Talbot Effect Increases spaceCoder Resolution by more than One Order of Magnitude

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An innovative configuration of the spaceCoder allows a dramatic increase in the performances of the spaceCoder technology by using the diffraction pattern generated by the periodic grating. Opening new horizons for the spaceCoder technology.

The spaceCoder [1] technology, invented and developed at CSEM, is an absolute measurement system based on shadow imaging. It consists in the detection of the position of a light source in its field of view with high precision and accuracy. The regular pattern of a reticle fixed on an imager is shadowed on its pixel array and processed with a Fourier-like algorithm, providing the position of the light source.

The aim here is to enhance the spaceCoder sensitivity by increasing the lever-arm effect of the technology (Figure 1). This means increasing the distance between the imager and the shadow mask (regular grating), but this effect degrades the signal due to interferences (diffraction). The use of a regular pattern enables us to turn this drawback into an advantage by working with the Talbot effect.

The Talbot effect is a diffraction effect: when a plane wave is incident upon a periodic diffraction grating, the image of the grating is repeated at regular distances away from the grating plane. The regular distance is called the Talbot length (Z_T), and the repeated images are called Talbot images. At regular fractions of the Talbot length, sub-images can also be observed: for example, at three quarters of the Talbot length, the self-image is halved in size, and appears with half the period of the grating, this creates a Talbot carpet pattern, see Figure1. The Talbot length Z_T depends on the light wavelength λ and the grating period a: $Z_T = 2\,a^2 / \lambda$.

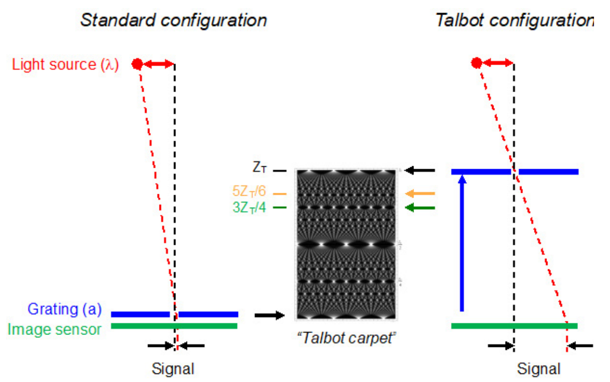

Figure 1: Lever-arm effect illustration between spaceCoder standard and Talbot configurations, Sub-periodicity effect illustration for particular Talbot distance fractions (orange and green positions).

As an example, a standard spaceCoder configuration consists of a regular pattern (period a=100 µm) fixed at 1 mm of the sensor active area, illuminated by a near-infrared source (λ=850 nm). Placing the pattern at the Talbot distance (Z_T=23.5 mm) allows the imaging of a pattern shadow without any diffraction effect (Figure 2). At 1 m distance, a 100 µm lateral displacement of the light source induces a displacement of the shadow signal of 100 nm in the standard configuration and 2.4 µm in the Talbot configuration, increasing the detection resolution by a factor of 24. Moreover, placing the pattern at twice the Talbot distance ($2Z_T$) provides an increase by a factor close to 50 whilst maintaining a good image quality. This lever-arm effect has been measured for various multiples of the half-Talbot distance, the enhanced measurements matching with the theory.

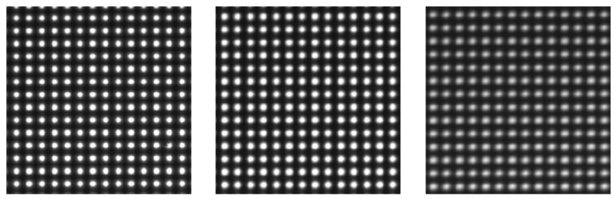

Figure 2: Image of a 100 µm regular grating in spaceCoder standard configuration (left) and in Talbot configurations, placed à Z_T (middle) and $2Z_T$ distances (right).

The measurement resolution can also be enhanced by an additional multiplicative sub-periodicity effect: In the spaceCoder technology, the signal precision is relative to the observed period. Placing the regular grating at a given Talbot distance fraction, where sub-periods are observed, provides an enhancement of the precision by the period multiplicative factor. For example, the precision enhancement is doubled at $3Z_T/4$ distance and tripled at $5Z_T/6$ distance (Figure 1, resp. green and orange arrows).

Both of these enhancements (lever-arm and sub-periodicity) can be combined, and their effects are multiplicative, allowing in such conditions to increase the spaceCoder resolution by more than two orders of magnitude, leading to the detection of displacements of the light source that are not perceptible with the standard configuration. The spaceCoder Talbot configuration has been successfully tested on large incident angles (>60°) with different combinations of pattern period (a), illumination wavelength (λ) and Talbot distance (Z_T) fractions and multiples.

Finally, this new Talbot configuration allows the use of very small grating periods to achieve even higher precision. Using such small periods was previously not possible with the standard configuration due to the substantial noise from diffraction. This is now resolved by placing the regular grating at a specific Talbot distance as this provides a clean Talbot image without interferences.

An absolute code can be designed in the regular pattern (for example with missing holes) to implement high-resolution absolute encoders based on Talbot effect. Such absolute code implementations have already been successfully tested.

This new patented Talbot configuration gives great perspectives for the spaceCoder technology. Practically, this solution appears applicable in many situations, providing higher precision, higher resolution and potentially higher accuracy. Next developments in spaceCoder industrial projects may include this new approach to achieve performances previously not possible.

[1] E. Grenet, *et al.*, "spaceCoder: a nanometric 3D position sensing device", CSEM Scientific and Technical Report (2011) 89.