Challenges In Digital Photofinishing*

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Abstract

The continued growth in the consumer digital camera market presents significant opportunities for the photo finishing industry to define new and diverse ways to generate revenue from prints and additional related products. One key driver of demand is customization and personalization of products such as 4"x6" prints with borders and effects and personalized Greeting Cards and Calendars.

There are significant challenges in adopting a digital photofinishing workflow that is profitable. At Shutterfly, we have found that the key is automation of the process from ordering to processing through printing and shipping products. Maintaining color consistency on multiple output devices, managing large amounts of image data, and maximizing output performance of printers are necessary requirements to build a cost-effective workflow.

Introduction

As the mainstream consumer's use of digital cameras continues to accelerate, there is an ever-increasing need for consumers to obtain prints and other unique products from their digital images. Consumers have a wide variety of printing options, including printing at home on inkjet printers, printing at retail locations that offer digital services, and using an online photofinishing service, such as Shutterfly.

Shutterfly is a leading online digital printing company serving both consumer and professional photographers. A typical Shutterfly customer uploads images from their digital camera to their account on Shutterfly, where the images are organized into albums. After upload, images can be enhanced by adding borders and applying other effects. Customers can then order a wide variety of customized photo products delivered through the mail to multiple recipients, and share their images online with family and friends:

- Silver-halide prints are available in sizes from 4"x6" to 20"x30". At present Shutterfly uses a combination of Fuji Frontier and Polielettronica digital minilabs to fulfill silver halide prints.
- Greeting Cards are available with a custom image on the front of each card. Card customization options include image enhancement features mentioned previously, choice of matte or glossy finish, mailing of each card directly to the recipient, as well as the ability to include a pre-printed personal message inside the card for each recipient.
- Spiral bound Calendars are printed on heavy card stock with one personalized photo per month. Both cards and calendars are printed on HP-Indigo 3000 digital offset presses.

Shutterfly's revenues for 2002 exceeded $16M and the business continues to grow at approximately 100% annually. Shutterfly does not charge a subscription fee to members or charge for long-term image storage. Scanning of 35mm film to produce digital images is a small fraction of the business. Thus, almost all Shutterfly's revenue results from transforming images from consumers' digital cameras into prints and other photo products.

Achieving profitability in a new market represents a significant challenge. We have found the following are key requirements to profitably produce printed products: Workflow automation; Cost-effective storage and management of customer images; Maximize output performance of printing systems. In the following sections we describe the challenges of developing an automated digital photofinishing workflow that satisfies these requirements, and discuss possible business opportunities in terms of new revenues opportunities and decrease in cost presented by digital photofinishing, relative to the traditional film-based business.

Challenges

Every month we print millions of digital images that come from a wide variety of capture devices including digital cameras, film scanners, and flatbed scanners. Producing this large number of prints presents significant challenges in managing data, maximizing output performance of printers, providing consumer acceptable output[1] and maintaining color consistency on multiple output devices.[2,4]

In consumer studies conducted at Shutterfly, we found that consumers overwhelmingly preferred images that had some post-processing performed on them to improve the color and contrast in the picture. The challenge in the post-processing is to make very little change to images that already have good color balance, lighting etc. and to improve the images as much as possible when the image would otherwise be unsatisfactory in the print. Our proprietary image processing called VividPics®[2] is applied

in a completely automated and image adaptive fashion. Both image measurements and metadata information are used to adjust image brightness, contrast and color balance. Given an ideal output device (one that can produce all colors with infinite color resolution) all image adjustments can be performed without any knowledge of the final printing device. Shutterfly uses its ColorSure™2 technology to ensure that all printing devices, irrespective of native printing technology, provide colorimetric reproduction at all times. ColorSure™ is a combination of both calibration and monitoring processes. Printers are calibrated using ICC profiles built using off the shelf software (Gretag's ProfileMaker software). Printers are monitored by automatically printing MacBeth color charts throughout the production day on each printer and the resulting charts scanned with a spectrophotometer. The goal is to maintain all printers within 2.0-3.0 ΔE of target colorimetric values. Production processes are in place to correct problems when scanned values exceed this target. We thus removed the need to make subjective evaluations that require additional training and are therefore less cost effective.

The typical printing solution provided by most manufacturers includes hardware and software in addition to the printer and its control system. Often the rendering subsystem introduces extra cost and becomes the bottleneck when trying to maximize the printer throughput. Further, the image processing provided with the printer varies among manufacturers. Even if the manufacturer's processing were used, it would be very difficult to maintain consistency among output produced from printers of different manufacturers. In order to achieve high throughput and scalability at low cost we built a centralized rendering system called the Renderfarm.[2] The Renderfarm consists of multiple servers, storage, networking, and software that performs load balancing, system monitoring, and all image processing in parallel. Standard protocols such as HTTP and FTP are used to issue render requests as well as transfer image data between the Renderfarm, image archive sources and printing devices. An image is transformed from its initial source input(s) to its final printer dependent color space, resolution and file format in two "render passes": the Device Independent pass and Device Dependent pass. VividPics® processing and other computationally intensive processing (such as re-sampling) is performed in the Device Independent pass. Since no device dependent processing is required, lower cost processors can be used provided the images are rendered well in advance of printing. All ColorSure™ processing is performed in the Device Dependent pass. ICC profiles are applied and the image is written to the appropriate printer, in the required output colorspace and file format. High throughput and cost effectiveness is achieved by using multiple low cost computers and rendering images to printers in a coarse grain, highly parallel manner. The Renderfarm is scaled with the number of printers simply by adding additional computers.

As volume of prints and other products from digital sources increase, there is a significant challenge in managing the large amounts of data required to produce these products. Bandwidth and storage costs to support services such as sharing and archiving are considerable, especially given the fact that no direct revenue is currently generated from these services. Multi-tiered storage solutions that have a decreasing cost/MB and reliability must be used to keep costs down. The data management is further compounded when producing products from these images. For many of our products there is a significant increase in data size when the final "printer ready" version of the image is printed. For example, a data transfer rate of 25Mbits/second to our HP-Indigo 3000 digital press is required when printing Calendars.[3] Further, as the print capacity of the lab increases the aggregate data throughput requirement increases significantly. Since many printers require uncompressed data to achieve their fastest throughput the bandwidth connecting all components of the lab must be adequate. Caching, pre-fetching, and local buffering of image data at key points in the digital workflow is essential to keep hardware costs down.

Film To Digital Transformation

The transformation of the photofinishing world from film to digital presents opportunities to increase profits both by increasing revenue and decreasing costs. Increased revenue is supported with new products and services along with highly customized traditional products. Costs are affected by decrease in labor and consumables required to process film. In digital photofinishing there are a number of emerging revenue opportunities based on new products and services that were not possible with film. Our customers are demonstrating that image "re-use" is a common practice. For example, a single image can be (and often is) electronically shared, printed as a 4x6 and used in a 12-month calendar. Highly customizable products such as folded Greeting Cards and Calendars are available to consumers. The amount and relative ease of customization along with the low cost at low volume is only possible in the digital world. This customization can also be applied to the traditional print products with the use of borders, effects and captions without impacting the cost of the prints. This further promotes sales of 4x6 prints as well as enlargements.

Electronic sharing, archiving of photos, and multiple destination shipping are services which also present significant revenue opportunities. At present, Shutterfly does not charge for these services as they support product sales. It is apparent, however, that the value of these services is significant to the customer.

The cost of producing products in the digital world is decreased with the removal of the physical handling of film. Savings are realized by reductions in labor and consumables used in processing film. In a purely mail order model, better capital utilization is also possible as 24/7 shifts can be run as opposed to the usual 8-10 hour overnight shift. Care must be taken, however, to ensure that costs associated with film's replacement by digital images, are minimized. Simply removing film from the cost equation does not mean that prints and related products can be produced at lower cost. It is critical that image storage costs and the bandwidth

charges required to transport digital images to and within the print facility are low. The cost of maintaining the digital infrastructure also must be considered. It is necessary for the infrastructure to scale linearly (or less) with volume.

At Shutterfly, we have also found that the order mix plays an important role in cost management. This is typically not an issue in the film world but has significant impact to our digital, mail order business. Since customers often order multiple products from a single image, it is necessary to consolidate these products into a single shipment in the production facility prior to shipping. This minimizes packaging and shipping costs (which is overhead cost that is introduced to the customer). This consolidation step introduces additional labor and/or complex automation processes and space requirements.

Recommendations

We consider many factors when choosing a new printer to use in a purely digital photofinishing workflow. Some of these factors are the same whether the printer is used in a mostly film-based photofinishing workflow or in a purely digital workflow: Color stability, reliability, and labor requirements. In a purely digital photofinishing workflow, some additional factors require more complex evaluation: price/performance, image quality, and reliability.

The price/performance of a printer and its associated finishing equipment must be evaluated with respect to how it will perform in a fully automated digital photofinishing workflow. High-speed digital silver-halide printers are usually designed to work in conjunction with high-speed film scanners, often from the same manufacturer. These film scanners and high-speed digital printers are designed to work together as a system, with the bulk of the images being fed directly from the film scanner to the printer, and a minority of original digital images being inserted into the printing path, often by operator intervention. In a purely digital photofinishing workflow, the film scanner is not used. Instead, the photofinisher must use the application programming interface (API) provided by the printer manufacturer to design software and network system that will submit fully rendered digital images for printing without any operator intervention. We have often uncovered performance bottlenecks in this environment that limits the performance of the overall system to a level that is substantially less than the peak performance of the printer. There may be performance limitations in the printer's API software, because it was designed for occasional rather than full-time use. In other cases, we have found network or Input/Output bottlenecks because the fully–rendered digital images are higher resolution or more lightly compressed than images from the film scanner.

Color stability and other image quality considerations must also be evaluated somewhat differently in a fully automated digital workflow. While good color stability over time is always highly desirable in any printer, an external Renderfarm[2] can correct for moderate color drift without shutting the printer down by updating the ICC profile for that printer. The Renderfarm[2] can also perform higher quality re-sampling algorithms that are not practical to run at real-time inside a printer. Image enhancement algorithms implemented inside a particular printer model are not useful for labs that want to maintain consistent color reproduction across a wide variety of printing technologies. Finally, features that provide modest improvements in image quality but significantly increase cost of hardware and consumables or decrease printer throughput are likely not be used in a central lab type environment.

Reliability of a printer and its associated finishing equipment also needs investigation in a mail order environment, where production frequently runs 24x7 instead of an 8- or 10-hour overnight shift. Machine downtime for preventative maintenance represents true lost productivity in a 24x7 environment. We therefore closely evaluate a system for single points of failure, redundancy and fail over features as part of ensuring maximum productivity of the printing systems.

Shutterfly's experience with Fuji Frontier 370 and 390 digital minilabs has been very positive. Their color stability and reliability are excellent. After some software improvements to the digital interface from Fuji, the printers are also now capable of producing prints at the speed of the paper transport. As digital photofinishing labs increase in size, however, the market for higher throughput printers with more automated finishing stations will continue to grow. It is key for these higher throughput printers to provide adequate data interfaces so as not to become the bottleneck in an all-digital workflow.

Manufacturers of equipment for digital photofinishing can enhance the attractiveness of their systems by ensuring peak performance of a printing system when used without a film scanner. This assumes that all image processing operations will be performed externally, and designing adequate reliability for a 24x7 operation by use of redundancy and automatic fail over features.

Summary

In this paper we have presented challenges in creating and operating a digital photofinishing workflow at Shutterfly. We have described the importance of maintaining color consistency, maximizing printer throughput and managing large amounts of data in producing prints cost-effectively. As well, we have presented opportunities to increase revenues and decrease costs by transitioning to a fully digital workflow. Finally, we provided recommendations for manufacturers of digital printers based on our experience in developing our digital workflow at Shutterfly. Our recommendations include:

- Ensuring that the software API for digital data does not be the bottleneck of the printing system,
- Printer/manufacturer specific image enhancements must result in consistent output from different printers,
- Reliability and color stability of the printer are essential.

References

* Aspects of the technologies described in this paper are covered in US patent 6,583,852 and other pending US patent applications.

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Biographies

Jeannine Smith is the Chief Engineering Officer at Shutterfly. She utilizes her eighteen years of experience leading hardware and software product development to manage Shutterfly's Imaging Science, Web and Lab Engineering teams, in addition to the Internet Operations team. Since joining Shutterfly in September of 1999, Jeannine has architected and managed the development of the company's automated photo lab workflow and VividPics® systems. Jeannine spent seven years at Silicon Graphics and subsidiary Alias|Wavefront, designing and managing leading-edge video products including device-independent video APIs, Internet-based video conferencing and professional video applications. Jeannine's experience also includes ten years in the networking field, building routers and other network products for a variety of companies.

Russell Muzzolini received his M.Sc. in 1991 and Ph.D. in 1996 from the University of Saskatchewan, both in Computer Science. In 1996 he joined Alias|Wavefront to work on an advanced 2D compositing and 3D graphics applications for film and video visual effects in the Entertainment Industry. Since 1999 he has been with Shutterfly working as an Imaging Researcher with the Image Science group. Russell's current research interests include statistical signal processing, hardcopy image reproduction, image segmentation and motion tracking.

Dhiraj Kacker received his B.Tech. from the Indian Institute of Technology, Bombay in 1993, MS from Washington State University in 1996 and Ph.D. from Purdue University in 2000, all in Electrical Engineering. Since 2000, he has been working as an Imaging Researcher with the Image Science group of Shutterfly, Inc. His present research interests include hardcopy image reproduction, image quality perception, gamut mapping, watermarking, and statistical signal processing. Dhiraj is a member of IEEE and IS&T.