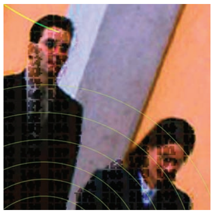
Expanding the Digital Camera's Reach



Today's digital cameras and large-capacity portable storage devices could soon be integrated into compact cell phones that establish symbiotic relationships with stationary devices in the environment, providing users with the ability to view and share images in many new settings and enabling the creation of several novel applications.

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Over the past decade, consumer digital cameras have evolved from expensive and bulky devices that provide low-resolution images to affordable compact units capable of recording high-resolution pictures. Recently, cell phones that integrate digital cameras have far outsold regular digital cameras. We expect this trend to continue because this combination provides great value.

First, the cell phone's voice communication capability makes it the most ubiquitous portable device. Second, people enjoy the convenience of capturing high-resolution digital images using a device they already carry. Third, this integration relieves people from having to make a conscious decision to take a camera in anticipation of taking pictures. Some digital cameras even offer integrated Wi-Fi capabilities for direct image transfer. Recent trends in portable storage devices indicate that cellular camera phones can integrate several gigabytes of storage.

More than a straightforward replacement for film cameras, digital cameras allow new and different uses. People tend to take more pictures in more situations with digital cameras than they do with film cameras. For example, because digital images require little physical space, some users have converted their children's space-consuming art projects into compact yet accessible digital albums. Others have recorded a skin rash's progress or a dog bite so that they can show their doctor the digital image.

Digital cameras have also become memory aids and transcription devices, creating a class of *ephemeral images* with shorter lifetimes than images taken with film cameras. People take pictures of where they parked their car at the airport so that they needn't spend time searching the lot when they return. Others have captured the license plate number of erratic drivers and reported them to authorities. Digital cameras have become input devices as well.[1,2] More applications like these will appear as high portability, minimal per-picture cost, and generous storage increase the digital camera's popularity.

Despite the increasing image resolution, storage capacity, and wireless connectivity of cellular camera phones, human preferences dictate their physical size, which essentially limits the integrated display's size. The advent of flexible displays could change this balance, but the size available in a truly portable form factor will limit the rolled-up display's area. Another alternative, projection technologies, consume too much power at the present time to be practical for most portable devices. Therefore, for the next few years, the camera's display size will remain constrained while the number of images that can be stored in the camera itself will incease dramatically. Although immediately viewing pictures on the integrated display is a valuable feature, it can show only a limited amount of detail.

To address this limitation, we recently described a futuristic scenario in which mobile computers establish symbiotic relationships with stationary devices in the environment to offer users a combi-

Table 1. Typical display and maximum possible resolution according to human visual acuity limitations.

Display type	User distance (inches)	Typical width (inches)	Typical width (pixels)	Typical resolution (dpi)	Maximum resolution (dpi)	Maximum width (pixels)
Cell phone panel	10	1.5	150	100	350	525
PDA display	12	2	300	150	291	582
Laptop display	16	10	1,200	120	218	2,180
Desktop monitor	20	20	2,000	100	175	3,500
Meeting room screen	230	80	1,200	15	15	1,200

Table 2. Some examples of camera specifications evolution, 1995-2003.

Camera	Year	Introductory retail price	Image resolution	Typical image size	Display size (mm)	Pixels	Maximum memory available	Image capacity
Ricoh RDC-1	1995	$1,800	768 x 480	100 Kbytes	51 x 31	72 K	24 Mbytes	240
Kodak DC210	1997	$600	1,152 x 864	300 to 400 Kbytes	37 x 27		64 Mbytes	160
Kodak DC290	1999	$800	1,792 x 1,200	600 to 800 Kbytes	41 x 28		128 Mbytes	160
Sony DSC-P10	2003	$600	2,592 x 1,944	2 Mbytes	31 x 23	123 K	2 Gbytes	1,000
Samsung VGA1000 cell phone	2003	$299	640 x 480	100 Kbytes	34 x 42	20.4 K		

nation of both systems' best attributes: large, easy-to-read, high-quality displays and content personalization through mobile computers.[3]

In this scenario, environmental displays become intelligent network objects that offer their services the same way today's network printers do. Mobile computers discover such displays, communicate with them to ascertain their characteristics, and securely transmit information.

SYMBIOTIC DISPLAYS IN THE ENVIRONMENT

Many researchers have explored the idea of using environmental displays to supplement portable devices' display capabilities.[3,4] They base this work on the key observation that every display has intrinsic limitations that create usage barriers. For example, human visual acuity imposes an upper bound on display resolution. Even people with perfect vision cannot resolve details smaller than one minute of visual arc angle for prolonged durations at comfortable brightness levels. Thus, increasing display resolution beyond that point does not contribute significantly to improvements in the displayed information's readability.

Table 1[3] shows the typical resolution of current displays and the maximum meaningful resolution as a function of display size. The table shows that technological advances will not improve portable displays enough to make viewing a large amount of detail easy. The improvements in picture quality resulting from better capture resolutions are seldom observable on a digital camera's integrated display. To provide an extended set of applications, we expect future digital cameras to establish on-demand symbiotic relationships with large environmental displays.

In addition to cameras, we expect several other mobile devices to leverage the services of network-attached displays to view documents and other types of content that cannot be viewed easily on small displays. We believe that a new class of intelligent network-connected displays will emerge to support such symbiotic relationships. These displays will have some or all of the following attributes:

- direct connection to the network infrastructure and network addressability;
- support for content formats such as ASCII, HTML, PDF, PostScript, JPEG, GIF, MPEG, and Flash, plus the ability to negotiate with other network devices, much as browsers express accept tags to Web servers;
- the ability to express their capabilities to mobile devices in terms of pixel resolution and dimensions;
- support for direct user interaction via a keyboard, mouse, touch-sensitive screen, or other forms of gesture recognition, so that users can perform simple operations such as scrolling and pausing video;
- downloadable code support, such as JavaScript and Java applets, for richer user interactivity;
- support for a short-range wireless network interface to communicate with mobile devices and make it easy for mobile devices to discover

just those displays in the immediate vicinity; and
- support for one or more wired interfaces such as USB or FireWire to connect directly to mobile devices.

Although network-attached displays have much in common with network printers, we believe these displays will be less expensive to operate because they use no consumables such as ink and paper. We already see trends in this direction with the addition of Ethernet and Wi-Fi interfaces to projectors, some of which even come with software to display content from a remote PC. We expect to see network displays become standard appliances eventually, deployed in various environments. Over time, we anticipate that several different types of network displays will become available, all supporting standard software and hardware interfaces. The prices of such displays will likely drop as well, widening their deployment further.

We have started prototyping such network-connected displays by enhancing standard projectors. Recently we demonstrated an application scenario in which our WatchPad wristwatch computer[5] and the Everywhere Display research prototype establish a symbiotic session.[6]

Figure 1. Cameras from 1995 through 2003. As technology improved, cameras became physically smaller, shrinking display size accordingly.

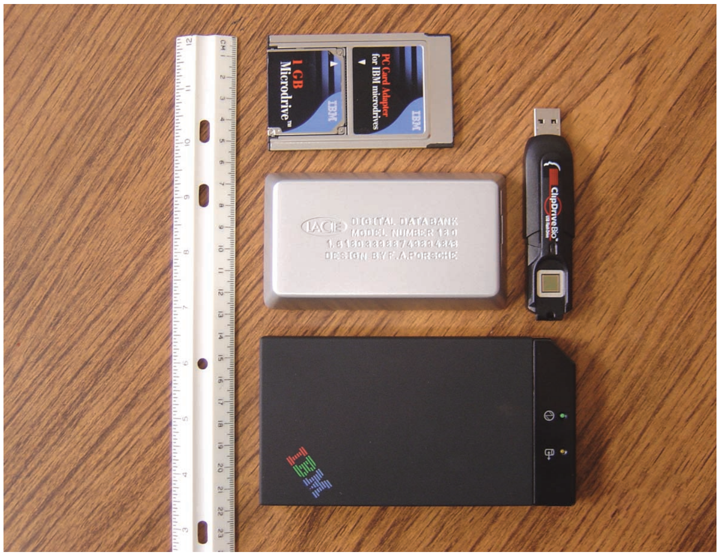

Figure 2. Portable-storage devices with capacities ranging from 512 Mbytes to 40 Gbytes.

APPLICATION ENVIRONMENTS

We expect digital cameras to be used symbiotically in several environments, including homes, offices, shops, cars, airplanes, and trains. This introduces several challenges because some of these environments are friendlier than others, some have better access to power, some have organization firewalls, and some are more private. This variability affects both the camera's design and required infrastructure.

Camera image capacity

Table 2 shows that the size of the images captured by digital cameras has increased at a steady pace in the past few years, thanks to higher-resolution imaging chips. The number of images that could be stored in the camera did not increase significantly during these early years because increasing image resolution neutralized the increased storage capacity. Figure 1 shows that as technology improved, several cameras became physically smaller, shrinking display size accordingly.

The human eye's limitations make it unlikely that the integrated camera's display size and resolution will continue increasing. While professional photographers may want higher capture resolutions, many consumers find the current image capture resolutions adequate because they can already print high-quality enlargements. Although larger cameras can include sophisticated optics, consumers often prefer the convenience of smaller devices.

In contrast, we can expect camera storage capacities to continue doubling almost every year, effectively increasing the number of pictures the camera can store. IBM's introduction of its MicroDrives, with a 340-Mbyte capacity in a compact flash form factor, began this trend. Atomic-force-microscope-based data storage technologies such as Millipede[7] can have a data storage density of 125 Gbytes per square inch—10 times higher than the densest magnetic storage available today.

This difference in the growth rates of image and storage size will eventually let users retain many images in their cameras. For example, the 40-Gbyte storage device shown in Figure 2 can hold 20,000 5-megapixel images. A VGA resolution thumbnail takes about 100 Kbytes, so thumbnails for 10,000

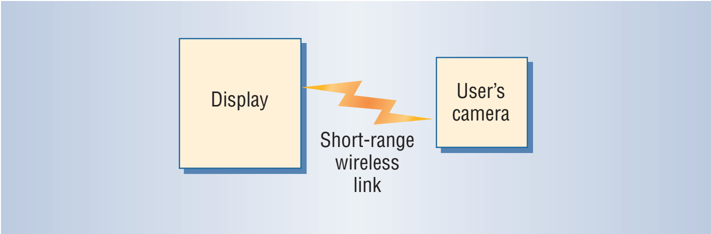

Figure 3. Image transfer via direct symbiosis. This approach transfers the image directly from the camera to the high-resolution display.

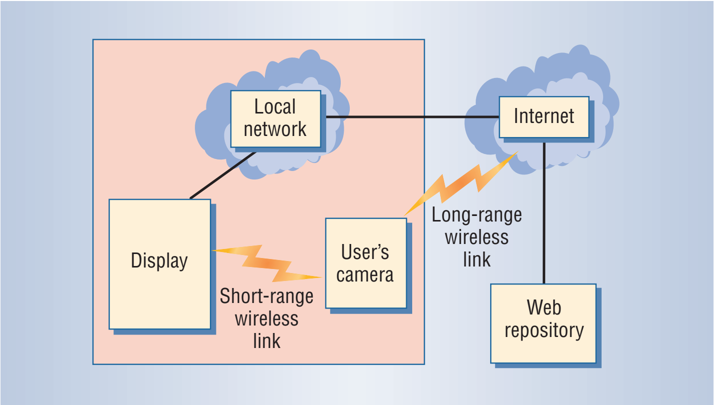

Figure 4. Image transfer via indirect symbiosis. When images are stored in a Web repository, if the bandwidth between the display and the Web server is greater than the direct link between the camera and display, letting the display fetch them directly can save the camera's battery power.

images will take only 1 Gbyte. Assuming that a user takes about 10 pictures a day, the storage device can hold five years' worth of images. If the camera retains only thumbnails when the actual image is transferred from the camera, a 40-Gbyte storage device could hold 400,000 VGA-resolution thumbnails.

Soon then, some cameras will be able to retain images taken over several years, along with annotations. Others will be able to retain thumbnails and annotations for all pictures captured over several years. Users will likely replace the camera before they run out of space. The function provided by auxiliary portable devices that help offload images from digital cameras will be integrated into the cameras themselves. As users upgrade to newer cameras, they could copy the entire contents of their current camera to a new one.

Videos captured by the camera will likely fill up even these large built-in storage capacities. Until storage capacities increase further, users will be forced to offload video content to auxiliary devices or storage media. This offloading of video content reserves ample storage capacity for still images.

Regardless of camera capacity, we expect users will often copy their images to home computers or Web repositories, primarily to safeguard against the camera's loss. Already, several providers—such as Ofoto, Yahoo, and Shutterfly—offer network-accessible storage and photo printing services. Such repositories also let users share their pictures with others and obtain prints when necessary.

Just as MP3 players let music lovers carry huge collections of their favorite music, technology trends will let consumers personally carry a large image collection. To unleash the full potential of these collections, users must be able to view and share images easily.

Direct symbiosis

How users view their images on intelligent environmental displays will vary depending on where the image is stored. If the image resides on the camera itself, the simplest approach transfers it directly from the camera to the display, as Figure 3 shows. However, to retain privacy and security in less secluded settings, a user can preview images on the camera display before sending them to the larger display.

To do this, once the camera discovers the display and its capabilities, the camera and display establish a session, and, if required, the session completes a mutual authentication. With the built-in camera display, the user scrolls through the image thumbnails and picks one to view on the environmental display. The camera sends the higher resolution image to the display. If the display does not support the high-resolution image, the camera can resize the image to reduce the amount of data being transferred.

The connection between the camera and the environmental display could be made over a short-range wireless link or through a wired connection such as USB. From a communication semantics perspective, the camera is the master and the display the slave, even though physical cabling can make the camera a USB slave.

Indirect symbiosis

When images reside in a Web repository, letting the display fetch them directly from the repository can save the camera's battery power. This approach, shown in Figure 4, may be faster if the bandwidth between the display and the Web server is greater than the direct link between the camera and display. We expect that the user will still view the thumbnails privately on the camera display before deciding which images to view on the large display. Image selection will thus still be a problem when dealing with hundreds or thousands of thumbnails.

Once the user selects an image, the camera can direct the display to fetch it from the repository. To use this approach, the camera must be able to authorize the image transfer. It can do so by accessing the Web repository via its long-range wireless connection and requesting that the repository create a freshly computed ephemeral token. To provide suitable security, the token could be derived based on the time, user's password, location, name and address of the display, and sequence numbers sent by the camera. The camera then hands off the token to the environmental display over the short-range wireless interface. The environmental display obtains the image from the Web repository on the camera's behalf, proving its authority by supplying the token. The repository rejects any requests without valid tokens.

The entire mechanism can be simplified if the camera can send a URL to the display that includes both the image identifier and the authorization token. The Web repository usually cannot initiate the image transfer to the display because the display may reside behind a firewall. The camera's short- and long-range wireless capabilities work in conjunction to download and view selected images without compromising the user's entire image collection.

This approach can also be used to share images. For example, a user could receive a message from a friend who has uploaded an image collection he wishes to share. The message might include thumbnails that arrive at the user's mobile device. While scrolling through the message's thumbnails, the user can instruct the mobile device to display selected thumbnails on the larger display. At this point, the user's camera delegates its authority to the display so that it can fetch the images from the friend's Web repository. Optionally, the display could transfer a copy of the image to the camera over the short-range link.

CHALLENGES

Digital camera designers must confront several challenges, including issues of security, usability, power management, wireless interface range, and storage type.

Image management

Cameras that store images must deal with the challenge of managing large amounts of data. This differs from managing thousands of songs stored on an MP3 player because songs have descriptive metadata such as names and artists, whereas images must be user annotated.

Given that thousands of images can be stored in one place, easy and effective naming schemes must be developed to replace sequential numbering. Voice-based input could be used for naming picture groups. Although people typically avoid annotating images because doing so is cumbersome, several approaches can make this task simpler,[8-11] such as allowing the addition of voice labels at the time of capture that PCs and similar devices can later convert to searchable text. Automatically recording a picture's context at the time of capture could be essential to building organized albums.

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Cameras can easily be enhanced to automatically record several parameters, such as location and the photographer's identity. Researchers have studied the benefits of using location coordinates to tag and organize digital images.[12,13] The camera could use such location tags to organize images into viewlists associated with specific locations. Or annotations could be built on another device and transferred to the camera. Many of today's cameras have no notion of accepting image content or metadata from other devices, so this shortcoming must be addressed as well.

Because users can keep copies of images on other devices and also edit image albums on them, the camera's stored images may not be synchronized with those on the other device. Thus, standard synchronization techniques have to be adapted for digital cameras. If images are deleted from the Web repository, for example, the corresponding thumbnails must be deleted on the camera as well. Given that some images will be ephemeral in nature, a mechanism must be provided to specify when those images can be automatically deleted.

Users often replace cameras every few years, and they will need to transfer images from the old camera to the new one just as we transfer data between computers today. Adjustments may have to be made to account for the differences in the cameras, such as image resolution and viewfinder size and resolution. Techniques to manage large collections of images on PCs[14] can be applied here as well.

Quick search and retrieval

Clearly, as the amount of storage in cameras increases, quick image retrieval and image management will become a problem. Several approaches can facilitate image retrieval. First and preferred, the input controls and software on the environmental display can be used to compose a query and overcome the camera's input limitations. The camera could send JavaScript code to the environmental display and present a form from which the user selects search criteria. The criteria would include all the metadata captured with the image,

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