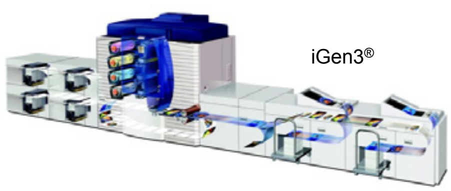
Digital Printing Control: Print Shop in a Box


DocuColor® 8002


iGen4®


iGen4® 220 Perfecting Press


iGen3®


Xerox® Color 800/1000


ColorQube™


Xerox® Color 560/570

The digital print process is remarkably challenging because it involves many process and digital actuators for applying a range of advanced control techniques. Many of the new challenges listed here opened the door for the insertion of new control theory. Numerous Xerox® printing systems (for example, iGen3®, iGen4®, DocuColor® 7002, DocuColor® 8002, DocuColor® 5000, DocuColor® 8000, iGen4® 220 Perfecting Press, Xerox® Color 800/1000 Presses, ColorQube™) produce high-quality prints using these control innovations to generate several billion dollars in annual revenue.

Control Challenges for Digital Printing

- Optimize job workflows via feedback from the press (streamline workflow and free operators to focus on running the print jobs)
- Increase productivity with automated color management tools
- Provide consistent color image quality (first page, between pages, job to job, operator to operator, machine to machine)
- Provide offset look and feel with the best image quality, no nonuniformity, and no defects
- Provide automated calibration (completely hands-free), spot color (Pantone® matching), and color management profiling for more stable color
- Allow mix-and-match of press configurations (any application to any printer, finisher, and feeder on any marking engine)
- Manage time-sensitive activities of various machine modules
- Adjust color dynamically using internal process control feedback loops
- Provide active control of registration of all color separations
- Compensate for sheet-to-sheet differences in the paper as well as drive system wear, temperature variations, and the like

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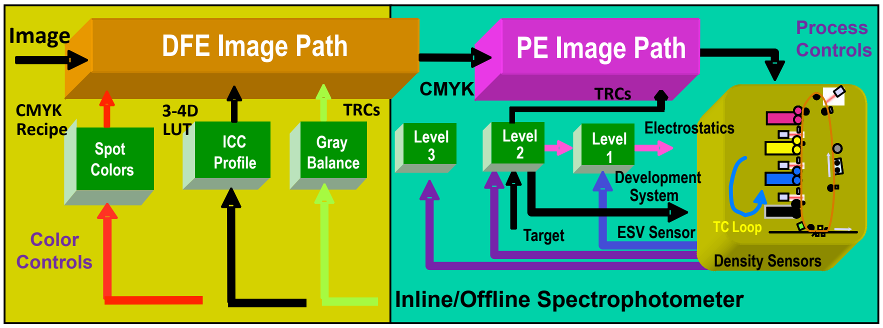
From: *The Impact of Control Technology*, 2nd ed., T. Samad and A.M. Annaswamy (eds.), 2014. Available at www.ieeecss.org.

Digital printing today is a complex, high-technology process requiring advanced sensors and actuators and state-of-the-art control algorithms. Processing of images occurs at multiple levels within and outside a hierarchical printing and publishing system. Time-based separation is adopted at each level, with higher-level functions (spot colors, ICC profiles, gray balance) occurring at a slower time scale in the digital front end (DFE) and faster real-time control functions (Levels 1, 2, and 3) typically occurring in the print engine (PE).



Control system architecture for digital printing (LUT: look-up table; ICC: International Color Consortium; TRC: tone reproduction curve; ESV: electrostatic voltmeter; TC: toner concentration; CMYK, cyan, magenta, yellow, black colors)

Inventions and Innovations

Xerox's new printing systems are tours de force for control technology! Highlights include:

- A hierarchical automation architecture distinguishes between different color control horizon levels.
- The control design includes classical single-input, single-output (SISO) PID-type controllers, with delay and anti-windup compensation, for several subsystems.
- Toner concentration control, although a SISO system, is especially challenging. The solution integrates a Kalman filter to handle noisy and unreliable measurements, a Smith predictor to handle the delay, and an anti-windup compensator for constraint management.
- Several multivariable controllers are also part of the design. These include state feedback, pole placement, model predictive control, and linear quadratic regulator designs. Systems under multivariable control include electrostatic control, spot color calibration, and color management profiling (ICC profile).
- A learning algorithm is incorporated for paper registration control.
- Singular value decomposition is used for dimensionality reduction to reduce gray-level samples while constructing spatial toner reproduction curves or functions on photoconductors.
- Ideas from cooperative control theory and simultaneous perturbation stochastic approximation have been used for gray-component replacement in the color management profiling (ICC profile) system.
- K-means clustering for spectral reconstruction in real time allows the use of a low-cost LED-based spectrophotometer.
- For complex printing jobs, scheduling of paper sheets is a difficult operation; constraint-based scheduling algorithms are used to solve it.
- Motion and unevenness in motion can induce disturbances in the printing process. Repetitive control and adaptive feedforward control algorithms help mitigate the effects of these disturbances.
- The printers integrate diagnostic and self-monitoring features using statistical process control, among other methods.
- A set of objectives customers may be interested in is taken into account (e.g., smoothness, spectral matching, and color difference) and the concept of Pareto front is used to provide optimal solutions to accommodate a wide variety of user preferences for spot color rendering.
- Constrained multi-objective optimization is used to optimize image quality criteria, noise mottle frequency, and smoothness during multidimensional image profile construction. Constraints are imposed in terms of color accuracy and spectral response to achieve robust color match under various illuminants.
- The process is fully automated to optimize Black point compensation (BPC) parameters (inputs), including a virtual sensor that estimates the effect of the parameters on three image metrics (outputs): shadow details, highlight details, and color attributes present in images. A model is developed using input/output data, and parameters for BPC are estimated with multi-objective optimization while constructing ICC profiles.

For more information: L.K. Mestha and S.A. Dianat, Control of Color Imaging Systems, CRC Press, May 2009; L.K. Mestha and A.E. Gil, Color controls — An advanced feedback system, in The Control Handbook, Second Edition, CRC Press, 2010.