Machine-Vision-Based Analytical Tools for Digital Fabrication

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Abstract

Machine vision systems have long played an integral part of the inspection and verification processes in the development and production of fabrication systems as well as the parts themselves. As part and component manufacturers have moved to embrace digital fabrication methods as well as hybrid systems including both new and traditional processes, the use of these systems has been gaining in popularity to enable objective measurement of materials as well as the final output. Machine vision based inspection tools aid in the optimization of materials, fabrication processes, and system design.

This paper will provide an overview of several machine vision based systems useful for digitally fabricated part inspection as well as process inspection tools.

Introduction

Machine vision based systems have been in use for many years for traditional print quality inspection. They have been used to assess parts used in printing system (such as nozzle plates), material interactions (such as paper and ink), and to verify printer performance and process control through print quality analysis in R&D and production. It is a natural progression to use these systems for analysis of objects such as printed electronics and other parts. And, as new materials and processes are used for digital fabrication, assessing the fabrication system performance may be of use as well.

Systems can be used for a wide variety of inspection tasks such as feature measurement (existence, shape, size, raggedness), dimension, and registration between layers. Interested markets include rapid prototyping, biotechnology and printed electronics.

This paper will focus on three system configurations:

- Flat-bed scanner-based system works with a variety of materials and can operate in both transmission and reflection modes.
- Camera-based full motion system for non-contact automated 2-D and 3-D analysis. This system supports multiple cameras and camera formats, as well as additional instrumentation such as a laser module for 3-D.
- And JetXpert, which is a specialized system designed for analysis of drops in flight. JetXpert can be used with any frequency-based jetting and deposition system where individual drops are ejected or dispensed singularly or in series.

Part Inspection Tools

Scanner-based inspection tool

Flatbed scanners have been used for a long time for traditional print quality analysis[1,2,3]. As a low cost, flexible image analysis system, it offers many benefits to digital fabricators who are using many different materials and processes.

Flexibility comes from user selectable scanning resolution up to 2400 dpi optical resolution (10.6 microns per pixel), color or gray scans and reflection and transmission modes. Since many parts are made in sheets of multiple units, the large format of the scanner is useful in accommodating samples up to A3+ size (12.8" x 18").

The scanner system allows imaging and measurement of plates, and parts of many different materials. Translucent and opaque, color or monochrome- the scan options allow the system to be set up to capture the best possible images of the parts or materials under inspection. Once the images are captured, ImageXpert software is used for image analysis. Figures 1a and 1b show a digitally exposed flexo plate and subsequent flexo print under inspection.

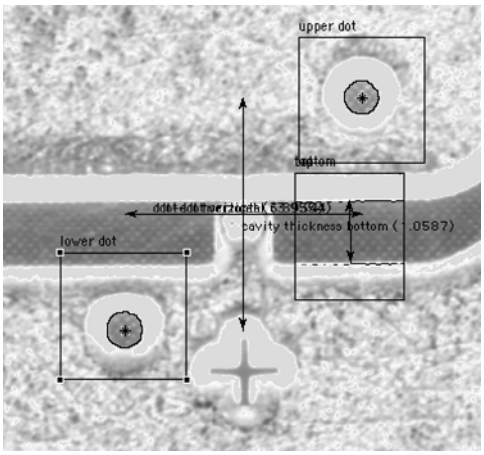

***Figure 1a**. Flexo plate inspection (transmission, color scan, showing red channel only)*

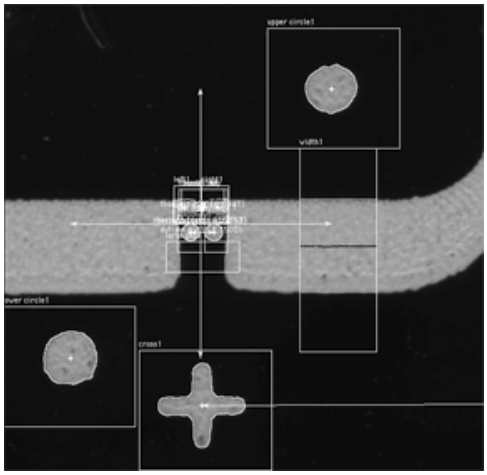

***Figure 1b**. Flexo print inspection (reflection, gray scan)*

Figures 2a and 2b show a translucent polyester substrate printed with conductive ink imaged in two ways: reflection and transmission. Notice the difference in the features that are highlighted using each of these modalities.

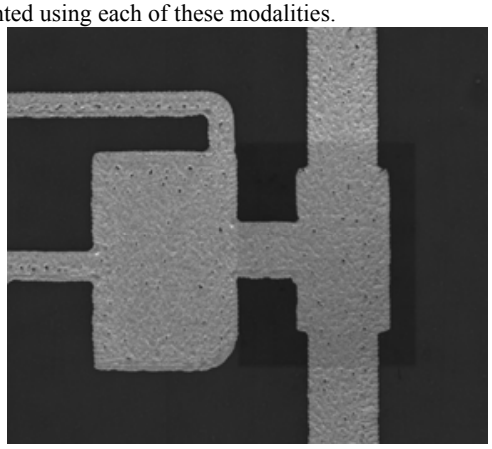

***Figure 2a**. Translucent polyester substrate, conductive ink: Scanned in reflection mode*

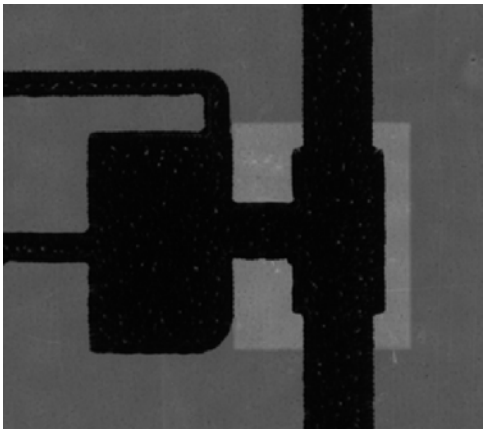

***Figure 2b**. Translucent polyester substrate, conductive ink: Scanned in transmission mode*

Since the scanner can also scan in color (not just black and white) this can be useful for increasing or decreasing the contrast of a particular part or feature as shown in Figures 3a and 3b.

***Figure 3a**. Translucent substrate, conductive ink: Scanned in transmission mode in color, shown in full-color.*

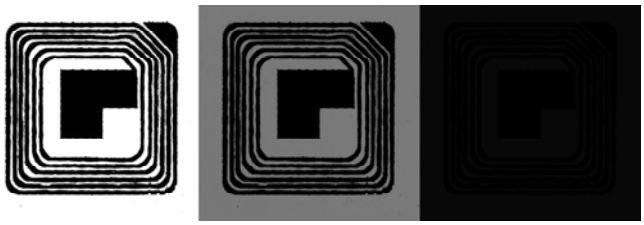

***Figure 3b**. Translucent substrate, conductive ink: Scanned in transmission mode in color with the three channels shown separately: R,G,B left to right.*

By using an appropriate color channel, defects and features can be more easily measured.

For all of the flexibility scanner systems offer, the main drawback of scanner-based systems is that they are not non-contact. The sample is placed on the platen for scanning, and most often, the printed side is face down, and therefore is in contact with the glass platen. For wet samples or for samples where contact is not desired or possible, camera based systems may be more appropriate.

Camera-based inspection tools

Camera-based systems have been a staple in machine vision systems since their inception. They have long history of use in both print and part inspection.[4,5,6] Camera-based machine-vision systems can have many different configurations based on the requirements of a specific application. In the most general terms, a camera system includes a camera, appropriate lens system and lighting, and software for image analysis.

Camera based systems can be interactive or automated. A full motion system allows for fully automated 2-D and 3-D analysis by combining cameras for 2-D image capture and analysis, and a laser module for height measurement. Automated systems are ideal for larger volumes and can be useful in both R&D and production environments.

These systems can support multiple cameras on the same system allowing for multiple resolutions for image capture and different imaging modalities. Cameras can include black and white, color (either lower cost single array matrix CCD, or 3-CCD cameas that offer full CCD arrays for each color plane), large format black and white (2048 x 2048), line scan cameras and cameras with different spectral sensitivities such as IR cameras.

In addition to the cameras, fully integrated instrumentation can be added such as a laser for height measurement

For full automation, there is I/O for integration into production lines.

Here is an example of 2-D inspection showing bidirectional errors imaged with a camera-based system (Figure 4).

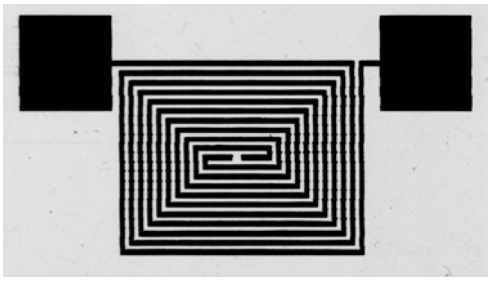

***Figure 4**. Bidirectional errors in ink-jet printed target imaged by camera system*

Here is an example of 3-D inspection showing the laser for ink profiles and ink volume measurement, (Figure 5a, 5b).

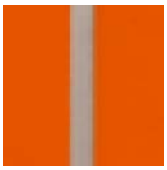

***Figure 5a**. Translucent substrate, conductive ink: scanned with laser system for ink volume calculation.*

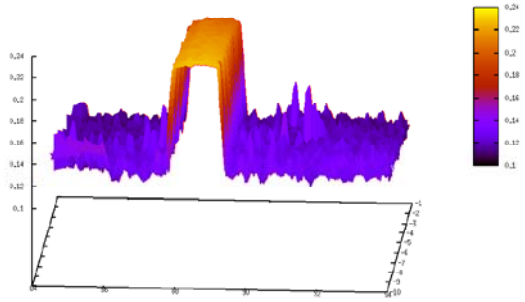

***Figure 5b**. Plot of height profiles from which the volume measurement was calculated. Ink volume was calculated to be: 0.808 microliter/ 5mm length*

Process Inspection Tools

JetXpert system for analysis of drops-in-flight

JetXpert provides a flexible platform for analyzing print head performance through drop-in-flight visualization and analysis for any frequency based deposition system using discrete droplets such as ink jet.

JetXpert combines state-of-the-art strobing technology with powerful ImageXpert software and hardware. A conceptual drawing of the system is shown in Figure 1a.

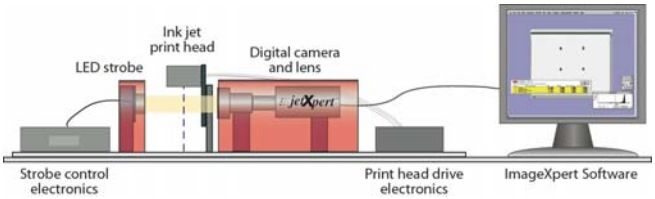

***Figure 6a**. JetXpert system diagram: Strobe, strobe control box, digital camera and lens system, strobe control software and image analysis software*

The system can be used with any print head or frequency based dispensing system since the strobe is synchronized with the firing frequency of the print head or dispensing system (or an external frequency generator).

The strobe can be set up to fire once per frame, enabling imaging of single droplets. This method of image capture minimizes the blur that can be caused by multiple droplet aggregation from multiple strobes (and, therefore, images) per camera frame. Image aggregation is a commonly used imaging method for imaging drops in flight with lower-powered strobes, since multiple strobe events are needed to build sufficient image contrast for measurement. By using a high-powered LED, only one single strobe is needed for image capture suitable for analysis.

Once images are captured, ImageXpert image analysis software is used to perform analysis of the droplets such as velocity, trajectory and volume.

Hardware

The hardware consists of a black and white firewire camera and a special lens system. The illumination source is a custom, high-powered LED strobe that is controlled by proprietary electronics. An image of the image capture hardware is shown in Figure 1b.

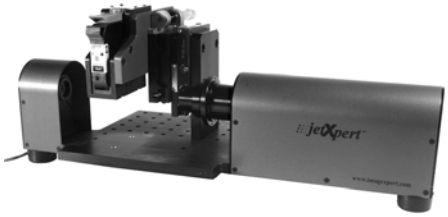

***Figure 6b**. JetXpert system image (showing a HP45 head mounted between the camera and the LED strobe)*

The print head or dispensing head is positioned such that it fires between the camera and strobe so the images of the droplets can be captured in silhouette.

Software

The image analysis package used in the JetXpert system is ImageXpert software. Droplets are identified via a threshold-based algorithm (with dynamic threshold adjustment). Drop velocity, volume and trajectory are calculated (Figure 7).

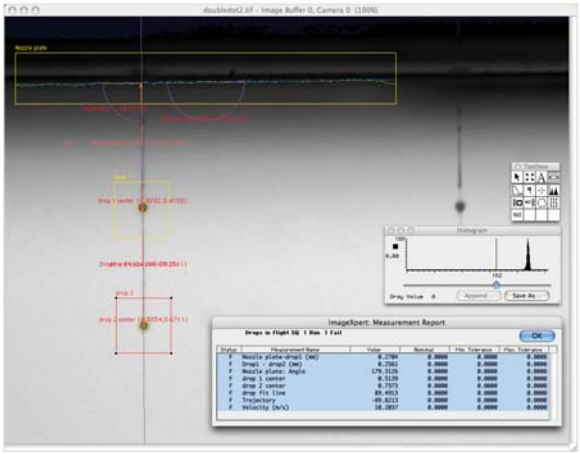

***Figure 7**. Example of JetXpert image with analysis (Kodak print head).*

Conclusion

Machine vision based systems offer a wide range of benefits to the digital fabrication market. By applying proven technology for process and part inspection, system designers, materials developers and part fabricators can use these systems to assess the quality of their materials, processes and parts. Inspection in R&D can inform design choices, material formulation, selection and system optimization. Once in production, upstream inspection can save time and costs by providing timely information about process quality or control. While part inspection allows for quality control at end of line.

References

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[6] Y. Kipman et al., Robust line scan camera-based inspection system for ink-jet nozzle plates, Proc. SPIE Vol. 4301, pg. 1. (2001)

Author Biography

Mr. Kipman is the president of ImageXpert Inc., the industry leader in automated machine vision systems for print and process analysis and part inspection. Mr. Kipman founded ImageXpert in 1989. ImageXpert offers a diversified product line that addresses the needs of a wide range of markets including digital printing and related fields. Mr. Kipman holds a M.S. in mechanical engineering, with a major in electro-optics from the University of Connecticut and a B.S. from the Technion Institute of Technology.