RECENT ADVANCES IN ANGLE ENCODER TECHNOLOGY

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ABSTRACT
Surveying instruments like theodolites or laser scanners become smaller, more light-weight and easier-to-use while at the same time improving measurement performance. To allow this trend, the angle encoder, a crucial element of such an instrument, also needs to shrink. In this paper, we show how we were able to halve the diameter and the height of an angle encoder, while maintaining or even improving the angular performance. To this end, the alignment of the optical elements is changed, the mirror is integrated into the disc and the compensation algorithms were extended to account for harmonic errors of higher order.

KEYWORDS: angle encoder, coded disc, compensation algorithm

INTRODUCTION
Angle encoders are commonly used in theodolites, laser scanners, laser trackers or portable measuring arms to provide precise angular information of the captured measurement points. To achieve highest accuracy, an optical measurement principle is typically used. An optical angle encoder consists of an electronic board containing light sources, line sensors, and a microcontroller or an FPGA, a disc with an absolute code, and some mirrors to reflect and project the code onto the line sensors. The code on the disc is often produced lithographically and consists of radially aligned strokes, which are absolute and continuous [1]. Figure 1 (a) shows the basic operating principle of a single read head of the angle encoder and Figure 1 (b), the printed circuit board (PCB) of an angle encoder with four read heads. Multiple read heads help to remove harmonic errors and improve the angle encoder performance. Two opposite read heads are sufficient to remove eccentricity errors, whereas four read heads allow to account for Pi-periodic errors which are for example introduced by a tumble of the disc with respect to the rotating axis.

As these instruments become smaller and smaller while the system accuracy should remain the same, the angle encoders need to shrink as well. In this paper, we try to highlight recent advances to halve diameter and thickness of an angle encoder while maintaining the angular accuracy.

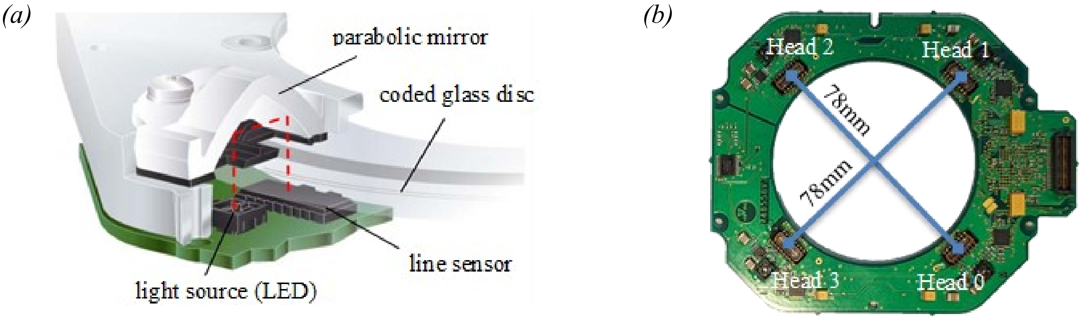

Figure 1: (a) operating principle of an angle encoder read head, (b) HA80 angle encoder PCB of the highest-end theodolite consisting of four read heads with 78mm sensor distance.

HARDWARE CONCEPT
Thanks to technical advances in electronics and integrated circuits, shrinking the PCB by a factor two is quite straight-forward. Figure 2 (a) shows the angle encoder PCB, where we have a sensor distance of 40mm. The LEDs are assembled on the opposite side of the line sensor, but upside-down such that the hole of the PCB also becomes an aperture to avoid stray light. To become more compact in height, different concepts for the optical path have been developed, where we integrate the mirror into the glass disc. Figure 2 (b) shows the mirror disc approach, where the light is reflected forth and back between upper and lower mirror. The light needs to have a certain path length to illuminate the entire line sensor. This concept leads to the most compact solution but has quite stringent requirements on the mirror quality (reflectivity, defects) and manufacturing tolerances. Figure 2 (c) shows the thick disc concept, where we only require a mirror on the bottom side of the disc. The thickness of the disc is selected such that the entire line sensor is illuminated with only a single reflection. The requirements on the mirror reflectivity and the tolerances are reduced compared to the mirror disc solution.

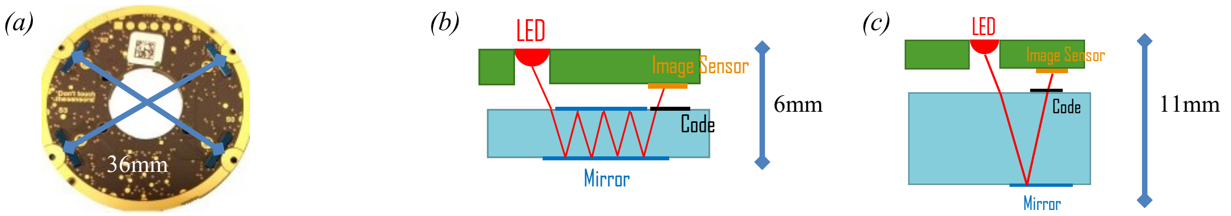

Figure 2: (a) Angle encoder PCBA with 36mm sensor distance, (b) Mirror disc principle with multiple reflections, (c) thick disc principle with a single reflection.

ALGORITHM IMPROVEMENTS

Shrinking the sensor distance by a factor 2 increases the noise by the same factor. Furthermore, imperfections in the manufacturing process and the assembly of code disc and PCB will not scale with the diameter. Therefore, their impact becomes more pronounced. To keep the angle encoder accuracy performance, several measures have been developed to reduce the impact of those errors and achieve similar performance as the HA80 angle encoder used in highest-end theodolites and laser trackers. To improve performance, during assembly of the instrument, each angle encoder is self-calibrated, i.e., without any external reference, to determine the individual compensation factors for each read head and each pixel of the line sensor. Furthermore, Figure 2 (a) shows that the two pairs of opposite read heads are no longer aligned perpendicular [2]. This allows us to observe harmonic errors of higher order than just π-periodic errors and can also be compensated in the mentioned self-calibration step.

RESULTS AND DISCUSSION

Table 1 compares the measurement results of the HA80 angle encoder with the HA40 angle encoders developed for the latest laser scanners and portable measuring arms. Measurements are carried out on a dedicated jig, where we use a highest-accuracy off-the-shelf angle encoder as reference. Accuracy denotes the standard deviation to the reference encoder over a full rotation. The accuracy number in Table 1 represents the tolerance for master discs, i.e., angle encoders are typically below this number. Noise is the standard deviation when all harmonic errors would be compensated.

Table 1: Key performance parameters for different encoder configurations

Encoder	Sensor distance	Height incl. comp. w/o connector	Disc type	Accuracy (1σ)	Noise (1σ)
HA80	78 mm	20 mm	separate mirror	1.3 µrad	0.38 µrad
HA40	36 mm	6 mm	mirror disc	2.0 µrad	0.6 µrad
HA40	36 mm	11 mm	thick disc	0.8 µrad	0.38 µrad

With the HA40 angle encoder and the thick disc, we achieve a slightly better performance than the HA80 encoder, which has more than twice the diameter. The thick disc gives a factor of 2 in accuracy compared to the mirror disc. Also, the noise is significantly reduced and on par with the HA80 encoder. The explanation for this improvement is that by the multiple reflections at the upper and lower mirror of the mirror disc the point source, required for a clean projection of the code on the line sensor, becomes an extended one.

CONCLUSIONS

In this paper, we showed how we were able to halve the diameter and reduce the height of an optical angle encoder while maintaining the performance. Two key contributions are explained: asymmetric alignment of the read heads allows to observe harmonic errors of higher order, and the thick disc concept where the mirror is integrated on the disc and PCB holes serve as aperture for the illumination with the LEDs. These smaller high-performance angle encoders allow us to design more compact surveying instruments to capture the real-world and build digital twins on reality capture platforms like HxDR.

REFERENCES

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