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Camera Phones Zoom in on Fixed Lenses

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Despite consumer demand, few camera phones provide optical zoom capabilities, instead relying on the more technologically inferior digital zoom. Traditional optical zoom involves either changing the position of lenses on the optical axis of a camera or altering the shape of fixed-position lenses. While both approaches are perfectly acceptable, they tend to be quite large, power hungry, and not particularly robust. Therefore, they are both incompatible with cell phone cameras, where the current trend is toward a thinner footprint, more durable cases, and a longer battery life. A potential solution is available in the form of a specially-designed lens combined with a simple algorithm.

TRADITIONAL ZOOM

Before getting into solutions, however, it's important to understand camera zoom, which permits the photographer to get closer to the subject in a much more convenient manner than moving the camera. It's not surprising that consumers rate zoom high on the list of "must-have" features when purchasing a digital still camera or camera phone. Camera manufacturers have responded to this demand. Most digital still cameras come standard with optical zoom, while camera phones have digital zoom.

While optical zoom is bulky, fragile and doesn't meet the ruggedness requirements of a camera phone, digital zoom is radically inferior to optical zoom. A 3x optical zoom magnifies an area of the scene, increasing the optical resolution in the zoomed frame by three. With optical zoom, information quantity is preserved as the magnification varies. In contrast, digital zoom includes the process of cropping an image and expanding the remaining portion to fill the original pixel count so the image appears magnified. With digital zoom, the optical resolution is fixed at image capture and the information quantity in the zoomed image degrades with the square of the magnification. As a result, a digitally-zoomed photograph quickly becomes visually unacceptable. For a 3x digital zoom, 91 percent of the information quantity in the captured image is decimated. Nevertheless, digital zoom has the singular advantage of being based on software and is, therefore, physically compact, rugged, virtually instantaneous, consumes negligible power and can be implemented at relatively low cost.

SOFTWARE-ENHANCED LENSES

The sole purpose of conventional camera optics is to replicate a scene onto the imager as closely as possible. Extreme effort is invested in achieving the best possible chromatic and illumination uniformity, frequency-contrast response, and other optical metrics so that the scene presented to the image sensor pixels has the highest possible optical fidelity.

The relatively new software-enhanced lens combines a special lens design with an algorithm that processes the images produced by this specialty lens. The lens manipulates the optical rays to provide an intensity distribution on the camera sensor with desired features. These can include predefined compensation distortion or robust point-spread function behavior for an extended depth of field. In most cases, the manipulated image is not used as is; it needs further software correction. However, because the image was manipulated in a known manner, it can be digitally restored so high-quality output can be extracted. Software-enhanced lenses provide access to some very desirable lens functions, of which optical zoom from fixed lenses is one example.

FIXED-LENS OPTICAL ZOOM

The new solution that overcomes the issues in optical and digital zoom uses a special lens that is permanently fixed in position, while the algorithm is small and time-efficient. This technique can achieve 3x optical zoom that is smaller than mechanical zoom, consumes negligible power, has no moving parts and can be produced affordably, making it a very compelling solution for camera phones.

A software-enhanced lens provides optical zoom by means of a specially-designed fixed lens that provides intentionally non-uniform optical information density over the image area, to match the quantized format of the solid-state imager. This is, in effect, the converse of the approach taken by nature. Many animals with single aperture eyes, particularly birds of prey, have a standard lens, but a non-linear distribution of rods and cones in the retina. In both cases the resulting image is distorted, but can be rectified because the lens design and pixel distribution of the imager (or retina) are known.

The image distortion produced by a software-enhanced optical zoom lens superficially resembles a fish-eye lens. However, the software-enhanced optical zoom lens offers advantages across the zoom range. For a zoom magnification of 1x, the algorithm has to compress details in the central portion of the field of view, where magnification and resolution are increased by the software-enhanced lens. Thus, the compression does not drastically degrade image quality. The software-enhanced lens and its coupled algorithms are designed so that, in this mode, the picture quality is almost as good as in a conventional camera. Therefore, it’s superior to center-zoom in a fish-eye lens, which suffers from excessive border loss on image restoration at low magnification.

For operation of the software-enhanced lens at higher magnifications, the image borders are cropped off, and the already magnified center is retained. The image is then corrected for distortion. This is fundamentally different than digital zoom because magnification is the result of the lens action, so that the zoomed image retains its high resolution. The typical requirement from a zoom system in digital photography is to allow a 3x magnification. The software-enhanced lens technique described here, when fortified with additional cost-effective solution components, can be used to achieve 3x magnification.

A consequential benefit of a software-enhanced lens solution for optical zoom is that the F# of the optics does not vary with magnification, because the focal length is fixed. This avoids a serious deficiency of mechanical optical zoom systems that have poor low-light performance in the zoom state. Another important benefit of this approach is that the height of the lens stack is dramatically smaller than the height required for achieving the same magnification with a mechanically moving zoom apparatus. This leads to a much shorter camera module and thinner camera phone.

The software-enhanced lens solution for zoom is easily implemented. The lens is manufactured and located in the optics train just like standard fixed lenses. The distortion correction is a fixed mathematical transformation. It can be implemented at the end of the image processing chain before jpeg compression, and is sufficiently small enough to be compatible with video frame rate images.

The software-enhanced lens presents a distorted image with boosted magnification and resolution in the central region. A simple algorithm removes the distortion and allows the field of view to vary continuously between the wide and narrow limits of the zoom range. The zoom can achieve up to 3x without loss of information quantity. This approach provides a unique, inexpensive and novel solution to providing the optical zoom feature, while meeting the price, size and reliability constraints of cell phone camera.

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