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TR2020-145 November 25, 2020

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International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)

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I. INTRODUCTION

ENCODER has been widely used for detecting position change in various motion and systems. Optical encoders are the most commonly used in industrial applications, but in severe environment dust and dirt can result in a loss of measurability of optical signal. Magnetic encoders have resistance to such environment, but the working distance between a sensor and a scale is limited since the magnetic field intensity follows the inverse cube law. Our motivation is to realize an encoder with environmental resistance and wide gap tolerance, as a position sensor for motion systems and mobile body systems in severe environment.

To this end, we focus to use THz bands, since THz wave has the robustness to the ambient condition [1]. To achieve the wider gap tolerance than the conventional encoders, which detect position based on the intensity information, our idea is to use the polarization information. Fig. 1 (a) shows the schematic diagram of the proposed THz polarimetric encoder [3]. The encoder consists of a THz sensor head and a periodic linear array of polarizing plates. Here, we define that the polarization parallel to the moving direction as "H" and vertical to the moving direction as "V". When we scan the received signal intensities of two orthogonal beams along the scale, we obtain the two signal traces I_H and I_V (Fig. 1 (b)), which can then be converted into differential signal I_H - I_V as shown in Fig. 1 (c). The position can be determined by extracting the change of sign in the differential signal. In this paper, we simulated polarization dependent reflection signals using the ray-tracing modeling. Position errors for the intensity-based detection, like conventional encoders, and the proposed polarization-based detection were compared under various conditions.

II. SIMULATION AND RESULTS

We assumed propagation of continuous wave (CW) Gaussian beams with the frequency of 0.3 THz and used the ray-tracing modeling. We assumed that the optical axis of the vertically and horizontally polarized beams are ideally aligned to coaxial and that the received signal intensity for these two beams are balanced. We defined displacement and rotation of the THz sensor head using four parameters (gap distance, roll angle, pitch angle, and yaw angle) as indicated by red arrows in Fig. 1 (a). Here, the roll and pitch angle were simulated within 6 degrees at most. To consider different focusing conditions, we varied a diameter of focusing lens from 10 to 50 mm. As a scale, we defined a periodic linear array of polarizer plates (20 mm×20 mm). We assumed the polarization dependent reflectance for the polarizer plates of uni-directional carbon fiber reinforced plastic plates used in [4].

We simulated the polarization dependent received signal for "H" and "V" polarized beams along the scale. We found that the gap displacement causes a periodic variation of the intensity due to standing wave. The roll and pitch reduces the received signal intensity due to beam roll-off and specular reflection. The yaw decreases the intensity due to the reduced orthogonality between the polarization of the beam and polarizer plates. Fig. 2 shows the simulated encoder signals under (a) rolling and (b) pitching condition. Focal length and diameter of the lens are 100 mm and 10 mm, respectively. For both rolling and pitching condition, the amplitude of the encoder signal become half when the angle becomes 5 degrees due to beam-roll off and specular reflection. For pitching condition, the zero crossing offset in the negative position direction, since the beam spot geometrically shift along the moving direction depending gap distance and pitch angle. The signal has also become asymmetric, because vignetting of the returning beam prevent the influence of polarizing plate away from the sensor in the direction of travel.

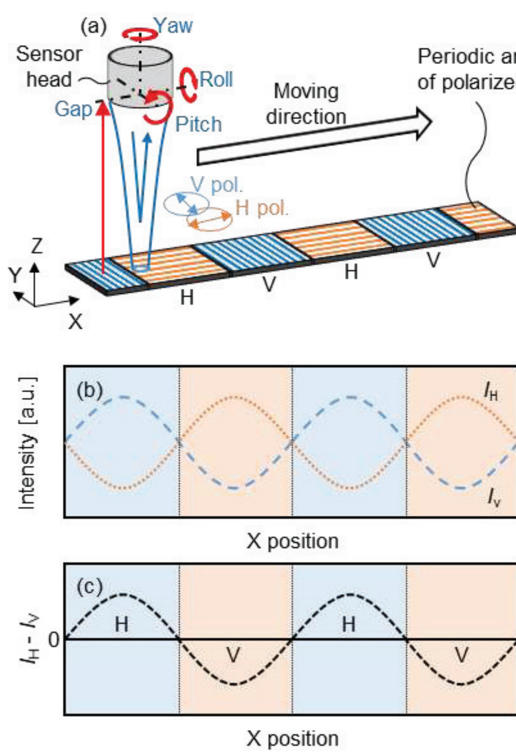

Fig. 1. Schematic diagram of (a) proposed THz polarimetric encoder, (b) signal traces of I_H and I_v using two orthogonally polarized beams and (c) differential signal intensity I_H - I_V using two orthogonally polarized beams.

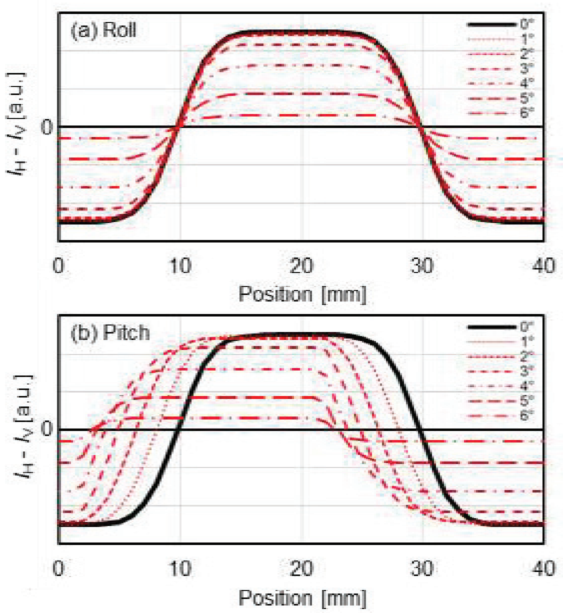

Fig. 2. Simulated encoder signals under (a) roll condition and (b) pitch condition. Focal length and diameter of the lens are 100 mm and 10 mm, respectively. The results under 0 and 5 degree are shown in bold for clarity.

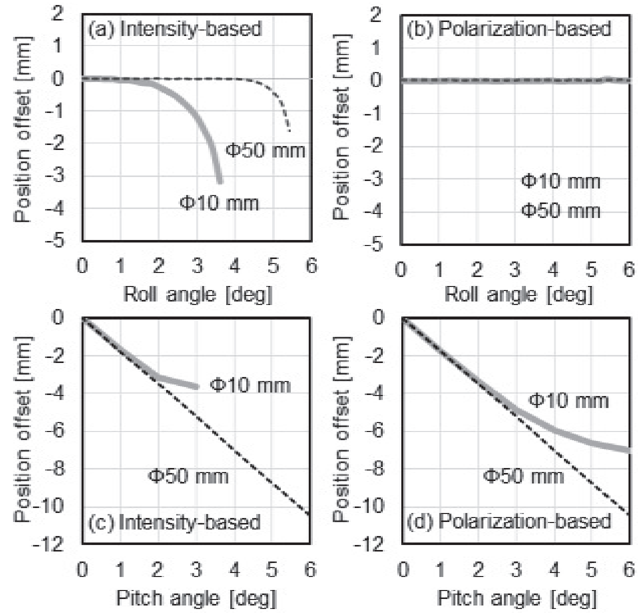

Fig. 3. Simulated position errors for (a, c) conventional intensity-based detection and (b, d) proposed polarization-based detection under roll and pitch condition.

To describe the roll and pitch induced position errors, Fig. 3 (a) shows the rolling induced position errors for the intensity-based position detection. The result showed that the errors increase with the rolling and that the error can be kept small by using a larger lens. This behavior could be explained as tightly focused beam prevented the reduction of the signal intensity due to beam roll-off. Fig. 3 (b) shows the position errors for the proposed polarization-based detection. We found that the rolling and the diameter of the lens have little effect on the error since the use of polarization prevents the change in signal intensity. Fig. 3 (c) and (d) show the pitching induced position errors for the intensity-based and polarization based detection, respectively. As mentioned before, we observed the geometrical offset and that the offset deviates from the linear due to the vignetting when the diameter of the lens becomes small. These results suggest the proposed encoder has superior robustness against the rolling independent of its beam spot size. Since the use of tightly focused beam makes it possible to narrow the scale pitch, the resolution can be increased. Therefore, the proposed encoder has potentials to achieve wider gap tolerance.

III. Conclusion

This paper reported the simulation results of the THz polarimetric encoder using the ray-tracing modeling. The encoder signals and the position detection errors are simulated under various sensor displacement conditions. For future efforts, to experimentally evaluate the performance of the encoder under various environmental conditions.

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