NSF GOALI Projects with Academia and Xerox Corporation

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Lalit K. Mestha, PhD
Principal Scientist and Project Leader
Xerox Research Center, Webster
800 Philips Rd
Webster, NY 14450

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Xerox…helping our customers do great work!

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HALOID XEROX

XEROX CORPORATION

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THE DOCUMENT COMPANY
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THE DOCUMENT COMPANY
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Xerox Innovation Heritage

5,000 world-class scientists & engineers

Fuji-Xerox partnership

$1.4B R&D/year

Breakthrough research

- 50,000 global patents
- A top US innovator:
  2 patents/day

US National Medal of Technology

IEEE Corporate Innovation Award

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Xerox Research Worldwide

Xerox Research Centre of Canada
Mississauga, Ontario, Canada

Xerox Research Centre Europe
Grenoble, France

Fuji Xerox
Japan

Palo Alto Research Center
California, USA

Xerox Research Center Webster
New York, USA

...leveraging top talent globally

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Open Innovation

“Not all the smart people work for you, so you better go find them, connect to them, and build upon what they can do.“

Henry Chesbrough

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iGen3™ 110 Digital Production Press

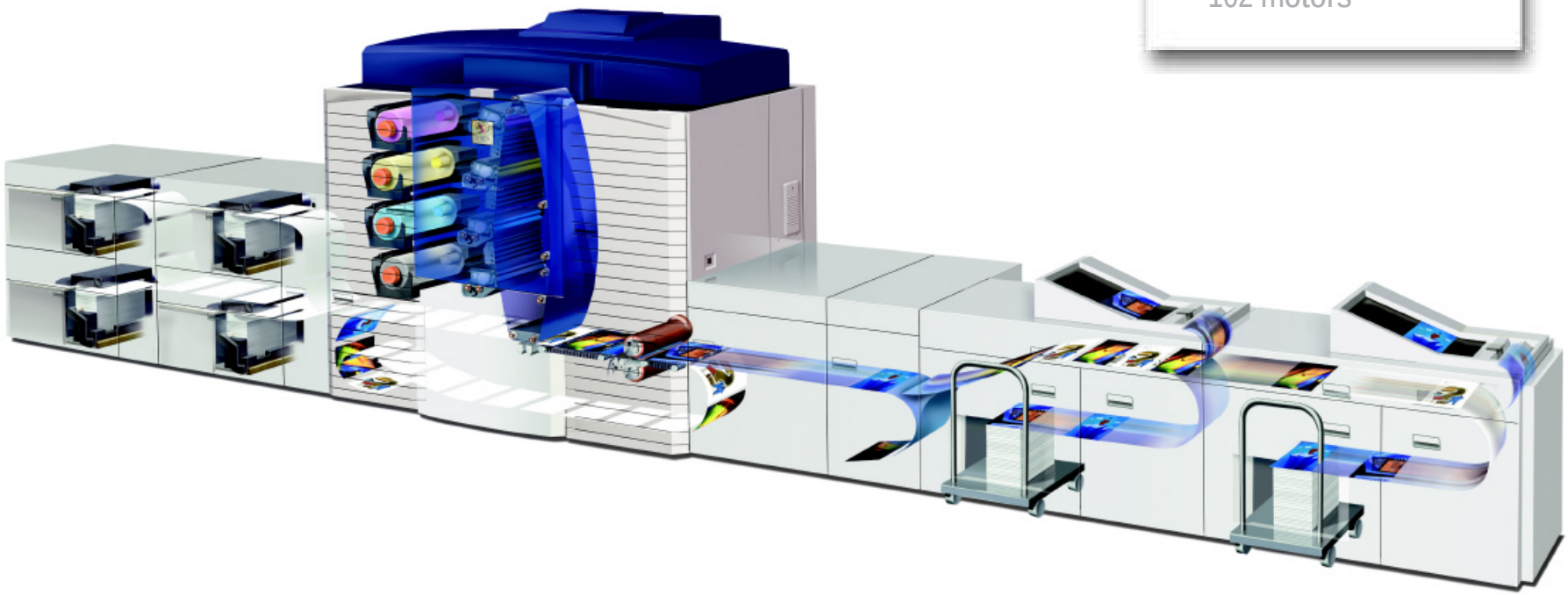
Berkeley

University of Michigan

National Science Foundation
WHERE DISCOVERIES BEGIN

R&D: $1B/400 Patents

- 85 computers
- 5 M lines of software
- 192 sensors
- 102 motors



…creating new markets

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iGen3™ 110 Digital Production Press

Berkeley

University of Michigan

National Science Foundation
WHERE DISCOVERIES BEGIN

- **Xerox demonstrated a concept press – the Xerox ConceptColor 220 with Tightly Integrated Serial Printing (TISP) architecture at Drupa 2008 Trade Show.**

…creating new markets

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Control Challenges for Production Printing

- **Consistent Color**
  - First page, between page, across jobs, between machines
- **Offset Look and Feel**
  - Best Image Quality with no non-uniformity and defects
- **Lower Cost at Shorter Run Lengths**
  - Optimal paper path controls
  - Quicker Setups
- **Lower Cost by Producing Finished Documents**
  - Numerous Feeding / Finishing Options, Flexible Scheduling
- **Lower Cost for Lean Document Production in print shops**

Challenges are for handling variety of media & variety of print requirements across single/multiple printers and multiple technologies

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Successful Collaborations since 1996

NSF GOALI

- University of Michigan; July 1996-June 2001
- University of California, Berkeley; 1996-2001,2002-2006
- Purdue University & University of Minnesota; 2002-2005

UAC (Xerox Foundation Grants)

- Purdue University; 2001-2003, 2002-2004
- University of Minnesota; 2004-2006
- Rochester Institute of Technology; 2003-2005
- University of Illinois at Urbana-Champaign; 2005-2008
- University of California, Berkeley; 2005-2008

NY CAT/CEIS Grants

- Purdue University; 2001-2003, 2002-2004
- University of Minnesota; 2004-2006
- Rochester Institute of Technology; 2003-2009

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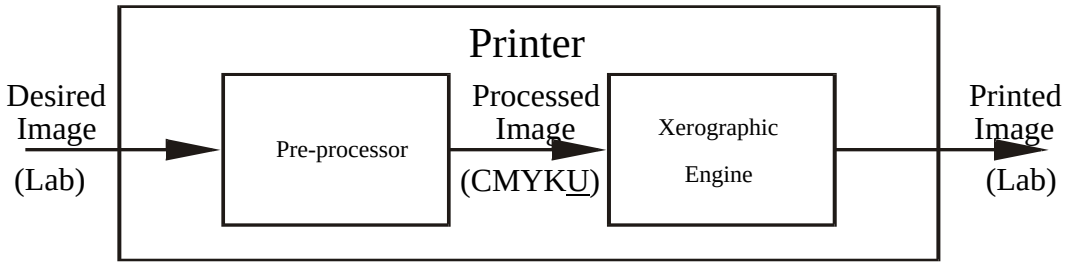
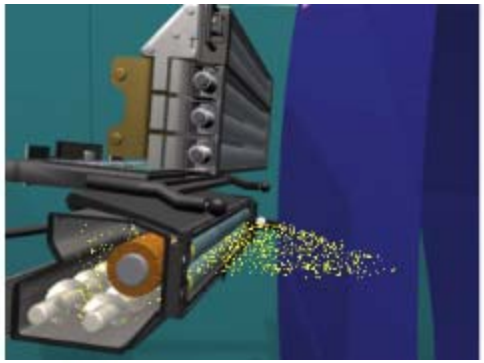
Modeling, Sensing and Algorithm Design for Color Xerographic Process Control

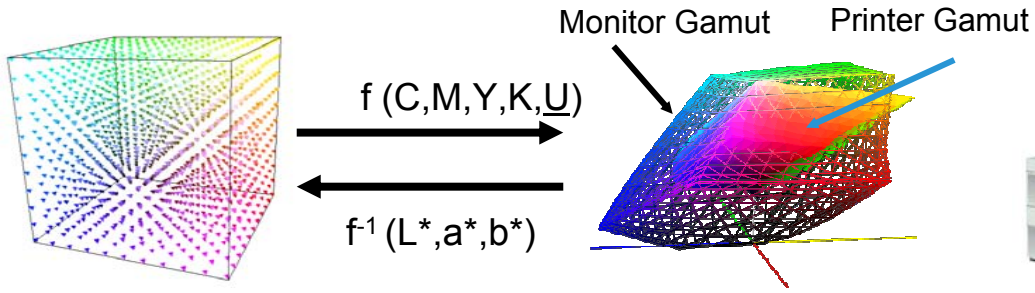
Richard E. Groff (UMich, UC Berkeley), Lalit K. Mestha (Xerox), Tracy E. Thieret (Xerox), Pramod P. Khargonekar (UMich, UF), and Daniel E. Koditschek (UMich, UPenn)

Objectives: **Develop Sensing & Control Algorithms for Color Xerographic Process**

Duration: **Since July 1996 – June 2001**

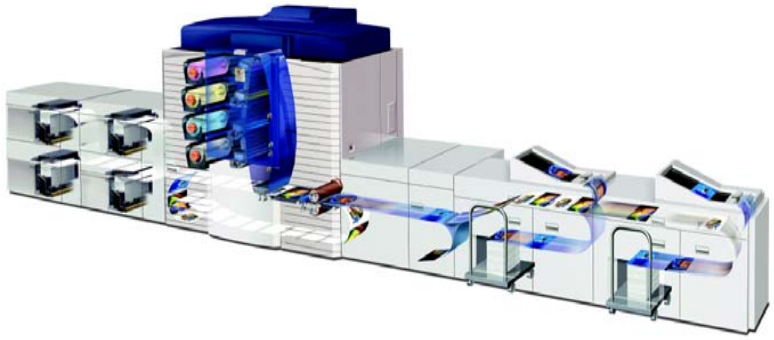






Domain CMYK Space
Device Dependent Specification

Co-Domain L*a*b* space
Device Independent Specification



Key Output: Produced 4 patents, 5 papers, Design strategies, 1PhD and 3 New PhD hires

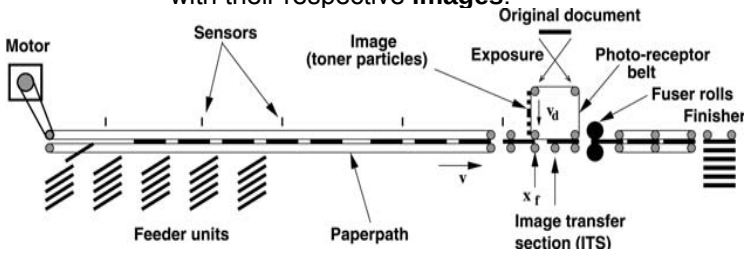
Printer Paper Path Control

Carlo Cloet (UC Berkeley), Martin Krucinski (UC Berkeley), Sudhendu Rai and D. Kamprath (Xerox), Perry Li (Univ. Minnesota), M. Tomizuka(UC Berkeley), and R. Horowitz (UC Berkeley)

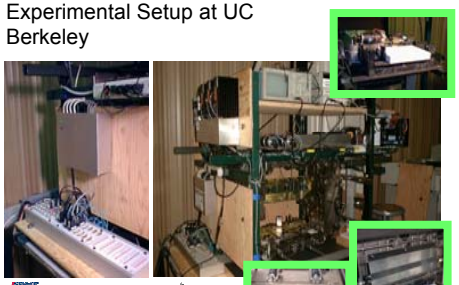
Objectives: **Improve media handling robustness by introducing closed loop sheet control and re-designing paper path drive and sensing architecture.**

Duration: **July 1996 – June 2001**

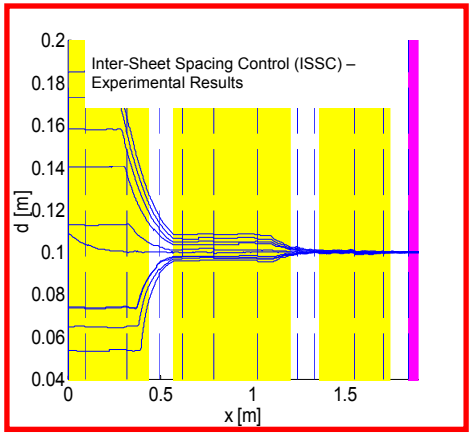
System under control is a **printer paperpath**: must control **sheets** to synchronize with their respective **images**.



Experimental Setup at UC Berkeley

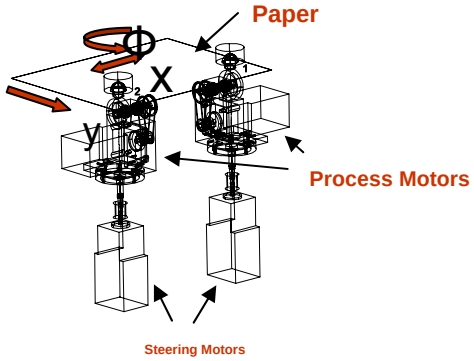


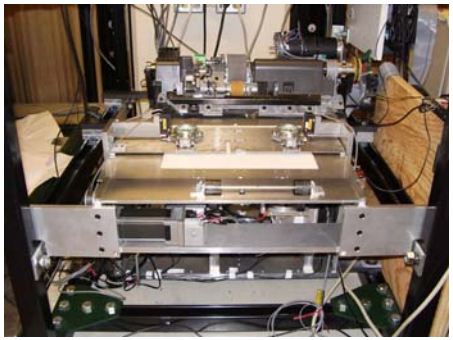
DS1103PPC DSP board (333 MHz PowerPC)



Printer Sheet Registration Control

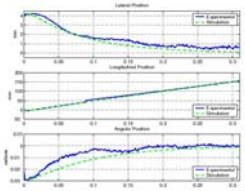
Rene Sanchez (Xerox / UC Berkeley), Edgar Ergueta (UC Berkeley), Benjamin Fine (UC Berkeley) and Martin Krucinski (Xerox), M. Tomizuka(UC Berkeley), and R. Horowitz (UC Berkeley)

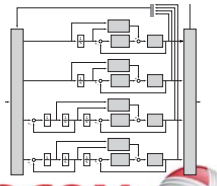




Objectives: **Research & develop new sheet registration systems complete with sensors, actuators and controls for 3 DOF sheet registration control.**

Duration: **July 2001– October 2007**



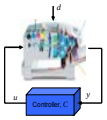


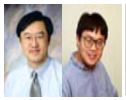
Key Output: 10+ papers, design strategies, simulators, 1 Patent, 5 PhD, 1 MS and 2 New PhD hires, 1 summer intern

Sensing and Control of Digital Color Xerographic Imaging Systems

Purdue University & University of Minnesota

NSF: 2002-2005
Budget: $360K



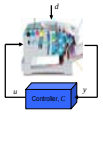


Eric H. | Eric G.

Control System Analysis and Design for Xerographic Systems

Purdue University

UAC: 2002-2004
Budget: $60K

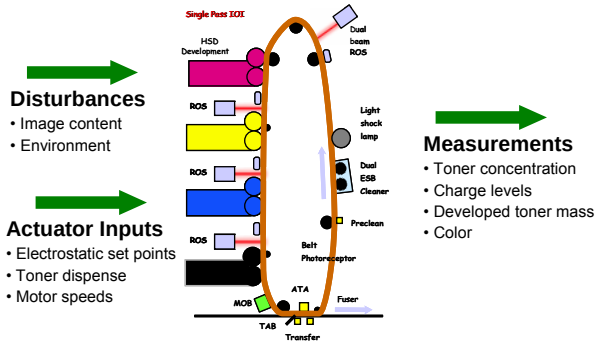


Eric H.

<u>Project Objective</u>: Construct model-based control strategies for producing consistent, high quality prints from xerographic marking processes despite environmental and material latitude, wear, and degradation type disturbances.

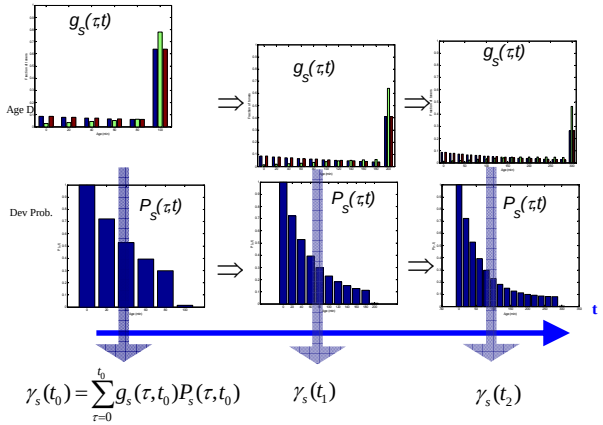
Control-oriented modeling problem: Construct a parsimonious marking engine model that 1) dynamically tracks key process states and 2) maps inputs to outputs.

Xerographic Process



Distribution-Based Development Model

- High dimensional, physics-based
- Open-loop prediction



$$\gamma_s(t_0)=\sum_{\tau=0}^{t_0} g_s(\tau,t_0)P_s(\tau,t_0) \qquad \gamma_s(t_1) \qquad \gamma_s(t_2)$$

Control-Oriented Development Model

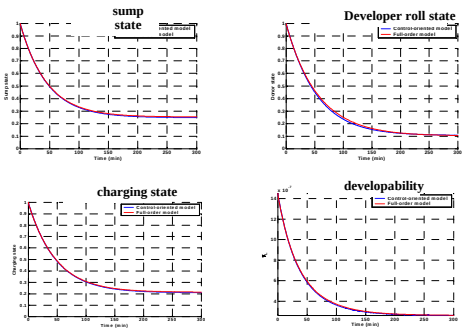
- Transform distribution model into lumped parameter model
- Maps inputs to output through a reduced number of states.

$$\begin{bmatrix}\dot{x}_1(t)\\ \dot{x}_2(t)\\ \vdots\\ \dot{x}_n(t)\end{bmatrix}=\begin{bmatrix}f_1(x,\theta,d)\\ f_2(x,\theta,d)\\ \vdots\\ f_n(x,\theta,d)\end{bmatrix}+\begin{bmatrix}g_1(x,\theta)\\ g_2(x,\theta)\\ \vdots\\ g_n(x,\theta)\end{bmatrix}u(t)$$

$$\gamma_L(t)=h(x,\theta,d)$$

x – state vector: sump, charging, developer roll
u – input vector: dispense, bias voltage
θ – model parameter vector
d – disturbance vector: image content and environment
γ – developability output

Sample Model Results



Research Initiatives Supported by Model

- **Xerographic process analysis from a system-theoretic viewpoint**
- **Control design for bilinear systems.**

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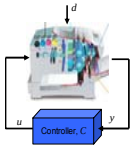
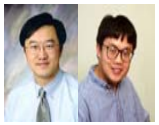
Sensing and Control of Digital Color Xerographic Imaging Systems

Purdue University & University of Minnesota

NSF: 2002-2005
Budget: $360K





Eric H.

Eric G.

Consistent Color Problem: Control of color is high dimensional and time varying.

Sensing challenge:

- Print & measure small test patches
- Gamut sampling is wasteful and costly
- Limited sensing

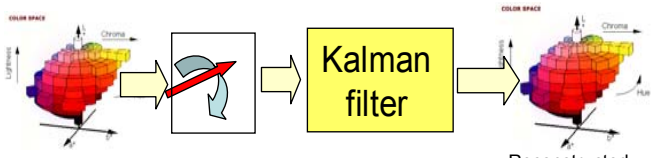
Time sequential (T-S) sampling:

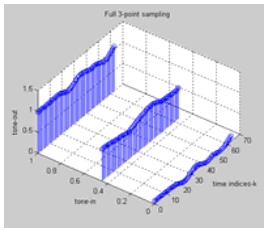
- Sample different colors at different times
- Reconstruct time varying color reproduction function from T-S samples
- Trade-offs color-space bandwidth with temporal bandwidth

Research Issues:

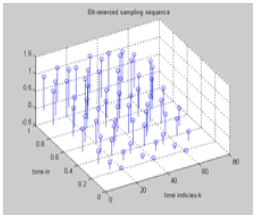
- Dynamics of reproduction functions?
- Optimal sampling sequences for color space?
- Reconstruction algorithm?
- Integration with control?

Time Sequential Sampling Approach for Gamut Estimation

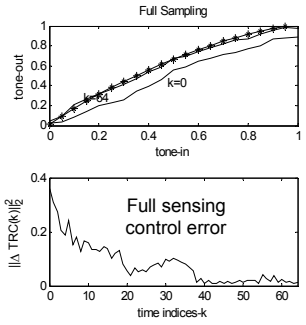


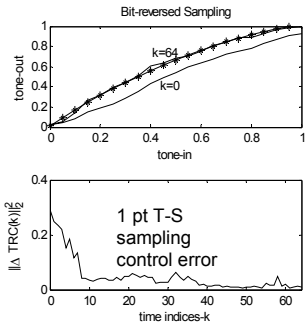


3 point fixed sampling



1 point T-S samplings





Single colorant control with full (21 points) sensing and 1 point T-S sampling sensing have similar control performances

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Collaboration: A Formal Process Can Help

A good match with the University projects and the company needs is a must

- Requires good communication – many barriers make this difficult.
- Consulting arrangements help for open communication (this is considered selfish by the University; e.g., relationship with EE & Computing Dept., Univ of Michigan) .
- Matching of projects with industry roadmaps can help.
- University sabbatical or temporary summer appointments can help to generate good match (e.g., relationship with EE Dept., Rochester Institute of Technology) .
- Faculty comfort level with industry interaction.

Contracts

- Industry projects contain 'mile stones', 'dead lines' and crisp deliverables. These are required to place the contract. Collaboration, consulting, internship, co-op studentship.

Intellectual property

- IP portfolio is industry's bread and butter.
- Differences between 'leveraging existing theory' and new theory should be made clear while generating IP agreement. This is a difficult issue, agreements should be well crafted to avoid conflicts. Consulting agreement will minimize this issue.
- Discovery, learning and students are considered primary outputs of Universities. IP issue is an impediment.

Cost sharing, speed of delivery

- Project cost depend on funding source.
- Completing 'milestones' on time is key.

[Ref. (1) Contributions by E. Hamby, Prof. G. Chiu, E. Gross and (2) Industry-University Interactions by D.H.R. Sarma, Delphi Delco Electronics Systems, Jan 17th 2001]

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Measuring Success – Lessons Learned

1) Products/Services

- We can see and feel
  (e.g., ACQS on iGen3, iGen4)

Normally, commercial products/services do not come out of direct research with University collaborators – particularly true in Controls.

2) Intangibles

- New hires
- Design methodologies & theoretical tools
- Technical Papers, Reports
- Gain knowledge through interactions
- Patents

Successful collaboration helps in improving the intangibles

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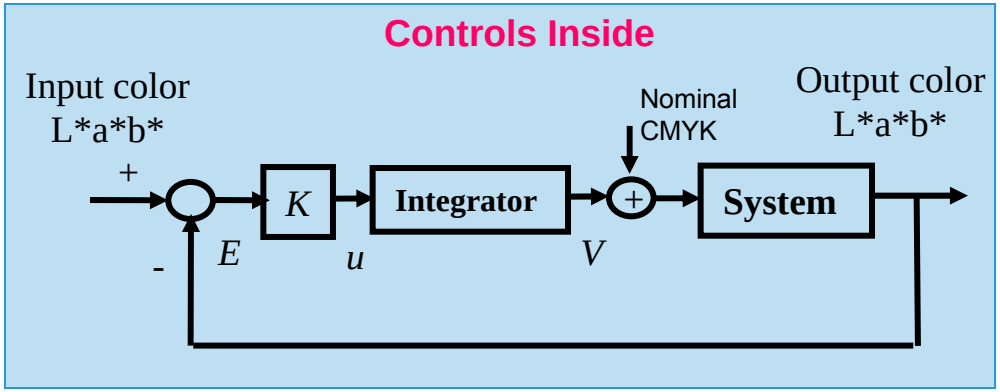
Product: ACQS - Automatically better.

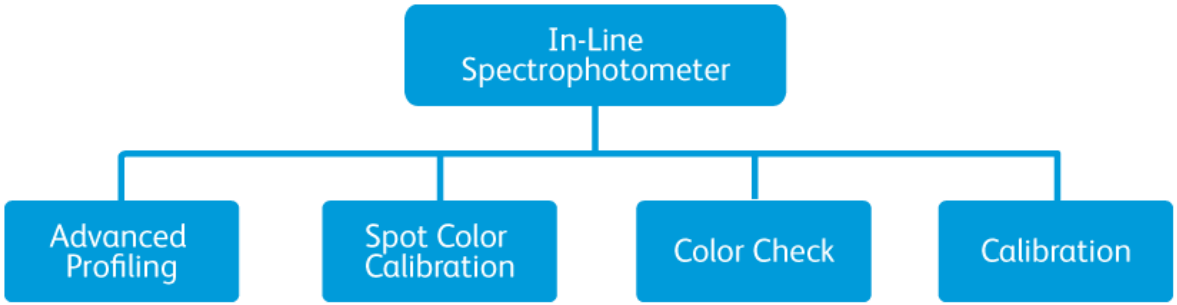
The ACQS Press Matching System* improves the efficiency of iGen3® and boosts your productivity using an automated In-Line Spectrophotometer.

At the heart of ACQS system, controls is used to achieve good matching.



The ACQS Press Matching System delivers:

- Press-like color matching
- Greater productivity through automation
- Increased capacity
- Superior image quality on the most



*Xerox FreeFlow Print Server 6.0 only

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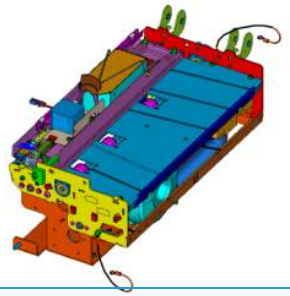
ACQS: Improved Image Quality, Match to Press, Increased Production Capacity

In Line Spectrophotometer

- Hands off control of Press IQ
- Increase press availability

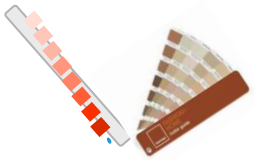


Advanced Destination Profiling

- Match offset and iGen3 output by default
- Precision control of managing multiple color spaces

Automated Spot Color Calibration

- Hands off process eliminates subjective adjustment by press operator
- Match Pantone spot colors with no or limited operator intervention



Automated Calibration & Color Check

- Tells pressman if the press is ready to go to production
- Eliminates unneeded maintenance and increases production time

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Thank You!

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