

NANOMETRIC RESOLUTION ABSOLUTE POSITION ENCODERS

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ABSTRACT

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.

1. 1D MEASUREMENT PRINCIPLE

An optical absolute position encoder technology developed at CSEM has the potential to combine all the above mentioned attractive features. Nanometric resolution has been established using ultra-compact USB camera, linear glass scale and LED illumination without the need for optics, as shown in Fig. 1. and Fig. 2. 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 10'000 pixel image.

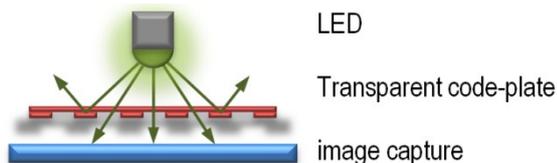


Figure 1. Main components of the position measurement: the pattern on the code-plate is projected on to the image sensor.

Optic-less shadow-imaging permits compact design and major cost reduction. Note that the detectable displacement is several hundred times smaller than the wavelength of the light and only 10 times larger than the diameter of the silicon atom. High-speed opto-ASIC implementation by CSEM proved that sampling frequency of such an encoder may exceed 1 MHz [1]. The very high resolution absolute position measurement is achieved with a double track marking as shown in Fig. 3. Coarse absolute position measurement is obtained by decoding the subsection of the Manchester code (upper track of Fig. 3) typically 8-16 bits, which is seen at a given position by the sensor. Fine relative position measurement is attained by Fourier analysis of

the regular grating (lower track of Fig. 3) at the fundamental frequency. Robustness, precision and very high resolution is guaranteed by heavily oversampling the pattern (typically 8-16 pixels per pattern period) and relying on the phase information which is distributed in the entire image among hundreds or thousands of pixels.

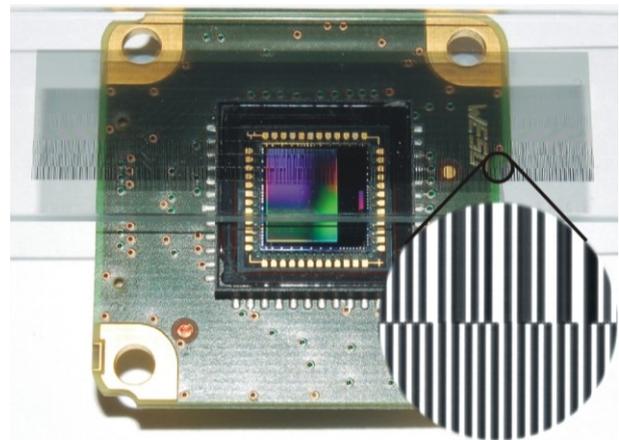


Figure 2. Shadow imaging experimental setup consisting of a compact USB camera, transparent scale and LED illumination (LED not shown here)



Figure 3. Image of a double-track linear scale consisting of a 12 bit Manchester code and 100um regular grating. Image obtained by ultra-compact USB camera and shadow imaging.

The fine measurement principle is shown in Fig. 4. One possible interpretation of the method is that each pixel represents one point in the "cloud of measurements" and the center of gravity gives the final result. The combination of the coarse and the fine measurements yields very high-resolution absolute position, typically 26 bits for a Ø 32 mm rotary or 100 mm linear encoder. The maximum attainable resolution scales linearly with the diameter of the rotary or with the length of the linear encoder.

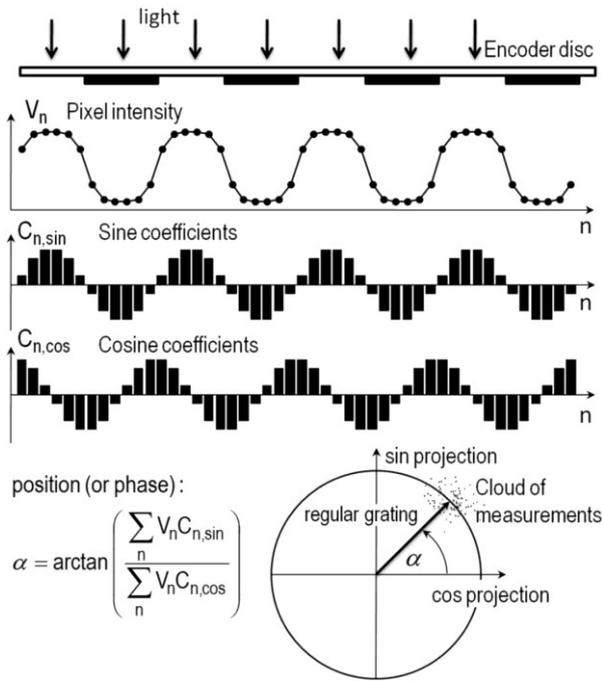


Figure 4. Outline of a robust, high-precision position measurement principle

2. 2D MEASUREMENT PRINCIPLE

The above mentioned 1D measurement principle can be extended to 2D. 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 Fig. 5. In this case the regular grating is composed of an array of squares while orientation of the diagonal bars encodes the 2D absolute position.

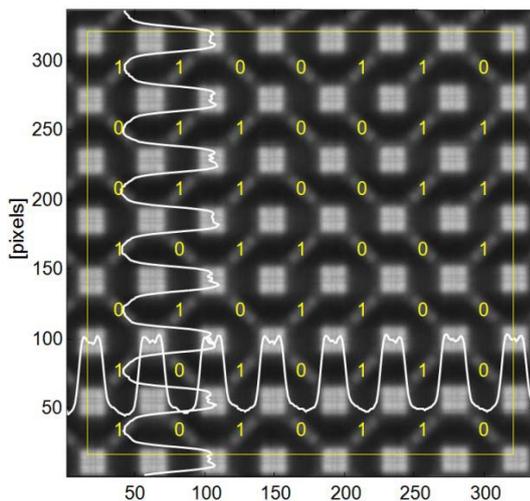


Figure 5. The 2D pattern of the code-plate is projected to and captured by the image sensor. Absolute position is encoded by the bar orientations. Regular grating facilitates high-resolution position measurement within one code period.

Coarse absolute position is obtained by decoding the binary code, which is seen at a given position by the sensor. 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. Similarly to the 1D case the combination of the coarse and the fine measurements yields very high-resolution over practically infinite range. Because the principle uses information which is 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.

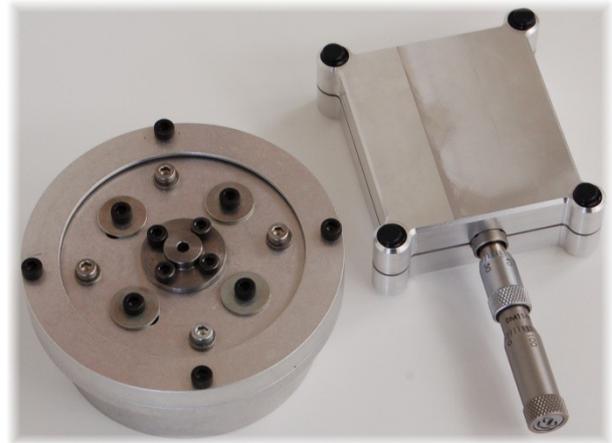


Figure 6. Absolute encoder demonstrators: 1-Dimensional linear encoder (right) and 2-Dimensional encoder (left).

3. FLEXIBLE SYSTEM IMPLEMENTATIONS

System implementation is highly flexible. In a basic demonstrator configuration as shown in Fig. 6, 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 ASIC [2] [3] 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. Such approach may provide smaller than 1 cm³ absolute encoder solutions reaching more than 1 MHz sampling rate.

4. ENCODER PROTOTYPING PLATFORM

A flexible, customizable prototyping platform is under development, which is based on the icycam SOC (System On a Chip) [2] [3]. The image captured by a 320 x 240 HDR (High Dynamic Range) pixel array is

processed in real-time on the same chip by the 32-bit icyflex processor [4]. Prototyping of 1D rotary, linear, 2D, 3D and 6D position encoders are supported by this platform. Thanks to the single chip, general purpose imaging and computing architecture optical encoder prototypes can be developed quickly. These prototypes may fit in a few cm³ volume, may reach up to 10 kHz sample rate and can provide absolute position measurement up to 6D with nanometer resolution.

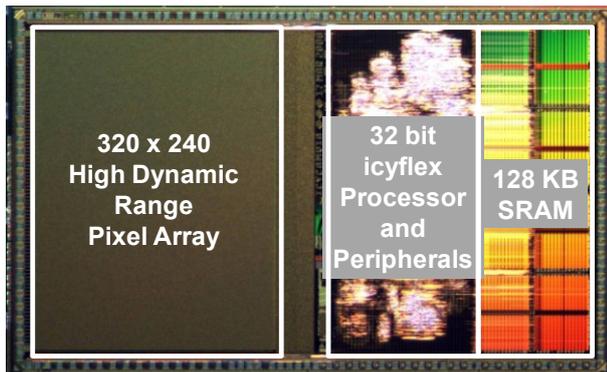


Figure 7. icycam SoC with main blocks highlighted

Icycam, illustrated in Fig. 7, is a major step toward a single chip vision system, which is also suitable for optical encoder applications. It incorporates on a single chip a QVGA (320 by 240), 132 dB intra-scene dynamic pixel array, a processor and memory. The 32-bit, 50 MHz icyflex processor [4] has a 64-bit data path and 128 Kbytes internal SRAM is used as data and program memory. It can be complemented by an external memory via a 100 MHz SDRAM interface. A wide range of interfaces are available to improve flexibility and ease of use: PPI, SPI, GPIO, UART and JTAG. The icyflex processor benefits from a dedicated graphical processing unit able to perform simple arithmetic operations on 8- or 16-bit data grouped in a 64-bit word in order to relieve the processor from repetitive tasks (e.g. difference between 2 images). The pixel array achieves a sensitivity of 6 V/lx/s, while the dark current at room temperature represents 44 mV/s. The pixel size is 14 by 14 μm^2 with a 20 % fill factor. The total chip area is 44 mm². Power consumption is 80 mW with a 1.8 V supply voltage for the digital part and 3.3 V supply voltage for the analog part.

CONCLUSIONS

Novel, nanometric resolution, absolute optical encoder technology has been presented and demonstrated. 1D linear, rotary, 2D, 3D and 6D encoder demonstrators have been built using off-the-shelf components. An encoder prototyping platform is under development using the icycam SOC. The prototyping platform facilitates quick prototyping of peak-performance, optical, multidimensional, absolute position encoders.

5. REFERENCES

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