Fast and Robust Camera's Auto Exposure Control Using Convex or Concave Model

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***Abstract*--A fast and robust camera's auto exposure algorithm is proposed by modeling its luminance characteristics as a concave/convex function of a control parameter. A proper parameter value is computed using a modified secant algorithm with fast convergence. The superior performance of the proposed algorithm is confirmed by experimental results.**

I. Introduction

Auto exposure (AE) control is an important function of modern digital cameras. Simple AE algorithms [1]-[3] are designed with respect to a specific type of camera sensors. Advanced AE techniques [4]-[8] have been developed to tackle a wider class of camera sensors and/or high contrast lighting conditions, yet they are computationally intensive and, thus, difficult to implement in a resource-constrained environment such as phone cameras. Besides, none of existing solutions provide robust performance if erroneous exposure occurs. To address the aforementioned issues, we develop a fast and robust AE algorithm with several attractive features in this work. First, it covers a wide variety of camera sensors yet allows fast and simple implementation. Second, it can adjust itself automatically when erroneous exposure happens.

The proposed AE algorithm is based on convex or concave modeling of the relationship between a luminance-related function and the control parameter. It determines the control parameter for a predefined brightness level (*e.g.*, the averaged image pixel value) by a modified secant method.

II. Root Finding for Convex and Concave Function

In numerical analysis, root finding algorithms have been developed to solve $f(X)=0$ for variable X without knowing the exact form of $f(\cdot)$. In this section, we propose a modified secant method to find X for a monotonically decreasing convex or concave $f(\cdot)$ defined between X_{min} and X_{max}.

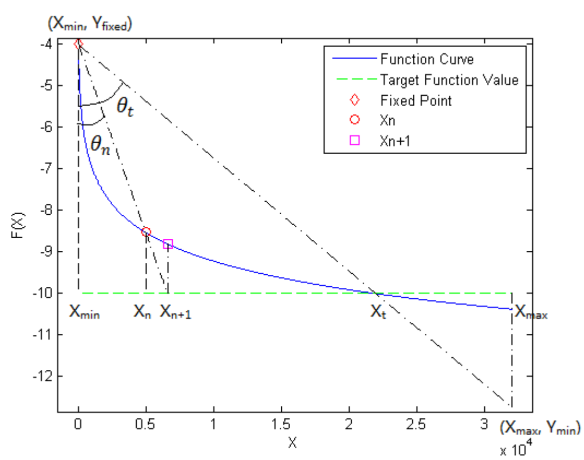


Fig. 1. Illustration of the modified secant method for a convex model in form of $f(x)=-ln(x+20)$, ln is the natural logarithm, $X_{min}=50$, $X_{max}=32000$, $Y_{fixed}=-4$ and $X_n=5000$, and the target function value is $f_t=-10$.

1) Convex Model

As shown in Fig. 1, we have

$$\tan\theta_n=\frac{X_{n+1}-X_{\min}}{Y_{fixed}-f_t}=\frac{X_n-X_{\min}}{Y_{fixed}-f(X_n)}\ . \tag{1}$$

Thus, given an arbitrary initial point x_0, we can calculate new point x_{n+1} recursively as

$$X_{n+1}=\frac{\alpha X_n-f(X_n)X_{\min}+\beta}{Y_{fixed}-f(X_n)}\ ,\ n=0,1,2\ldots \tag{2}$$

where $\alpha=Y_{fixed}-f_t$ and $\beta=f_t\cdot X_{\min}$, and where $f_t=f(X_t)$ is a predefined value chosen by the user. Typically, f_t is set to the mid-value of the full dynamic range, *e.g.*, 128 for an 8-bit image. The above iteration stops if the distance between $f(X_{n+1})$ and f_t (or the distance between X_{n+1} and X_n) is less than some preset threshold. Then, we choose X_{n+1} as the desired solution.

It is worthwhile to point out that we update X_n while fixing a point, denoted by (X_{fixed}, Y_{fixed}), that lies in the top and left-most position of the convex model. In practice, we can set X_{fixed} to X_{min} to meet the left-most condition and set $X_n=X_{\min}+\varepsilon$ where ε is a small positive number if $X_n=X_{min}$. Furthermore, one can set Y_{fixed} to the maximum of the dynamic range plus one (e.g. 256 for an 8-bit image) since $f(X_{min})$ is unknown.

2) Concave Model

By following a similar procedure, we can derive an iterative algorithm to determine the root of a concave model. First, we have the relationship:

$$\tan\theta_n=\frac{X_{\max}-X_{n+1}}{f_t-Y_{fixed}}=\frac{X_{\max}-X_n}{f(X_n)-Y_{fixed}}\ . \tag{3}$$

Then, we can write an iterative formula as

$$X_{n+1}=\frac{\alpha X_n+f(X_n)X_{\max}-\beta}{f(X_n)-Y_{fixed}}\ ,\ n=0,1,2\ldots \tag{4}$$

where $\alpha=f_t-Y_{fixed}$ and $\beta=f_t\cdot X_{\max}$. The above iteration demands a fixed point, which is located in the bottom and right-most position of the function curve for a concave model. Now, we can set X_{fixed} to X_{max} to meet the right-most condition and set $X_n=X_{\max}-\varepsilon$ if $X_n=X_{max}$. Furthermore, one can set Y_{fixed} to the minimum of the dynamic range minus one to avoid Equation (4) being divide by zero.

III. CONCAVE/CONVEX MODELING OF AE FUNCTIONS

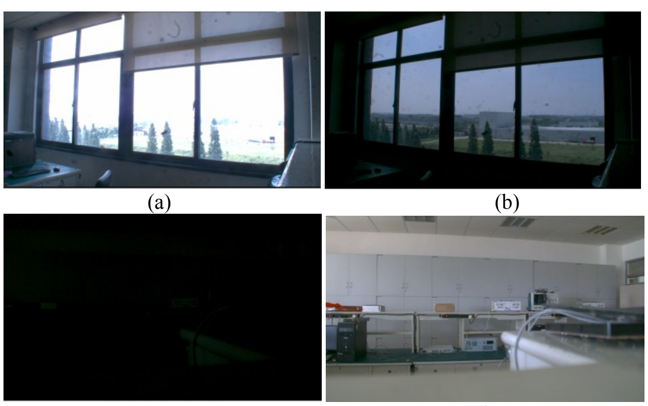
In this section, we show that the AE function of camera sensors does satisfy the convex/concave model requirement. Most digital camera sensors available in the market are linear with their typical dynamic range of 55dB. Such camera sensors often use the exposure time for their control parameter. The so-called linear cameras are actually quasi-linear due to its limited dynamic range and non-linearity introduced during various image acquisition stages [9],[10]. The AE control methods based on a strict linear model do not perform well in practice because of non-linearity. Although it is difficult to model non-linearity, we can characterize it by a convex or a concave model.

A convex model can be created by defining a new control parameter called exposure speed in form of $X=1/T$ where X is the exposure speed and T is the exposure time. Since T is largely linear with respect to image brightness, the exposure speed vs. image brightness response is close to an inverse function, leading to a convex model. Then, the modified secant method presented in Sec. II can be applied to it. Then, new exposure time T_{n+1} can be iteratively updated via

$$T_{n+1} = \frac{[Y_{fixed} - f(T_n)] \cdot T_n \cdot T_{\max}}{[f_t - f(T_n)] \cdot T_n + \alpha}, \qquad (5)$$

where $\alpha = (Y_{fixed} - f_t) \cdot T_{\max}$, $f(T_n)$ is image brightness under T_n, and T_{max} is the maximum exposure time. Typically, f_t is chosen as the mid-value, Y_{fixed} is set to the maximum value plus one and set $T_n=T_{max}-1$ if $T_n=T_{max}$. That is, $f_t = 128$ and $Y_{fixed} = 256$ for an 8-bit image.

IV. EXPERIMENTAL RESULTS



(a) (b) (c) (d)

Fig. 2. The over-exposed scenes before and after adjustment are shown in (a) and (b), respectively. The under-exposed scene before and after adjustment are shown in (c) and (d), respectively.

In this section, we report the experimental results of the proposed AE control method applied to video cameras. The video frame rate is 25 f/s. The camera sensor used in the experiment is CMV4000 with pixel resolution of 2048×2048. The exposure time vs. image brightness response is about linear and its dynamic range given by the instructions manual is 60dB. With observed image brightness, the traditional trial-and-error method increases or decreases the control parameter by a fixed step size until a satisfactory brightness value is achieved. We compare the convergence time and the number of tumbling occurrences of the proposed method with the traditional trial-and-error method and the electronic-centric AE method proposed in [3] in Table I. By tumbling, we mean the alternating image brightness between over-exposure and under-exposure. We show one over- and one under-exposed scenes in Figs. 2 (a) and (c) while the adjusted results are given in Figs. (b) and (d), respectively.

TABLE I
CONVERGENCE TIME COMPARISON

Method	Step Size (in ms)	Convergence Time (in s)		Tumbling Effect	
		Over Exposed	Under Exposed	Over Exposed	Under Exposed
Trial and Error	0.1	11.20	3.36	0	0
	0.25	4.40	1.24	0	0
	0.5	2.24	0.64	0	0
Electronic-centric AE [3]	N/A	0.16	0.56	1	6
Proposed	N/A	0.48	2.6	0	0

The camera may lag in the response occasionally when an updated exposure setting is requested. Such an operation is carried out with the delay of a few frames. The old exposure setting is still used during the transition, resulting in erroneous exposure. The proposed method still performs well under such a circumstance with no tumbling effect.

V. CONCLUSION

A fast and robust AE control method was proposed and its performance was demonstrated, where the key idea is to apply an iterative root finding algorithm to a convex/concave model.

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