Image Processing of an Absolute Rotary Encoder for Determining Torque

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ABSTRACT

In this article image processing of a binary single track code for determining torque is presented. The aim of the research is to determine the absolute angular position of a shaft and the applied torque. For capturing an image of the binary code two independent imaging modules are used, both allowing for measuring the angular position and rotational speed. Combining both imaging modules, torque can be determined. Position markings are directly applied on the shaft using a laser to ensure a simple integration of the system into any application. The selected technological approach is based on a contactless measurement method using angle differences. The concept of image processing as well as first research results are presented for determining the angular position twice and thus the torque applied to the shaft.

1 INTRODUCTION

The knowledge of current torque and rotational speed is an essential prerequisite for precisely controlling automated systems as well as monitoring their power. In [1] the concept of a novel non-contact torque measuring method was presented. Existing industrial applicable measuring systems, that detect rotational speed and torque, do not offer combined, non-contact and direct measuring methods. Most measuring methods detect absolute angular position and torque separately by means of rotary encoders and torque transducers. This separate detection, however, results in some disadvantages: often the measuring devices are incompatible to each other, inaccurate, require a lot of installation space and increase the weight and costs of the entire system. Furthermore, in most cases existing measuring systems require constructive changes and additional attachments to the measuring shaft which increases the weight as well as the installation effort.

Various methods to measure torque, rotation speed or rotation angle separately are already presented in literature, and therefore are not described in this paper. But it needs to be mentioned that a trivial interconnection of existing technologies is not possible for technological and economical reasons. Hence the development of a combined system for measuring torque and rotational speed is required.

2 STATE-OF-THE-ART

In the following methods for determining the angle of rotation of rotary encoders are presented.

Basically it can be distinguished between incremental and absolute angular position encoders which can be differentiated by contact and non-contact measurement methods [2]. These, in turn, can be classified by the underlying physical principal. Optical, magnetic, capacitive and inductive measurements play an important role. Typical methods for optical angle measurements are, for example, four-field scanning, utilization of the Vernier-principle (also known as the Nonius-principle) or Gray-coding. In each case these show different advantages and disadvantages. Other measurement methods and additional functional principles as well are already described in literature in detail, so that no further description follows at this point. For further information see [2, 3, 4, 5, 6].

Subsequently the current development of optical angular position encoders is mentioned, as they operate wear free and provide relatively high resolution. The measurement method presented in this paper also belongs to these encoders.

Conventional angular position encoders are based on expensive coding discs made of glass and applied markings made of chromium. HOPP et al. investigate a replacement with plastic discs which are produced based on the relatively cost-effective DVD-injection molding [7, 8]. The presented measuring method is based on diffractive grids that are applied circularly as measuring elements. A laser diode is used as a light source and guided through optics to the diffractive grids and photodiodes. A resolution of the angular position of more than 14 bits (equivalent to an angular division of about 0,022 °) and an accuracy of about 0,064 ° are achieved.

Existing optical rotary encoders are used with high quality markings with clearly defined edges for example prepared by photolithography.

The measurement system presented in this paper uses markings directly applied to the steel surface. Due to the fact that these are not specially treated for low surface roughness, the surface contains defects and characteristic properties from manufacturing. Therefore existing optical technologies for determining the rotational angle are not applicable and hence the development of a new system is required.

3 CONCEPT OF THE ENCODER SETUP FOR DETERMINING TORQUE

The solution presented in this paper is based on measuring absolute rotational angle twice and thus torque by two independent measuring modules (imaging modules) in combination with a processing module. In each case the imaging modules capture the markings applied to the shaft (solid cylinder). The markings are applied using a laser process and serve as location encodings. By the use of the two imaging modules two absolute rotation angles are detected. Using the equation presented in [1] the applied torque can be calculated from the angular difference. Furthermore the rotational speed and thereby the power can be determined.

The imaging modules in each case consist of a CMOS array, a pulsed LED, a beam splitter and corresponding optics for imaging, focusing and image correction. The LED's light is guided to the shaft, reflected and then detected by the CMOS. Depending on the shaft's rotational position a different area of the coded markings is visible, which can be imaged directly and processed by the processing module, see *Fig. 1*. A short exposure time by means of short LED pulses allows sharp images at high rotational speeds of the shaft, as they e. g. appear in gearboxes or turbines.

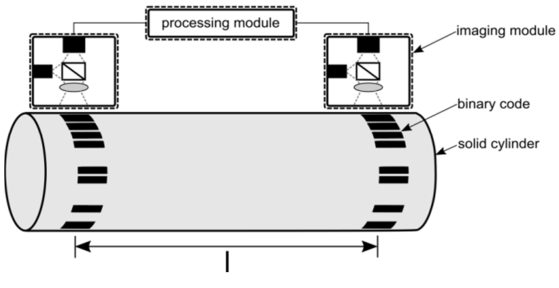


Fig. 1 Setup for determining the absolute angle twice and thus torque (simplified representation)

4 IMAGE PROCESSING OF THE ANGLE ENCODER

Existing approaches for pattern recognition (e.g. lines) [9] are offered by the so-called Hough-transformation and threshold method. In this paper the Hough-transformation is used for angle correction first to reduce possible tilting between the laser markings and captured images and to minimize influences of error. For subsequent image segmentation the so called „Otsu's method", a threshold method, is utilized. Additionally a 1D-lowpass filtering in the direction parallel to the markings is applied to reduce the influence of the characteristic surface quality on the image processing. Finally a field of interest (FOI) is chosen to increase the image processing speed on the one hand and to suppress artifacts of the lowpass filtering on the edges on the other hand. Fig. 2 shows the schematic process.

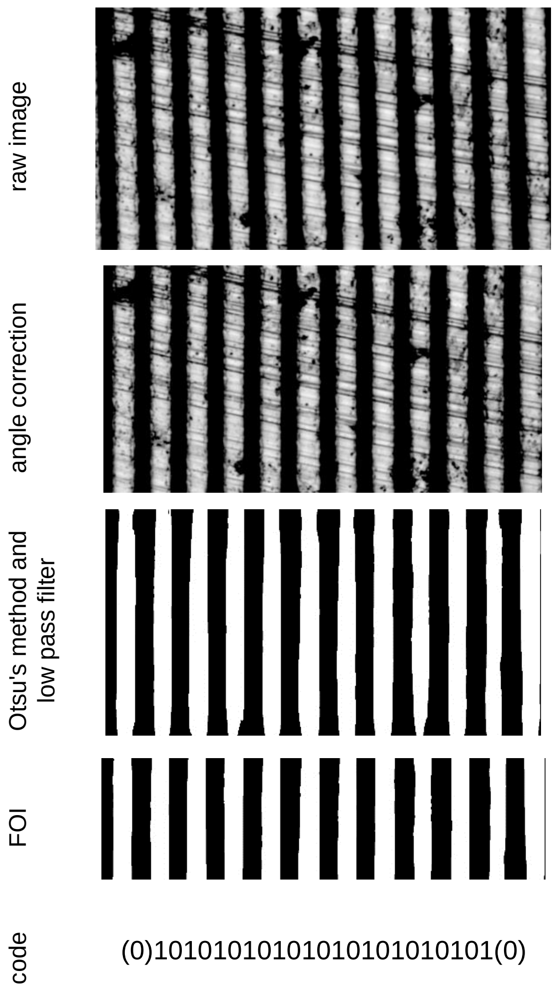


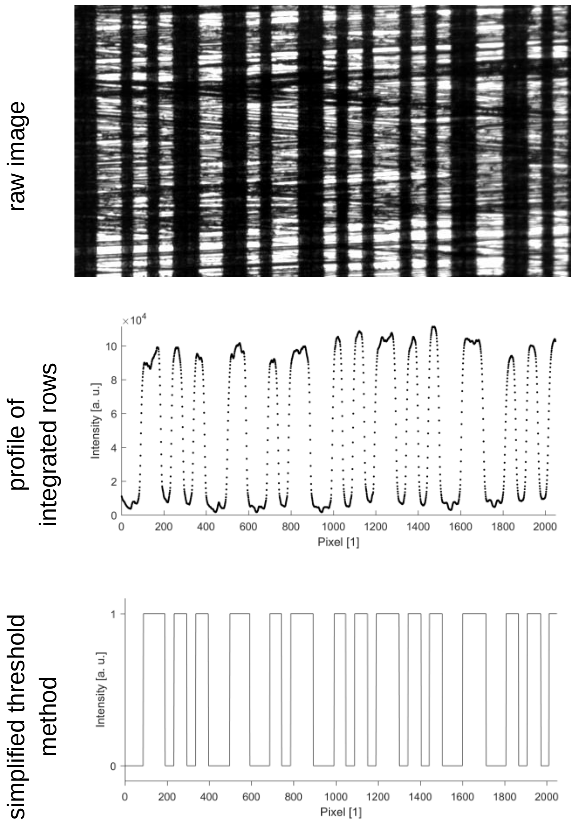
Fig. 2 Example of image processing using the Hough-transformation and Otsu's method

After coding the code section can be compared with the complete code, from which the angular position can be determined.

5 RESULTS AND DISCUSSION

First experiments of image evaluation with MATLAB showed that the method described in chapter 4 is suitable for determining the present coding. However, good results can only be achieved if no contamination or defects of the shaft surface exist. Furthermore based on stopwatch timer it is notable that the elapsed time of the image processing is highly due to the mentioned imaging operations. Due to these two effects the less complex approach descried in the following is analyzed.

Initially the image’s size has to be reduced as soon as possible. A second approach for decoding the image is shown schematically in Fig. 3.



code (0)11010100110010110010101101010 011001010(1)

Fig. 3 Example of image processing using the profile of integrated rows

In this approach, the raw image is transformed from 2D to 1D by integrating the brightness values vertically (parallel to the laser markings). In the next step, a simplified threshold method is used to differentiate between a binary 0 (laser marking) and a binary 1 (no laser marking). Based on the different widths of the laser markings a single marking (0 or 1) can be distinguished from a double marking (00 or 11), thus the image section can be decoded.

The following calculation of angular information proceeds in further steps. An approximate positioning of the code section within the complete code is possible by trivial comparison. A subsequent exact positioning can be achieved, for example, by an offset calculation of the first total marking. An even more precise position detection results from using a Gaussian fit in the raw image, so that the center of a marking can be assigned exactly, independent of the quality of the edges, for example.

6 CONCLUSION

Approaches to possible image processing were presented. A first approach to perform line detection via Hough-transformation and threshold value generation according to Otsu was implemented and tested successfully. However, this approach seems not practicable due to computation-intensive imaging operations. Therefore a further approach was examined. In a second approach the image is transformed from 2D to 1D and a threshold value generation is applied. By means of a „Gaussian fit“, the exact angular position can be identified using the determined marking widths.

Next, further investigations on decoding the absolute angular position and the angular difference between the two imaging modules with a subsequent implementation in C++ are performed. Then the applied torque can be determined.

7 ACKNOWLEDGEMENTS

The IGF project 18200 N of the German Research Association for the Application of Microelectronics (DFAM) is funded via the German Federation of Industrial Research Associations (AiF) in the program of Industrial Collective Research (IGF) by the Federal Ministry for Economic Affairs and Energy (BMWi) based on a decision of the German Bundestag.

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