White Paper

# Using interline transfer CCD imaging devices in TDI scanning mode

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Almost every modern manufacturing process or apparatus uses machine vision systems. These systems ensure fast, accurate and repeatable results, and therefore guarantee consistent quality over time. The main component of every machine vision system is a camera utilizing either a CCD or CMOS image sensor. While there are many variations of image sensors, most of the cameras utilize interline transfer imaging sensors, which can be generally classed in three categories - area-scan, line-scan or Time-Delay Integration (TDI) devices. While useful in many machine vision systems, area scan image sensors are generally not used for web inspection applications where products need to be scanned across a wide field of view at high-speed. In these applications, line-scan sensor based cameras are used. They often consist of a single row of pixels (usually several thousand) that are exposed sequentially as the camera (or more often the object to be inspected) moves under the field of view of the camera. Since the integration time for such high-speed imaging needs to be short, high-brightness line-lights are used to illuminate the object. In some very high-speed line-scan applications, however, even the brightest line-scan lights may not provide enough illumination. In such cases, TDI imagers can be used to increase the responsivity of the imaging system. TDI imagers are a variant of line-scan devices that feature multiple rows (stages) of photo-sensors. As the object moves under the TDI array, each of the multiple rows shift charge to the adjacent row synchronously providing multiple exposures of the same scene, the final line-scan image when read from the imager will have a much higher sensitivity. Increasing this sensitivity is useful in high-speed web applications and applications such as aerial reconnaissance and satellite mapping where low-light levels may be encountered. Unfortunately all line-scan TDI imaging sensors have significant drawbacks – the resultant image is not two dimensional – in all cases it is only a one dimensional line image. Also, the number of TDI stages is factory pre-determined and cannot be changed by the user, and in most cases the number of stages is always divisible by 2. Furthermore, the direction of scan is preset by the TDI manufacturer and cannot be changed. This imposes severe restrictions on a variety of applications.

The existing TDI techniques have been limited to line-scan like imagers, but it is possible to use the ordinary area scan interline transfer CCD imaging devices in TDI scanning mode, which allows the user to obtain a high resolution area-scan image with very high sensitivity from any conventional interline transfer CCD imager. This TDI scanning mode can be achieved by a series of exposures and shifts, resulting in a two dimensional image. If the user is imaging a scene with a fast moving object, the resultant image will be produced by accumulation of many spatially shifted image frames, thus providing a plurality of motion synchronized exposures of the same scene and object. The big advantage of this method is the user's flexibility to change the timing parameters on the fly. The exposure time for the individual frames, as well as the number of shifts (N) can be adjusted in order to achieve the required image quality and/or to track an object, whose motion is not constant. The resulting accumulation of multiple images provides a stable image with much higher image sensitivity. If the exposure time of each individual frame is 100 microseconds and 200 shifts are performed, for example, then the effective frame exposure time will be 20 ms. The TDI scanning mode can be applied to Mono, Bayer (RGBG or YCMG) color or SPARSE CFA imagers without any restrictions. It also can be applied to imagers with multi-tap structures, where the Interline transfer CCD has a top-bottom symmetry and well defined horizontal CCD registers, present at the top and the bottom of the chip (such chips with quad structure are available from On- Semi and SONY). With such an imager we can perform a bidirectional TDI scan where the shift direction can be set to be towards the top or towards the bottom of the imager. This bidirectional TDI mode can be used to track an object with a fast periodic (pendulum like) motion – such operation is not possible using conventional TDI imaging sensors.

Another significant benefit of utilizing a conventional interline CCD imager for TDI scanning is that a normal image can be produced by simply switching the mode back and forth between TDI and conventional area scan. This TDI scanning mode is very useful in applications, where a fast relative motion between the camera and the object is present, such as in low altitude flying platforms (drones, planes, helicopters or low-orbit satellite reconnaissance systems). If a normal camera is used, the integration time must be very short in order to avoid motion smear. In such applications controlled lighting is usually not possible, so TDI mode of operation is useful in increasing the sensitivity of the imager while retaining the ability to image full image frames.