Encoder – Nanometric Resolution Absolute Position Encoders

P. Masa, E. Franzi, J. Pierer, J.-M. Mayor, C. Urban, D. Fengels

Linear, rotary and 2D optical, absolute position encoder principle combines several competitive features such as sub-nanometric resolution over practically infinite range, up to 1 MHz sampling rate, compact design, optic-less imaging and robustness. As an example, a linear encoder with standard, VGA-size image sensor can reach 60-bits dynamic range, which can cover 1'000'000 km range with a 1 nm resolution. The proofs of concept demonstrators are built from off-the-shelf components such as miniature USB camera and LEDs.

Novel linear, rotary and 2D optical, absolute position encoders, combining several competitive features such as 26-bit resolution per 100 mm, compact design and robustness, were built and demonstrated. The principle of operation is shown in Figure 1. The position of the code-plate with respect to the imager is measured. The light emitted by the LED traverses through the code-plate while being modulated by the code pattern and finally captured by the image sensor. High-resolution absolute position information is obtained by processing the typically ten-thousand-pixel image.

Figure 1: Main components of the position measurement: the pattern on the code-plate is projected on to the image sensor.

The pattern on the code-plate is composed of two different markings: (1) a binary code and (2) a regular grating. A 2-dimensional proprietary code example is shown in Figure 2. In this case the regular grating is composed of an array of squares while orientation of the diagonal bars encodes the 2D absolute position. Coarse absolute position is obtained by decoding the binary code, which is seen at a given position by the sensor. Within one period of the binary code, a fine position measurement is attained by Fourier analysis of the regular grating at the fundamental frequency. Robustness, precision and very high resolution is guaranteed by heavily oversampling the pattern (typically 12-24 pixels per pattern period) and relying on the phase information which is distributed in the entire image among thousands of pixels.

Figure 2: The 2D pattern of the code-plate is projected to and captured by the image sensor. Absolute position is encoded by the bar-orientations. Regular grating facilitates high-resolution position measurement within one code-period.

Thanks to the large number of pixels and the innovative image processing, the smallest detectable displacement is 1/100'000-th of the pattern period (100 micrometer), less than 1/1000-th of the pixel-dimension (5 micrometer) and is typically below 1 nanometer. The combination of the coarse and the fine measurements yields very high-resolution over practically infinite range. Because the principle uses information distributed over the complete field of view, neither precise marking nor complex optical substrates are required. For example, in reflective setup, laser marking on metal or plastic substrate is suitable.

Figure 3: Absolute encoder demonstrators: 1-Dimensional linear encoder (right) and 2-Dimensional encoder (left).

System implementation is highly flexible. In a basic configuration as shown in Figure 3, the code-pattern is illuminated with a LED; the image is captured on a standard USB camera and the signal is processed on an external CPU yielding up to 300 Hz sampling rate. A more compact, higher-speed configuration uses an image sensor/DSP integrated circuit, such as the CSEM “icycam”[1] ASIC with the 32-bit “icyflex” processor providing up to 10 kHz sampling rate. Finally, to fully optimize size, speed, cost and power consumption a dedicated encoder ASIC is used, whose design is specific to the application[2]. Such solutions may provide few cubic centimeter encoder solutions reaching 1 MHz sampling rate.
