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Camera Phones: A Snapshot of Research and Applications

Franklin Reynolds

Once considered science fiction, mobile phones with digital cameras are now inexpensive, widely available, and very popular. Significantly more camera phones are sold each year than dedicated digital cameras. According to Strategy Analytics, it's likely that over one billion camera phones were sold last year (see http://ce.tekrati.com/research/9039/). Surprisingly, the tremendous popularity of camera phones has caused little controversy. A few companies and institutions have banned camera phones owing to security concerns, and there has been some abuse of personal privacy, but for the most part, there has been worldwide acceptance of this new technology.

Of course, camera phones still have serious limitations, especially compared to dedicated digital cameras. Even high-end camera phones have small lenses, limited or no support for attachments (such as filters or telephoto lenses), and limited controls. However, they do have gigabytes of storage for images and video, high-speed local area networking, and high-quality Carl Zeiss lenses. They can capture five-megapixel images, and they include 3x optical zoom, autofocus, a macro mode for close-ups, a xenon flash, self timers, light and dark settings, and relatively powerful processors. Couple these features with the convenience of a mobile phone, and the benefits are compelling.

Flickr, YouTube, and other content-sharing websites contain vast amounts of content created by camera phones. There are even annual competitions for videos created by mobile phones, including Ithaca College's CellFlix Festival (www.cellflixfestival.org). Furthermore, integrating programmable smart phones with smart cameras has enabled new applications, ranging from video conferencing to digital photography to various smart sensors and even augmented reality.

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VIDEO TELEPHONY

A few years ago, my wife gave me a copy of *Tom Swift and His Photo Telephone*, a science fiction novel originally published in 1914 (see figure 1)! Clearly, people have been thinking about integrating telephony and photography for a long time.

Two of the earliest demonstrations of video telephony occurred in the 1960s. AT&T introduced its Picturephone at the 1964 World's Fair in New York (though several years passed before commercial products were available). Doug Engelbart's famous 1968 demo at the Fall Joint Computer Conference in San Francisco was the public debut of the mouse, hypertext, and video conferencing.

Today, video telephony is a practical reality. PictureTel and other companies have been making successful commercial products for years. Skype Video Call is free and available on several different platforms including Windows, MacOS X, Linux, and Nokia N800 tablets. As long as you have sufficient network connectivity, it works reasonably well.

Mobile video calls have been commercially available in some countries for a couple of years. Many operators that provide 3G cellular networks also provide a video call service. Mobile phones such as the Nokia N80 have two cameras: a high-resolution camera that faces away from the user for taking pictures and a second camera facing the user for video calls.

Consumer adoption of video calls, though increasing, hasn't been as quick as the telecommunications industry had hoped. A variety of reasons exist for this, including slow deployment of needed technology and services, diffi-

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culty of use, and price. Other, perhaps less obvious reasons, include social comfort (is my hair combed?) and cognitive load (the effort needed to keep track of what the other party sees).

COMPUTATIONAL PHOTOGRAPHY

In the March/April 2007 issue of *IEEE Computer Graphics and Applications*, Frédo Durand and Richard Szeliski described the computational photography field as lying somewhere in the intersection of computer graphics, computer vision, and image processing. Broadly speaking, the field aims to exploit digital image processing to produce better images. Researchers have developed a wide range of techniques over the years, including image denoising, panorama construction, and enhanced dynamic range via image layering.

Recently, researchers have also started exploring ideas for smarter cameras. In addition to processing captured images (using tools such as Photoshop), the idea is to apply certain techniques when the image is captured. It's no surprise that the possibility of compensating for some camera phone limitations by making them smarter is particularly interesting to mobile phone vendors.

Two common camera phone complaints are that it's difficult to hold the camera steady and to keep the subject in focus. Software has been developed to remove motion blur,[1] though it's not yet commercially available. Face recognition has been used for years to automatically remove "red eye" caused by a flash, but Sony Ericsson and other vendors have also begun to use it in some of their camera phones to automatically improve the focus of portraits.

A good introduction to computational cameras is Shree Nayar's article, "Computational Cameras: Redefining the Image," which appeared in the August 2006 issue of *Computer*. In that same issue, Michael Cohen and Richard Szeliski wrote about their moment camera, which captures many images—sort of like short film clips—and combines them to create images with reduced noise, increased resolution (or superresolution), a larger field of view, greater dynamic range, motion-invariant image stitching, and an effect they call *group shot*. This lets you take several pictures of the same group, select the best image of each person, and combine all the selections into a single image. Also, you can apply super resolution to videos captured with a camera phone. This technique can transform grainy artifacts into much higher-quality videos (because the original videos contain many consecutive frames that are very similar).

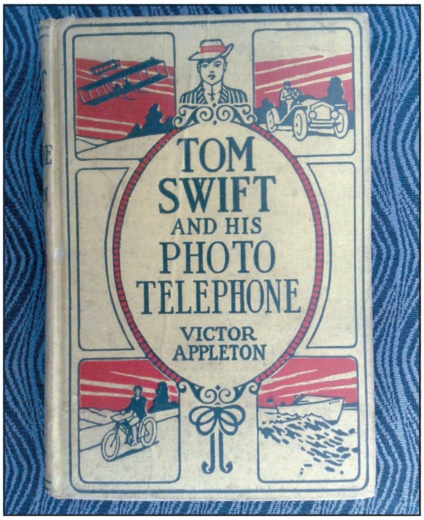

Figure 1. The cover of *Tom Swift and His Photo Telephone*, originally published in 1914.

The introduction of camera phones is transforming the industry. Future computational photography research should benefit the hundreds of millions of camera phone consumers.

CAMERA AS A SENSOR

Cameras are extremely versatile sensors. Although it might not be obvious to someone primarily interested in photography, cameras coupled with a convenient computing and communication platform, like a mobile phone, enable a surprisingly wide range of applications.

You can already use camera phones as copiers and scanners, and using them to fax a document is old news. Multiple companies have also begun delivering optical character recognition software for camera phones. One company, Abbyy, has announced a software developer's kit for mobile phone application developers who want to add OCR functions to their applications (see www.abbyy.com/sdk/?param=56223).

For years, consumers in Japan have been able to use their camera phones as 2D bar code readers. A consumer can take a picture of the bar code to automatically fetch a web page or send email. A recent innovation in this area are *screen codes*, introduced at HotMobile 2008.[2] Instead of a static 2D bar code, a screen code is a series of bar codes. Think of it as a 3D bar code, with two spatial dimensions and one temporal dimension. Screen codes have the potential for delivering much more data than traditional 2D bar codes.

Cameras can also serve as motion detectors by analyzing the differences between a sequence of images.[3] Researchers can use this approach to create gesture-based interfaces to games[4] or other applications. For example, simple gestures can create different views—tilting the phone can make it scroll, moving it closer to your face can make it zoom in, and moving it away from you can make it zoom out. Simple gestures can help create a playful and satisfying UI that permits one-handed operation, which is important for mobile phones. CaMus (short for Camera Music) is another interesting application; it uses camera-based motion sensing to let camera phones act as composition and performance devices.[5]

The EcoPDA project at the Center for Embedded Networked Sensing is exploring how to use mobile devices to help monitor and assess the environment (http://research.cens.ucla.edu/projects/2007/Terrestrial/EcoPDA). One idea is to annotate images captured with a camera phone with time and location. Then, researchers could link certain information—such as the

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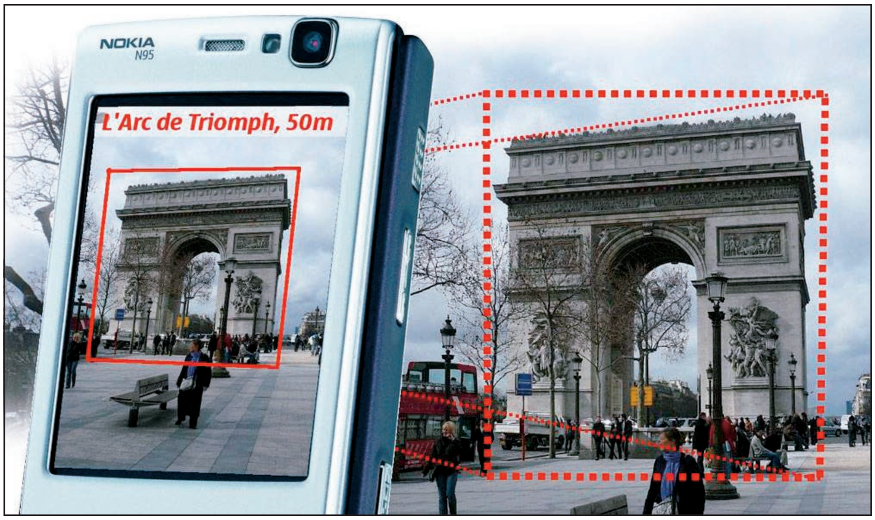

Figure 2. Image-driven inquiry: What's that tall building? A sample mobile augmented-reality application.

color of foliage during summer and the date the leaves changed color or fell from trees—to location data. This would provide valuable information for environmental studies.

Camera phones can also sense a user's location. Image-based scene analysis for determining user location is still impractical for the typical consumer, but projects such as TrackSense show promise.[6] The TrackSense researchers were inspired by algorithms that the robotics community developed: Simultaneous Localization and Mapping (SLAM) and a visual variant called visual SLAM. Because the TrackSense approach is based on learning and doesn't require a deployed infrastructure or a priori topological knowledge, it might be easier to move the technology out of the lab and into real-world applications.

Finally, cameras can help protect lost or stolen devices. For example, Omron, Sharp, and others have introduced face recognition as a type of biometric security feature for mobile devices. A user can "teach" the device to recognize his or her face by taking one or more reference pictures. Then, the user can configure the device so that only a recognized face can unlock it.

AUGMENTED REALITY

Talk about science fiction—just the phrase "augmented reality" conjures visions (pardon the pun) of futuristic virtual reality systems like the Star Trek HoloDeck. However, even progress toward the more modest research goal of augmented reality via mobile phones is exciting.

Years ago, a colleague and I filed a patent on an invention that let camera phone users automatically fetch the URL associated with a specific physical object by taking a picture of the object. Our approach combined very simple image-recognition algorithms with a location-aware service discovery protocol. The result was that users could wander through a smart space, such as a museum, and easily get additional information about objects of interest. The prototype was fun but had some serious limitations—the most glaring being the image recognition algorithm.

Within the last 10 years, the Scale-Invariant Feature Transform (SIFT) family of image recognition algorithms has dramatically improved object and scene recognition. Systems based on SIFT can use collections of images of an object taken from different angles and under different lighting conditions. With sufficiently rich image collections, SIFT provides robust image recognition. Researchers have been quick to use SIFT algorithms on mobile phones to enable various augmented-reality applications.[7,8]

Another Nokia Research effort has taken a different though complementary approach. Rather than emphasizing the best image recognition algorithms, they added GPS, a compass, and accelerometers to a phone.[9] They also experimented with superimposing other real-time, location-sensitive images or information on the viewfinder image (see figure 2). This makes it possible to create realistic illusions in real time, such as for games (for example, monsters roaming the streets) or travel-related applications (including real-time geotagged data with directions or traffic updates).

Smart phones with smart cameras have clearly enabled new applications. Even better, the widespread availability of these devices makes it possible to bring these new applications to hundreds of millions of users. That is pretty cool.

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