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A novel magnetic absolute angular encoder for robotic applications

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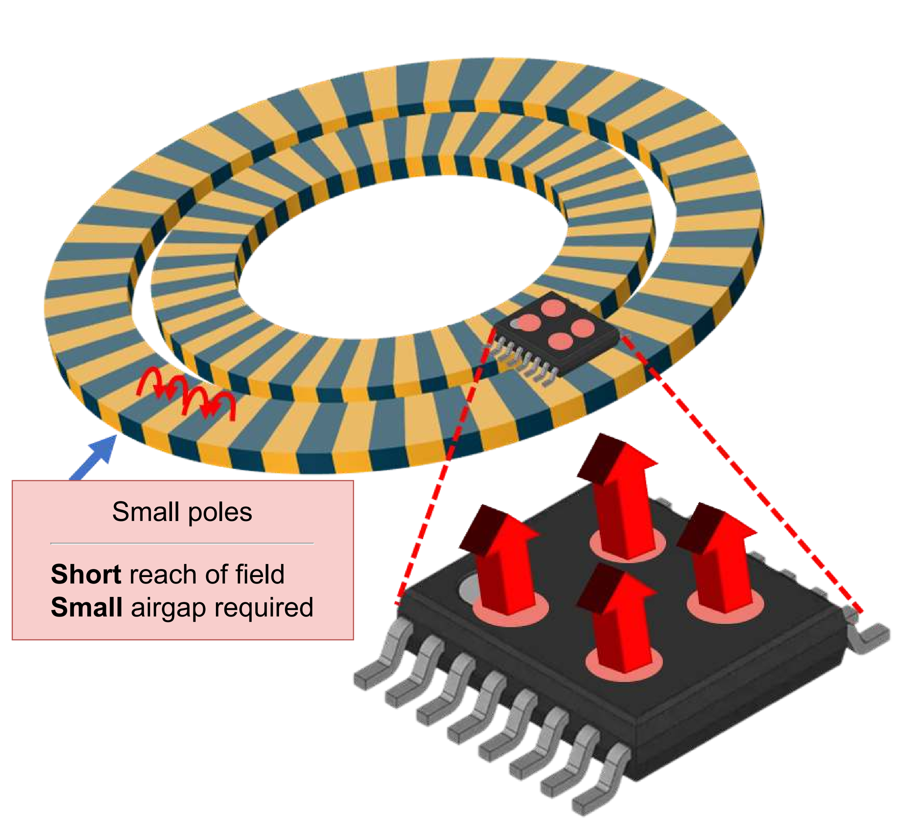
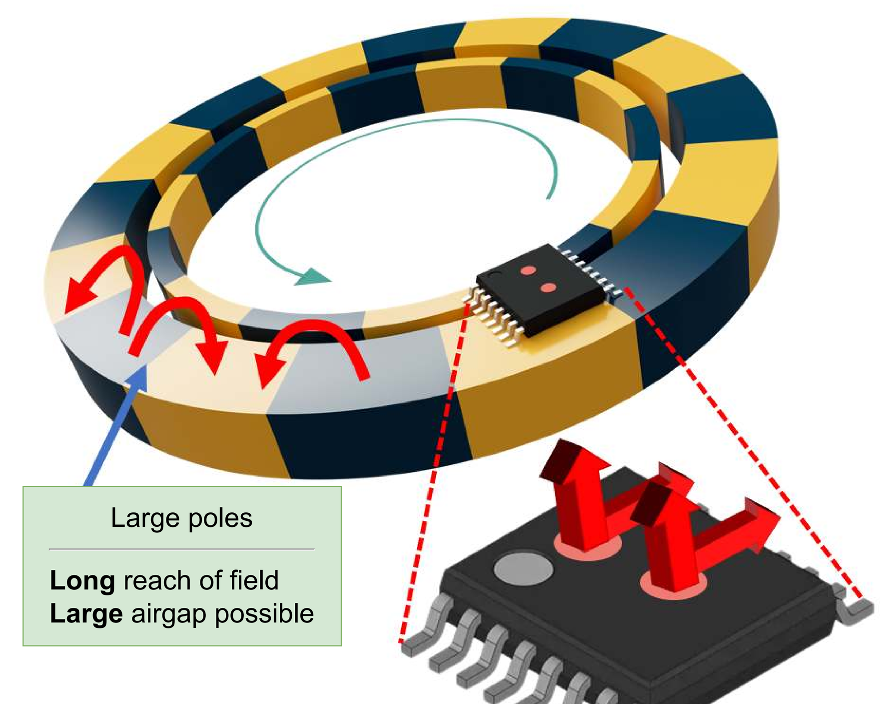
State-of-the-Art



This Work

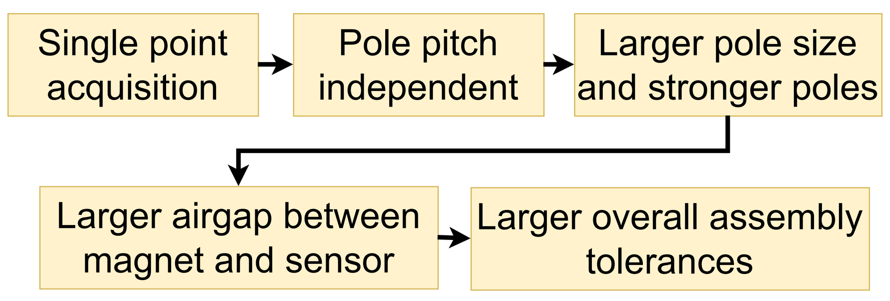


Angular Encoder Benchmark

Device	Technology	Accuracy	Resolution*	Power
[5]	Magnetic	10 bit	14 bit	50 mW
[7]	Magnetic	12 bit	18 bit	265 mW
[4]	Inductive	15 bit	20 bit	425 mW
[12]	Optical	14.5 bit	23 bit	650 mW
[11]	Magnetic	14 bit	19 bit	650 mW
This work	Magnetic	13 bit	17 bit	100 mW

*Resolution is the RMS noise in a bandwidth of 500 Hz

The key feature of this work is the use of only one master and one nonius sensing spot each measuring two orthogonal magnetic field components (B_t and B_a) that are naturally in quadrature (e.g. one represents a SIN and the other one a COS function).



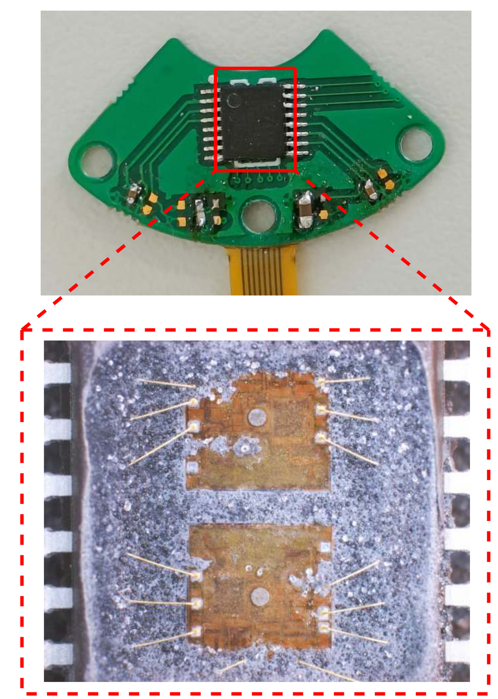
System Components

The Magnet

The dual-track magnet has an outside diameter of 24mm and an inside diameter of 14mm. The two magnetic tracks are separated by a 1mm code-free region. The outer master track contains 16 alternating north/south poles (8 pole pairs) with a pole pitch of about 4mm. The inner Nonius track contains 14 alternating north/south poles (7 pole pairs). The 1mm thin Nonius track is strong enough to determine the sector on the Master track and weak enough to generate only small crosstalk to the Master track sensor.

The large poles allow for an operating airgap of 1.5 +/- 0.5mm between the sensor surface and the magnet surface. This is about 3 to 5 times more than typical state-of-the-art magnetic systems.

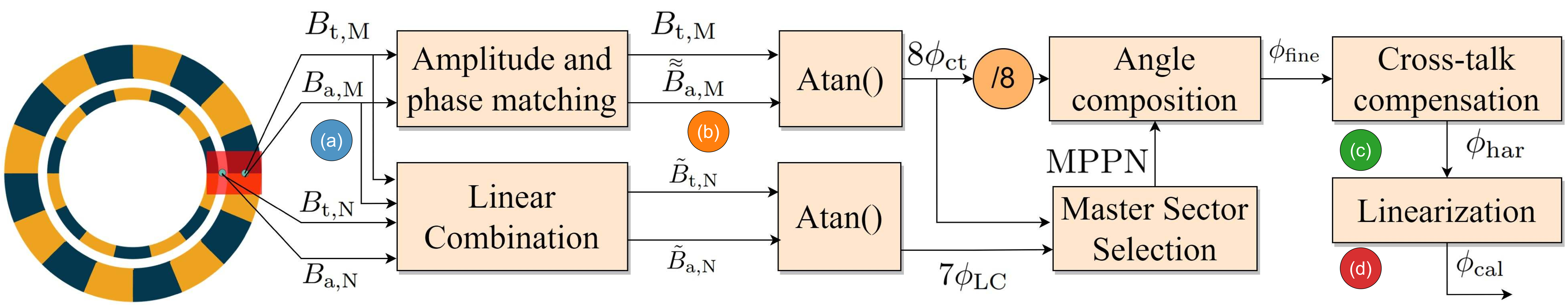
The Sensor



The sensor is composed of two Melexis triaxis magnetic sensors assembled side-by-side on the leadframe of a standard TSSOP16 package with a footprint of 5x5mm.

The integrated CMOS circuits contain all necessary electronics for transducing the magnetic field components into electrical signals, for signal amplification, filtering, AD conversion and 10MHz SPI communication

The Signal Processing Chain



Each of the two sensors is exposed to a mixture of magnetic field components on both of its orthogonal axes

$$B_{t,M} = B_m \cos 8\phi + c_1 B_n \cos 7\phi$$
$$B_{a,M} = B_m(1+\alpha_1)\sin(8\phi+\theta_1) + c_2 B_n \sin(7\phi+\theta_2)$$
$$B_{t,N} = B_n \cos 7\phi + c_3 B_m \cos 8\phi$$
$$B_{a,N} = B_n(1+\alpha_2)\sin(7\phi+\theta_2) + c_4 B_m \sin(8\phi+\theta_1)$$

In a first step the amplitude and phase of the two Master track components are adjusted and the Nonius signals are reconstructed by a linear combination of all four magnetic field signals.

$$B_{t,M} = B_m(\cos(8\phi) + k_1\cos(7\phi))$$
$$\tilde{\tilde{B}}_{a,M} = B_m(\sin(8\phi) + k_2\sin(7\phi))$$
$$\tilde{B}_{a,N} = d_1 B_{t,M} + d_2 B_{a,M} + d_3 B_{t,N} + d_4 B_{a,N}$$
$$\tilde{B}_{t,N} = d_5 B_{t,M} + d_6 B_{a,M} + d_7 B_{t,N} + d_8 B_{a,N}$$

In a second step the Master angle and Nonius angle are computed and composed to yield the fine angle

$$8\phi_{ct} = \arctan\left(\frac{\tilde{\tilde{B}}_{a,M}}{B_{t,M}}\right) = 8\phi + \epsilon_{ct}$$
$$7\phi_{LC} = \arctan\left(\frac{\tilde{B}_{a,N}}{\tilde{B}_{t,N}}\right)$$
$$\phi_{fine} = \mathrm{MPPN} \times 45^\circ + (8\phi_{ct} \mod 360^\circ)/8$$
$$\phi_{fine} = \phi + \epsilon_{ct}/8$$

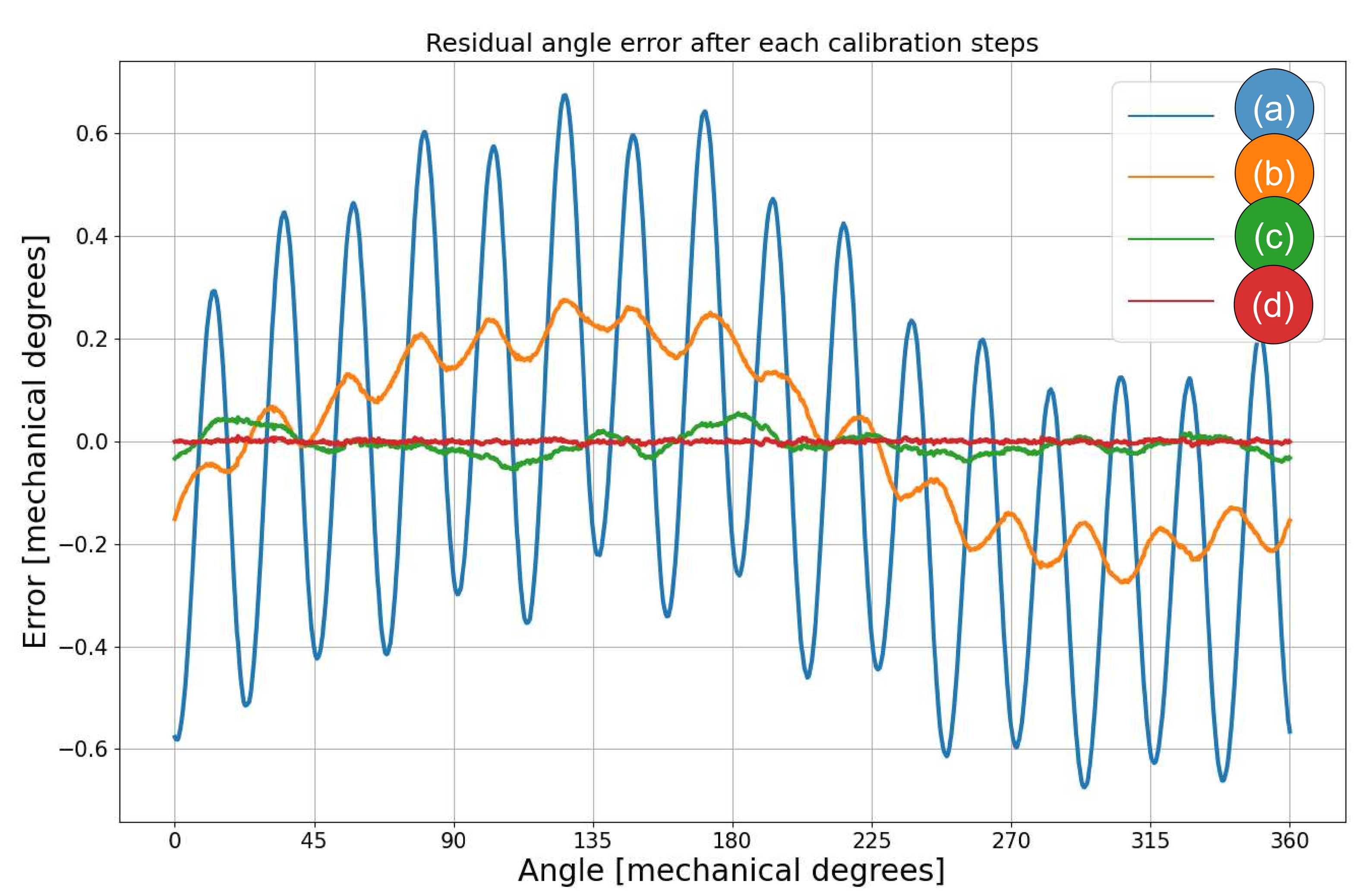
The third step consists of compensating the two structural error components arising from cross-talk between the tracks as well as from eccentricity

$$\phi_{har} = \phi_{fine} - \sum_{h\in\{1,15\}} j_h \sin(h\phi_{fine} + p_h)$$

By the fourth and last step the imperfections of the magnet are compensated via the correction values stored inside a look-up-table (LUT)

$$\phi_{cal} = \phi_{har} - f_{LUT}(\phi_{har})$$

Residual Angular Error vs. Calibration Steps



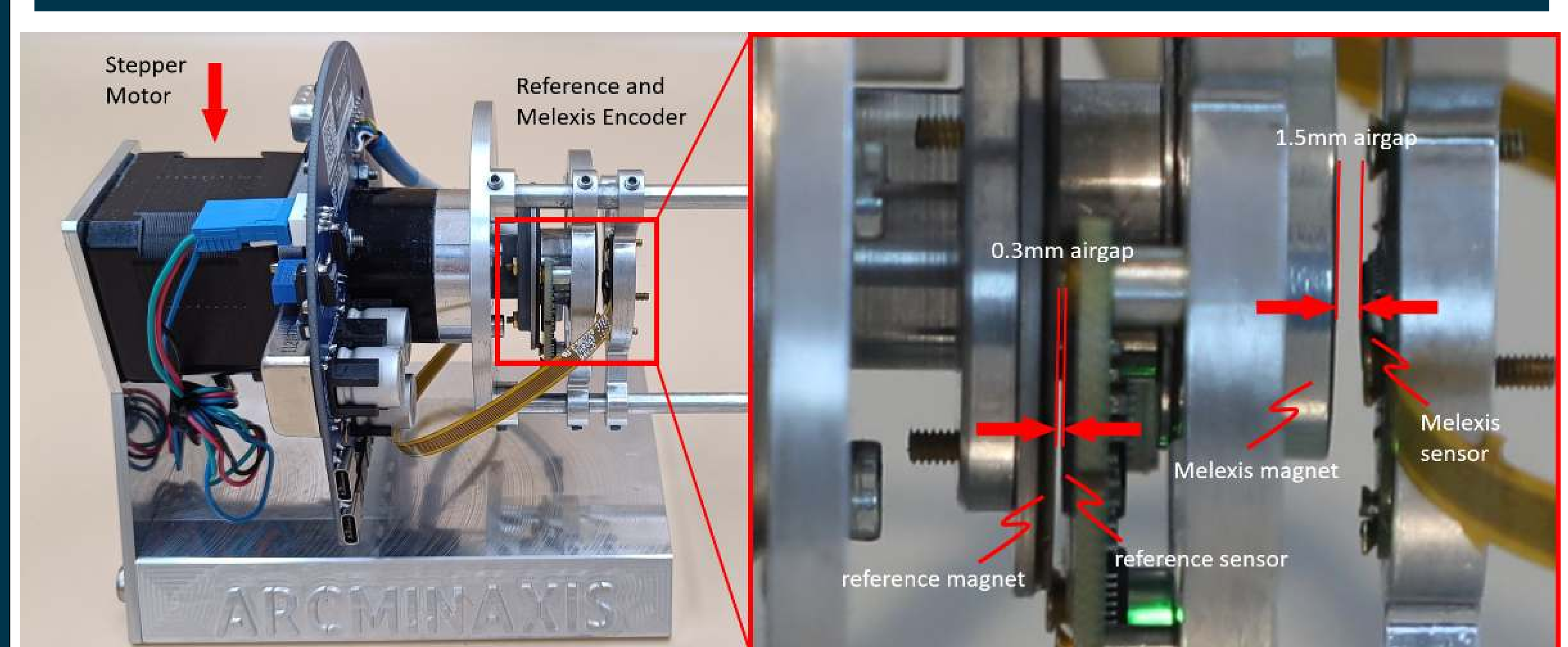
(a) The uncalibrated angle error is mainly affected by a 16th harmonic.

(b) The 16th harmonic is removed by amplitude and offset correction. We are left with the 15th and 1st harmonics

(c) The cross-talk compensation removes the 1st and 15th harmonics

(d) The linearization step corrects the remaining non-linearities

The Demonstrator



The image shows an implementation of the system together with a reference system. Notice how the reference system requires a very small air gap due to the very fine pole pitch used by this technology. The system accuracy is better than 0.03° over the full 360° rotation. The achieved RMS resolution at the nominal airgap is 17 bit (0.003°).

References

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