Image restoration from camera vibration and object motion blur in infrared staggered time-delay and integration systems

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Abstract. Time-delay and integration (TDI) arrays are of great interest, especially in connection with civilian applications such as document scanning and industrial product inspection. We consider here a staggered TDI system, in which the even field is delayed with respect to the odd field by 29 pixels. Because of cooling system vibrations and the field differences, pictures become distorted as a result of motion blur. The proposed algorithm improves image quality. We build an analytical model of this system to describe all motion in the picture, including object motion in addition to cooling system vibrations, or either type of motion. We present a number of approaches that can be useful to solve such problems. These solutions are based on different applications of a block-matching algorithm (BMA). Full-search BMA yields the lowest complexity but not necessarily the best image quality. Interpolation BMA yields the best image quality.

Subject terms: vibration; time delay and integration; block-matching algorithm; spline; mean absolute difference; motion-based segmentation; interpolation; motion vector; efficiency; infrared; thermal imaging.

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1 Introduction

The time-delay and integration (TDI) image sensor offers significant improvement in performance over linear CCDs and complementary metal-oxide semiconductor (CMOS) sensors with respect to sensitivity. Many potential applications, such as web inspection, pose a problem for TDI-based control, since the object, the web, is vibrating. This is a more significant problem for TDI cameras than for normal line scan cameras, because of the longer integration time. In the case discussed here, the main degradation source is field misalignment due to staggered topology. It is therefore important to study the effects caused by vibrations, such as those from cooling systems in infrared cameras. Most of this vibration is eliminated by special arrangements such as mechanical tension against a roller or squeezing against a suckbox by underpressure. But in spite of these arrangements, the distance between the web surface and the imaging optics tends to vary severely during inspection in some applications. We consider nonlinear vibrations and various moving objects, such as cars, people, and tree motion, that are not measured by simple detectors. It can be a significant waste of resources to use an expensive high-resolution sensor in a system where resolution is drastically limited by mechanical vibration. Solutions for uniform velocity motion correction were developed in Refs. 1 and 2 by using an analytical optical transfer function (OTF) unique to motion causing the blur. Other types of image motion can now be dealt with by a method of numerical calculation of a modulation transfer function (MTF) according to modulation contrast.3–6 The calculation of modulation transfer function of vibration (MTFV)7 was dealt with by the method developed according to Ref. 4 that uses the probability density function (PDF) of vibrations.8,9 The current distortion problem is not space invariant (SI); hence, not every linear solution is appropriate. TDI construction was described in Refs. 10 and 11. In this work the effects of vibrations are formulated and the solution is unusual, because it is spatially dependent and is not based on any concrete a priori motion model. The various methods described in this article are intended to improve staggered TDI systems. Vibrations of this system were measured. This data is very different from block-matching algorithm (BMA) results, which give us information about the nonlinearity of vibrations. The explanation for this disagreement is that motions of the whole system and the TDI detector may be different. Restoration of the picture is still possible because of the stagger effect or "staircase effect."12 Here, we proposed different approaches for interlace correction and vibration blur correction. The motion-based segmentation algorithm (MBSA) detects regions of moving objects and estimates its movement with time delay between the fields. The obtained block motion vector confirms that there is sufficient interlace correction. Adaptive BMA yields optimal block size to be used with minimum mean absolute difference (MAD). Among the various criteria that can be used as a measure of the match between two blocks,13 the MAD is favored because it requires no multiplication and yields performance similar to that of the mean-squared error (MSE). For an instantaneous field, we denote the intensity of the pixel