A study on low-noise high-sensitivity multi-aperture camera with selective averaging

（課程博士・様式７）（Doctoral qualification by coursework,　Form 7）

学 位 論 文 要 旨

Abstract of Doctoral Thesis

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Title of Thesis：
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Abstract：

Extremely low-noise and high-sensitivity that enable to distinguish one electron is desired for observation in very dim scenes and for very weak photon emission. In a low-light camera, low-noise high-sensitivity image sensor and fast small F-number lens for collecting more photons, are required to enhance image quality in low-light conditions. For the conventional single lens, with lens F-number decreasing, the lens becomes bulky and costly. To reduce the noise of CMOS image sensors many methods have been presented. The dark current shot noise is suppressed by a pinned photodiode technology. The reset noise and fixed pattern noise are cancelled by the correlated double sampling technique. Column readout noise can be reduced by the high gain column amplifier. The thermal noise and 1/f noise can be suppressed by the correlated multiple sampling technique. In recent years, the researches for the low noise CMOS image sensors have focused on the large noise, so-called random telegraph signal (RTS) noise, at in-pixel source follower amplifiers especially in deep submicron technologies. Although RTS noise can be successfully reduced by a buried n-channel in-pixel source follow, the thermal noise is increased due to the reduced transconductance.

The RTS noise becomes one of the dominant noise sources in deep-sub-micro CMOS image sensor technology. It causes bright spots in a low-light image, which degrades the low-light image quality. To enhance the low-light image quality, in this thesis, low-light image enhancement using a multi-aperture imaging system with a selective averaging method is studied. The multi-aperture imaging system is designed with an array of both lens and CMOS image sensor to increase signal power. One lens and one sensor constitute an aperture like a traditional single-aperture camera. In the multi-aperture imaging system, multiple images can be acquired simultaneously. However, the images are noisy in low-light condition due to poor signal to noise ratio. The noise levels of the corresponding pixels for a subjective point are different each other due to the random noise in each pixel. Although, noise can be reduced by averaging the noisy images, the bright spots which are caused by large sensor noise components such as the RTS noise and large dark current shot noise, cannot be removed. To make matters worse, the number of bright spots in a reproduced image increases due to averaging, which

greatly degrade the image quality. The selective averaging is proposed to eliminate the RTS noise and large dark current shot noise. In this method, the variance of every pixel value in dark is measured as pre-processing. In aperture selection, the variances of the corresponding pixels for every reproduced pixel are sorted from minimum to maximum, then only the apertures which can minimize a combination variance, are selected. Different from thresholding, the selected apertures are determined by the minimum combination variance. The RTS noise and large dark current shot noise will cause larger combination variance. Thus, these highly-noise pixels are excluded automatically. Note that the selective averaging is operated pixel by pixel in a reproduced image. In real capturing, the selected apertures are used to calculate the average pixel value of reproduced image.

The effectiveness of selective averaging has been verified by simulation and experiment. In the simulation, the effective noise normalized by the optical gain in the peak of noise histogram is reduced from 1.38e^- to 0.48e^- in a 3×3-aperture system using low-noise CMOS image sensor based on folding-integration and cyclic column ADCs. In the experiment, a prototype 3×3-aperture camera is developed. Under a low-light condition, in which the maximum average signal per aperture is 11e^-, the RTS noise and dark current white defects are removed and the peak signal-to-noise ratio (PSNR) of the image is increased by 6.3dB. The performance of selective averaging also demonstrated in color using a 2×2-aperture color camera. The color reproduction errors are quantitatively evaluated by simulation. The root-mean-square in the CIE-xy 1931 color space becomes approximately a half after the selective averaging.