Frozen in Time

Image Processing Basics: Moving Objects

A common situation in industrial image processing is to inspect moving objects in a production line. Parts on a conveyor belt, e.g., may drift through the field of view of the camera with constant velocity. Even moderate velocities will result in considerable smear of edges in the image due to the integration time of a standard camera. Lighting and image capture must be carefully triggered to achieve sharp images for proper image processing.

Smear

Transport velocities of several meters per second are quite common when handling parts in a production line. Mail processing or web inspection may well be performed at velocities of 10 m/s. Parts are transported by means of conveyor belts, slides or in free fall, and circumstances call for image capture while the objects are in motion. Figure 1 gives an example of the effects caused by moving objects. A colored chocolate lentil with a diameter of about 1 cm is moving from the right to the left, and the image has been captured with a 50 Hz interlaced camera. With this type of camera, the even field has a delay of 20 ms with respect to the odd field. The edge of the object in the first, third, fifth and so on line of the odd field is considerably shifted with respect to the position in the second, fourth, sixths and so on line of the even field. The edges are frayed like the teeth of a comb due to the delay between the fields. With progressive scan cameras, there are no fields, but only full frames, and the comb-effect can not occur. Nevertheless, edges will be smeared even with progressive scan cameras. Figure 2 shows an example, the so-called hummingbird-moth, a butterfly which is able to hover in front of a blossom by flapping its wings with an unusually high frequency and drinking nectar with its tube-like trunk. The region of the wings is only slightly tinted and completely blurred due to the relatively long integration time of the image.

Even at a transport velocity of 1 m/s an object will be shifted by 1 mm along the direction of motion within 1 ms. A progressive scan camera with a frame rate of 50 Hz, which may nowadays well be considered to be a standard in industrial image processing, features an integration time of 20 ms. An object with a velocity of 1 m/s will thus move through a distance of 20 mm during the integration time. In an image captured under these conditions, an edge will be smeared by 20 mm along the direction of motion. At 10 m/s, the smear will amount to 200 mm. Most image processing applications will break down under these circumstances. With moving objects, much smaller integration time intervals must be chosen to get proper images. The value for the acceptable time interval depends upon the transport-velocity and upon the smear which can be tolerated. In general, the pixel resolution of a camera will be compromised when the smear becomes larger than a pixel. Thus, it seems reasonable to reduce the smear to the dimension of a pixel or below. As an example, let us assume a field of view of b = 100 mm which shall be inspected by a camera with a pixel resolution of 1,000 x 1,000 pixels at a transport-velocity of v = 1 m/s in the direction of the x-axis. The pixel resolution in the field of view will thus be dx = b/N = 100 mm/1,000 pxl, which amounts to 0.1 mm/pxl. In order to reduce the smear below dx = 0.1 mm, the integration time interval has to be smaller than dt = dx/v = 0.1 mm/(1 mm/ms) = 0.1 ms, that is 100 µs or 1/10,000 s. In principle, there are two simple methods to implement these image capture intervals: the electronic shutter or strobe-lighting.

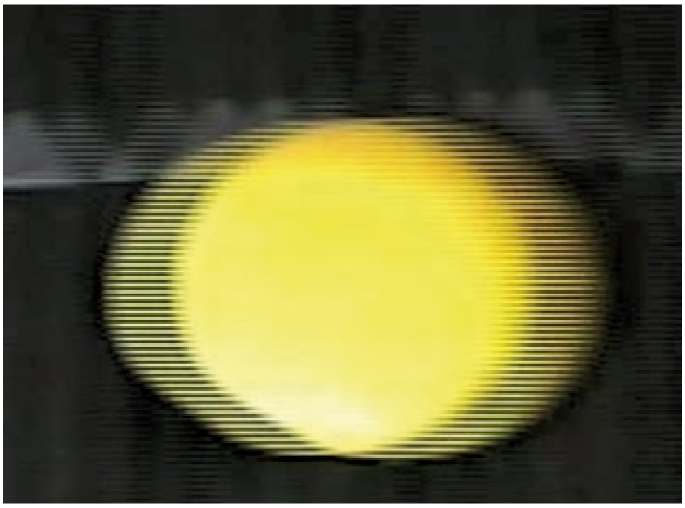

Fig. 1: An object moving from the right to the left, captured with a 50 Hz interlaced camera. The time delay between the odd and the even field causes the comb-like fraying of the edges along the direction of motion.

Fig. 2: Smear in an image captured by a progressive scan camera, to be seen in the region of the fast moving wings of the Hummingbird-moth; integration-time: 25 ms.

Electronic Shutter

The principle of an electronic shutter is depicted in figure 3. A standard camera captures images at a constant frame rate of 50 Hz, e.g. With a progressive scan camera, the charge generated by the incoming light will be accumulated within 20 ms in every detector pixel and read out at the end of the integration time period. The detector sites are empty, and the charges for the next frame may be accumulated. Likewise, a 50 Hz progressive scan camera with electronic shutter will produce a frame every 20 ms. The integration of the charges, however, will be modified: after 19 ms, e.g., the accumulated charges will be drained by a single pulse for all pixels simultaneously, and the array will accumulate charges for the remaining time interval, 1 ms in this case. The detector will then be read out at the end of the standard integration period, producing an image signal corresponding to an integration time interval of just 1 ms. The effective integration time can thus be modified by controlling the drain pulse without need to change the read out timing. An effective integration time of 100 µs as demanded in the example given above may easily be achieved with state-of-the-art cameras. The integration time interval, however, always will be the final part of the regular frame period. Unfortunately, the parts in a production line usually will not be delivered at a constant rate, but will appear asynchronously in the field of view of the camera. Most applications will therefore use a photo sensor to detect incoming parts. The next frame may then be used for image capture. If the sensor is triggered near the end of the frame period, the effective integration time interval will follow within a short time interval after the trigger signal. If the sensor is triggered just after the beginning of a new frame period, there will be a delay of close to 20 ms between the effective image capture provided by the electronic shutter and the trigger signal. Trigger signal and effective image capture may thus suffer a time delay between nearly 20 ms and no delay at all, depending upon the phase of the frame period at the time when the trigger occurs. Within 20 ms, however, an object will move through a distance of 20 mm at a velocity of 1 m/s and by 200 mm at 10 m/s. The image will be sharp, but the position of the object within the field of view will vary by up to 20 mm or even 200 mm, respectively. With a field of view of 100 mm, this “jitter” may be acceptable, but the image processing algorithm has to take care of this situation. With smaller fields of view and higher velocities, however, the object may well be already far beyond the field of view when the electronic shutter becomes active. Thus, the combination of a camera running at a standard frame rate with random phase and an electronic shutter will

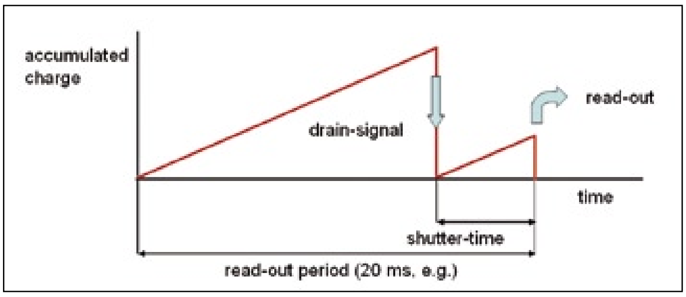

Fig. 3: Principle of the electronic shutter

generally not be the best recommendation for image capture with moving objects. One possible alternative are cameras with a restart/reset-feature. These cameras provide a trigger input suitable to cancel the current frame period immediately, to drain the charges accumulated and to instantly begin with the next frame period. In combination with a photo sensor this feature will result in a constant time delay between the reset signal and the time when the electronic shutter becomes active. With constant transport velocity, the photo sensor can be placed at a defined distance from the field of view of the camera such that the object will move precisely through this distance during the time delay between trigger and the effective integration time period. The object will thus be captured in a sharp image and will always appear at the same position within the field of view. As an alternative cameras with asynchronous shuttering are available. With these cameras the accumulated charge is drained immediately after the trigger pulse, directly followed by the beginning of the desired integration time interval. At the end of this time interval, the image is read out. These cameras are thus not restricted to a fixed frame rate, their image capture timing is asynchronous. Since the integration time period now begins immediately after the trigger signal, however, a time delay of the trigger signal may become necessary, depending upon whether the photo sensor triggers with the leading or the falling edge of the object and upon the distance between the photo sensor and the field of view.

Strobe-lighting

An electronic shutter usually will be used in combination with a DC-lighting device. In the example given above, however, an effective integration time of 100 µs will utilize only about 0.5 % of the available light intensity compared to the standard integration time of 20 ms. As a consequence, the illumination intensity has to be increased by a factor 200 to get image signals comparable to the situation without electronic shutter. A more efficient solution in this situation will be a strobe-lighting like an LED-device, e.g., with a defined pulse length. In the context of the example given above, a strobe time of 100 µs will have the same effect as an electronic shutter with 100 µs integration time interval. Provided that the ambient light level is sufficiently low or may be shielded, the movement of the object will be "frozen" by the LED-strobe, since only within the LED-pulse there will be enough light scattered back from the object to the detector to produce a significant image signal. The camera may be sensitive during the full frame period, and the LED-strobe will form the image randomly at some time during the standard integration time period. As with the electronic shutter, the timing scheme of the strobe illumination should also be triggered by the photo sensor, which detects the incoming object. This signal triggers the restart/reset of the camera und produces the trigger signal for the strobe, eventually after a defined time delay to allow for the movement of the object into the field of view. By this method, the pulse width of the strobe-lighting defines the smear in the image due to the movement of the object, and the time delay between the strobe pulse and the trigger signal at the photo sensor defines the position of the object in the image. In order to be flexible for different requirements, a special additional I/O-board may be helpful, which provides trigger signals for the camera reset and for the strobe unit, a programmable delay and shaping of the trigger signal from the photo sensor with regard to level, polarity and rise time. Convenient frame grabbers with these features are available.

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