Improved Contrast Enhancement Algorithm for Night Vision Systems using Thermal Camera

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Abstract— **Long-wave infrared-based thermal cameras employing uncooled detectors are extensively utilized in the night vision systems of autonomous driving platforms. In these cameras, contrast enhancement process is necessary to transition from low dynamic range to high dynamic range. Therefore, in this paper, we propose an improved contrast enhancement algorithm utilizing histogram equalization with gamma correction.**

Keywords; Thermal Camera; Night Vision; Contrast Enhancement; Histogram Equalization; Gamma Correction

I. Introduction

In the autonomous driving industry, achieving robust object detection and recognition in low-light conditions is paramount. To address this, researchers are investigating night vision systems employing long-wave infrared (LWIR)-based thermal cameras in advanced driver assistance systems (ADAS) for autonomous driving [1], [2].

Uncooled detectors are favored in LWIR-based thermal cameras for autonomous vehicle due to their cost-effectiveness. However, employing uncooled detectors necessitates the implementation of four essential algorithms: non-uniformity correction (NUC), temperature compensation (TC), dead pixel correction (DPC), and contrast enhancement. The processing of these algorithms between NUC and DPC introduces latency due to frame accumulation. Additionally, images generated with these algorithms often exhibit low dynamic range, underscoring the necessity for fast and high-performance. The simplicity in computation is crucial to ensure a fast response for object detection and recognition in real-world driving scenarios.

In this paper, we propose an improved contrast enhancement algorithm utilizing histogram equalization with gamma correction. Our proposed algorithm utilizes three types of images: the bit-depth reduced image and brightness level-adjusted images obtained through gamma correction. By employing three images for the contrast enhancement process, our algorithm offers the advantage of demonstrating above-average visible performance in challenging scenarios (e.g., tunnels).

II. Proposed Algorithm

The proposed contrast enhancement algorithm employs histogram equalization with gamma correction specifically designed for LWIR-based thermal cameras in night vision systems.

A. Depth Reduction

In the depth reduction step, the aim is to decrease the bit-depth form *N*-bit to 8-bit for the contrast enhancement process. This is achieved by applying the depth reduction operation using (1).

$$I_R(x,y) = 255 \times \frac{I_{in}(x,y) - min\,(I_{in})}{max(I_{in}) - min(I_{in})}. \quad (1)$$

where I_R represents the depth-reduced image with 8-bit, while I_{in} denotes the original input image obtained after applying NUC, TC, and DPC. The symbol min and max represent operations to select minimum and maximum pixel values, respectively, for the entire original input image.

B. Gamma Correction

When using only infrared image with extremely low or high brightness levels, the performance of contrast enhancement can be degraded. To address this issue, the gamma correction step utilizes the bit-depth reduced image to generate a brightness level-adjusted image. The brightness level-adjusted image is produced using the general form of (2)-(3).

$$I_{G1}(x,y) = 255 \times \left(\frac{I_R(x,y)}{255}\right)^{(1/\gamma)}. \quad (2)$$

$$I_{G2}(x,y) = 255 \times \left(\frac{I_R(x,y)}{255}\right)^{(\gamma)}. \quad (3)$$

where I_{G1} and I_{G2} represent the brightness level-adjusted images, and γ is the parameter for gamma correction. When the parameter value of γ is increased, the brightness level of the image is also increased. Conversely, when the parameter value of γ is decreased, the brightness level of the image is decreased.

C. Histogram Frequency Calculation

After applying the depth reduction and gamma correction processes, three types of input images are obtained: 1) the bit-

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

Figure 1. Experimental results using conventional and proposed algorithms: (a) 8-bit input image, (b) [3], (c) [4], (d) [5], and (e) Ours.

depth reduced image and 2) two types of brightness level-adjusted images. For software-based algorithm implementation on embedded platforms, histogram frequencies are calculated sequentially using a step-wise approach with the brightness level-adjusted images and the bit-depth reduced image. The operation process of calculating histogram frequencies using these three types of images can be performed using (3)-(5).

produced using the general form of (2)-(3).

$$F(a) = \sum_{x=0}^{N-1} \sum_{y=0}^{M-1} \delta(I_R(x,y) - a). \quad (4)$$

$$F(b) = \sum_{x=0}^{N-1} \sum_{y=0}^{M-1} \delta(I_{G1}(x,y) - b). \quad (5)$$

$$F(c) = \sum_{x=0}^{N-1} \sum_{y=0}^{M-1} \delta(I_{G2}(x,y) - c). \quad (6)$$

$$F(n) = \frac{F(a)+F(b)+F(c)}{3}. \quad (7)$$

where N and M represent the resolutions of the images, δ denotes the Dirac delta function, which evaluates to 1 when the condition is true and 0 otherwise. $F(a)$ represents the histogram frequencies of the bit-depth reduced image, while $F(b)$ and $F(c)$ are the histogram frequencies of the brightness level-adjusted images. $F(n)$ denotes the merged histogram frequencies used to compute the output image in the output value mapping process. Using (4)-(7), the required histogram frequencies for the output value mapping can be computed.

D. Output Value Mapping

After the histogram frequency calculation process, the output value mapping process is performed to compute the contrast-enhanced output image. In this process, the proposed algorithm utilizes a transformation function based on the general histogram equalization technique, which includes cumulative and probability density function, and normalization. Therefore, the output value mapping process can be performed using (8)-(9).

$$T(n) = \left(\frac{255}{N \times M}\right) \times \sum_{n=0}^{255} F(n). \quad (8)$$

$$I_O = \frac{T(I_R)+T(I_{G1})+T(I_{G2})}{3}. \quad (9)$$

where $T(n)$ represents the transformation function used select the value of the output image, and I_O denotes the contrast enhanced output image. To compute the contrast-enhanced output image, three types of contrast-enhanced images are computed using the transformation function, as described in (8), with both brightness level-adjusted and bit-depth reduced images. Subsequently, the final contrast-enhanced output image is computed using the three types of contrast-enhanced images, as shown in (9).

III. Experimental Results

Fig. 1 illustrates the experimental results comparing conventional and proposed contrast enhancement algorithms for night vision systems using LWIR-based thermal cameras. In our proposed algorithm, we set the parameter value of γ to 1.5. Fig. 1(b)-(d) depict the contrast-enhanced output images produced by three state-of-the-art (SOTA) algorithms [3]-[5]. In background regions, it can be observed that our proposed algorithm exhibits similar visible performance compared to the SOTA algorithms. Regarding vehicle object, both the SOTA and proposed algorithms show clear visibility of the object's location.

IV. Conclusion

In this paper, we proposed an improved contrast enhancement algorithm for night vision systems using LWIR-based thermal cameras, employing histogram equalization with gamma correction. When tested in a driving scenario within a tunnel scene, proposed algorithm demonstrated similar visual performance compared to conventional SOTA algorithms.

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