" process utilizing a cryolite solution. The ingots are then heat treated and rolled in hot and cold rolling mills and finally slit into coils which are shipped to the can making equipment.

The OTS is employed throughout the decating process and is required to detect and classify objects as small as 0.005 inch (less than .3mm) on aluminum webs moving at over 5,000 feet per minute (1,700 m/min).

The OTS uses both lasers and LCCD array cameras in an architecture that allows for not only detection but classification of anomalies in the aluminum surface at a rate of over 200,000 objects per second.

The principle of OTS is shown here, given an object in the field of view (dark field illumination for LCCD, and light field illumination with laser). An object description is pieced together with information gained from repeating scans from the LCCD or laser.

2-D information -- such as length of the object, width of the object, area of the object, areas of the web affected by the object, and grey scale, color or intensity levels -- can be determined for each object.

This diagram shows how information is tracked in the OTS. Subtle differences between, say, water spots and oil spots can be detected and anomalies classified so that proper remedial action, if any is required, can be taken.

Anomalies, such as coolant marks, scratches and burnish marks, have their own descriptions based on their geometry and intensity. With the capabilities of classifying hundreds of thousands of object segments per second, OTS is useful in a variety of applications.

Similar OTS systems are in use in papermaking and non-woven manufacturing plants and in the rubber and tire industry.

With additional higher order processing, an OTS is being used for real-time monitoring of the quality of disposable sanitary products. The contents of this project may not be discussed due the client's proprietary technology.

RELATIVE BANDWIDTHS

After comparing relative bandwidths of these two 2-D techniques, we can see the substantial demands on high bandwidth for template machine of required escape and overkill rates vs. object tracking or other 2-D image processing techniques.

Bandwidth represents the single most difficult criteria to overcome in advanced ar- tificial vision technologies. It equates to horsepower in internal combustion driven machines and to pressure per square inch in hydraulic systems.

As shown previously, image processing bandwidths for the inspection techniques of choice could range between 1/2M Pixel/Sec for limited gross flaw detection up to 200M pixels/sec to detect major, minor and fine flaws.

Some questions come to mind:

- What are the cost ramifications?
- What will the payback be for unit costs and development costs?
- What are the tradeoffs, if any, in performance for various system architectures?

In most continuous process Artificial vision systems application paybacks are less than 18 months, in many cases less than 12 months. Is it true in the case of security printing inspection? . . . Maybe.

The graph on the following page, which is strictly a marketing tool, and not a technical tool, shows development costs as compared to resolution. Bandwidth is roughly proportioned to the square of resolution, which tends to be directly proportional to development costs. From this graph, we can see the effect of the availability of off-the-shelf hardware in mitigating development costs for major and gross error detection systems and conversely the impact of higher level image processing bandwidth requirements on very fine flaw detection. When factoring the labor savings of replacing human inspections; when incorporating the requirement of small defect detection in sensitive areas of print and when utilizing as much existing advanced technology as possible, Integrated Automation believes Security Printers' development cost benefit analysis will favor a resolution that will detect almost all minor flaws and many fine flaws.

An important reasons for this is the favorable effect of resolution on unit cost. The graph on unit costs, drawn before a recent breakthrough in our labs in Alameda, is actually too steep. It now appears that the additional incremental unit cost for more resolution compared to anticipated benefits is most interesting in terms of cost effectiveness.

Some commercial considerations include:

- Cost/Benefit
  - Unit Costs
  - Development Costs
  - 1-D versus 2-D approach
- Visual Effect of Defects
  - Text
  - Vignette
  - Functional impact
- Spoilage and Labor Savings
- Product Consistency
- Programmability
  - Re-mastering
  - Change over time
  - Yield versus quality levels

Other commercial considerations involve the ease of reprogramming the automated inspection system to account for:

- Different desired quality levels
- Yield considerations during times of chronic problems
- In the case of low volume runs, change over time
- In case of design changes in currency, re-mastering time

SUMMARY

We have attempted to outline some of the practical considerations that complicate security printing inspection and that challenge those who endeavor to actualize this exciting technology.

We have discussed process variables that result in making good notes look dif- ferent from golden images of master references.

We have also touched on the technical requirements to prevent these "good-but- different" notes from mistakenly being called defective by an artificial vision system.

In this paper we have also reviewed a description of possible inspection objectives and categorized some of the visual effects (offensiveness) of the associate defect of flaws. We used the terms "gross, major, minor and fine".

In conclusion we can say quantitatively that some "major", most "minor", and certainly nearly all "fine" level flaws will require a template matching approach with image processing bandwidth in the 200s of Megapixel/second range.

In a qualitative sense, it is clear that the real-time inspection of security printing on a level that can replace human inspectors is an attainable if non-trivial goal.

We believe the challenging obstacles and problems encountered in implementing artificial vision in real-world security printing operations are solvable, both in theory and in practice. Integrated Automation expects to be able to produce a prototype inspection system:

- Capable of replacing human inspectors,
- Capable of detecting all the vision related defects referred to in the objectives lists.
- For installation in a real-time sheet, web or note processing operations at speeds of 400-800 feet per minute.
- Within a 12 to 16 month timetable.