

# Differential Microscopy Improvement Techniques Based on Position Sensitive Detectors

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**Abstract**—Position Sensitive Detector (PSD) have applications in microscopy systems. In our previous research, the many error factors that are caused by the pincushion-type distortion of these sensors were investigated and addressed to significantly reduce signal to noise ratio in PSD and the microscopy system. To achieve further improvements for the microscopy system an algorithm based on localized differential method can be used. This novel approach is implemented in this research resulting in significant improvement in the precision of the microscopy system.

**Keywords**— Differential Microscopy; Position Sensitive Detector; Localized differential method; Microscopy systems; PSD; Sensor calibration;

## I. INTRODUCTION

The optical position sensor includes a wide range of devices. One of them is the position sensitive detector or PSD. This sensor has been used in many applications including the atomic force microscopy [1]. This shows the range of applications that this sensor can cover. Still providing a precise measurement using the PSD is one of the challenges that is addressed in many researches.

The PSD is most commonly used as the lateral effect PSD (LEP). Despite dedicated and carefully optimized technology, the position sensing accuracy and sensitivity of LEPs are poorer than those of photodetector arrays such as CCDs [2]. This has led investigations in using the CMOS monolithic calibrated position-sensitive detectors [3]. Another application of these PSD in techniques including Laser Scanning Microscopy [4][5].

Some variations of the Laser Scanning Microscopy include CCDs [6] or they are based on using PSDs [7]. Using the Lateral Photoeffect is the common practice among these approaches [8]. In any case, these techniques are limited to 2D scanning and there very few successful approaches that include 3D reconstruction of the scanning although the original scanning was done in 2D [9].

Multiple different methods were suggested for performing measurements on the PSD. One of them is using the pulse amplitude modulation scheme [10]. The other technique is by using a local scanning of the object on the PSD [11][12]. Similarly, another approach was proposed by implementing a system for differential phase measurement [13]. The most interesting approach in this regard is the development of a LPS sensor system where PSD sensors are used as IR signal detectors [14].

The most important factor in improving the problem of non-linearity of the PSD is solving the problem of the accuracy of measurements in these techniques. Song et al improved the non-linearity of the PSD significantly [15] but this is still an ongoing challenge.

There are many approaches to enhance the measurement accuracy of the PSD, but still the SNR problem that causes the most important and boldest effect on the precision measurement of the PSD is left to be solved.

The proposed method in this research is investigating improvements in solving the non-linearity of the PSD. In addition to the simulation performed in MATLAB and PSpice, a model of the system was built to test the applicability of the proposed method. The presented results further confirmed the improvements that was seen in the computer simulation section.

## II. Methodology

A semiconductor position sensitive detector (PSD) has been used widely for mark position determination apparatus. Conceptual configuration of PSD and an equivalent pin-cushion PSD circuit is shown in Fig. 1

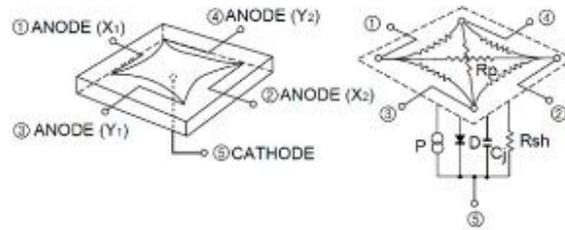


Figure 1. The pin-cushion PSD and its internal circuit.

To better illustrate the function of the PSD, a sectional cut is presented. Fig. 2 shows a sectional cut of a one-dimensional PSD that uses a uniform P-type resistive layer. The 2-D tetra-lateral PSD works based on the same principle too.

Photoelectric current flows between the resistance layer and the bias layer at the light incident point, then the output currents are detected from output terminals. By operating the output currents, the image position can be obtained according to the following equation:

$$X = xw = \frac{(I_b - I_a)w}{2(I_a + I_b)}$$

Usually, these operations are performed by adopting an analogue circuit at high speed.

Improvements to mitigate the pincushion-type distortion of the PSD by strengthening the scanning lines of the PSD microscopy system has been achieved by Rahimi et al [16] using the Brown’s distortion model [17]. This was also investigated by Villiers [18].

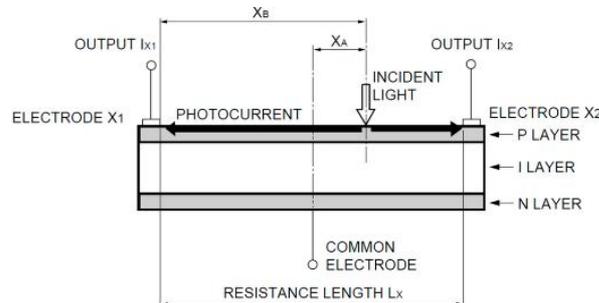


Figure 2. A sectional cut of a one-dimensional PSD is shown here. The incident light determines the photocurrent that the electrodes receive.

The Song method of improving the non-linearity of the is shown in Eq. 2

$$x = k_{x1} \cdot \frac{I_4 - I_3}{I_0 - 1.02(I_2 - I_1)} \cdot \frac{0.7(I_2 + I_1) + I_0}{I_0 + 1.02(I_2 - I_1)}$$

$$y = k_{y1} \cdot \frac{I_2 - I_1}{I_0 - 1.02(I_4 - I_3)} \cdot \frac{0.7(I_4 + I_3) + I_0}{I_0 + 1.02(I_4 - I_3)}$$

(2)

The duo lateral PSD uses both the top and bottom surfaces of the diode which gives a good linearity but will cause a more complicated processing and electrical connection to the detector.

In Fig. 3 the equivalent circuit diagram is shown which models the top and bottom resistive layers as two separate variable resistors.

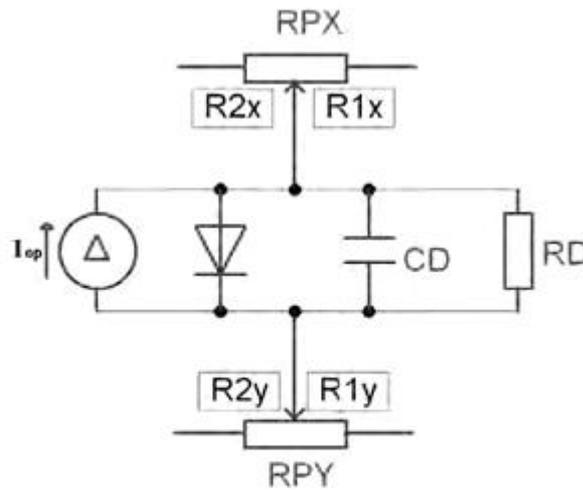


Figure 3. Equivalent circuit diagram of duo-lateral PSD.

The limits for the measurement accuracy are set by the achievable signal to noise ratio (SNR) and the reflector background contrast, defined as the ratio of the powers of the signals received from the reflector and the illuminated background. The former determines the achievable precision and the latter the lower bound for systematic errors.

### III. Simulation Results

The simulation of the proposed system was implemented in MATLAB and PSpice to verify the model system. Fig. 4. shows the overall noise of the PSD system before applying the filtering systems designed in this study.

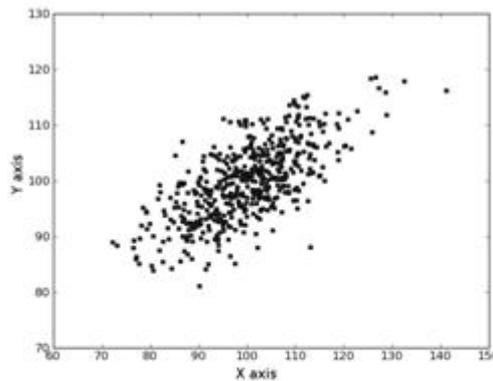


Figure 4. The overall noise associated with the PSD system in the X and Y axis of the PSD.

It can be noticed from Fig. 4 that the noise is not Gaussian in effect and have diagonal effects to it. That is why choosing a PSD that does not adhere to the tetra-lateral effect such as a lateral effect PSD is an ideal substitution. This is shown in the post-processing of the PSD signal [19] and has applications in the robotics localization [20].

Here the measured precision achieved using CCR method was assessed. The initial result of the simulation is shown in Fig. 5 and 6.

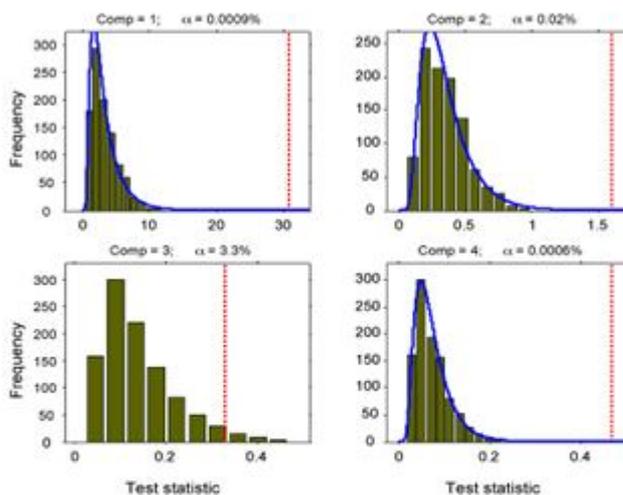


Figure 5. Randomization results for the example data set: histogram of 1000 ‘noise values’, fit using the inverse Gaussian function (the blue line). The red dashed line shows the value under test.

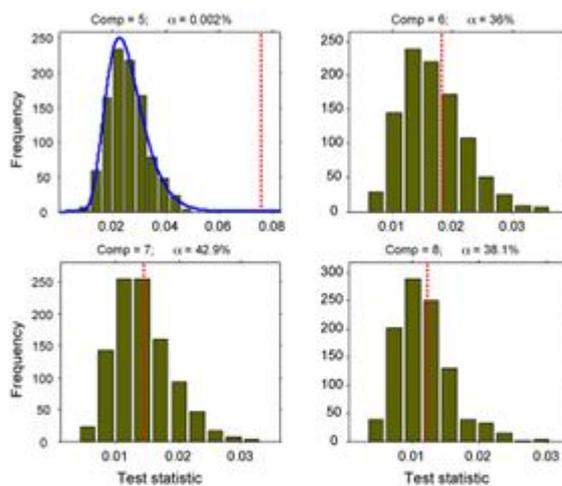


Figure 6. The noise power randomization results for the example data set: histogram of 1000 ‘noise values’, fit using the inverse Gaussian function (the blue line). The red dashed line shows the value under test.

The accuracy of the PSD alongside the sigma variable can be improved by

$$\sigma_{DPSD} \approx 0.21 \frac{p}{\sqrt{q}} = 0.21 \frac{p^{3/2}}{\sqrt{d_s}},$$

where the spot diameter  $d_s$  equals  $q$  and  $p$  is the pixel width. The method is reasonably effective up to an accuracy of about 1/10 of a pixel, which is achieved by extending the spot diameter over approximately five pixel widths. When

better accuracy is needed, the total number of triggered pixels, and accordingly the total signal energy, rises rapidly, reducing the sensitivity of the PSD.

A spectral analysis shows the significant improvement resulting from using this method. A comparison of the improvement is shown in Fig. 7.

To further validate this improvement, a sine wave tracking signal was performed using the PSD and the output was processed by the proposed method. The displacement can be significantly improved in this way. This is shown in Fig. 8.

It is shown in the simulation and the actual implementation of the system that the noise can be reduced significantly to improve the precision of the system.

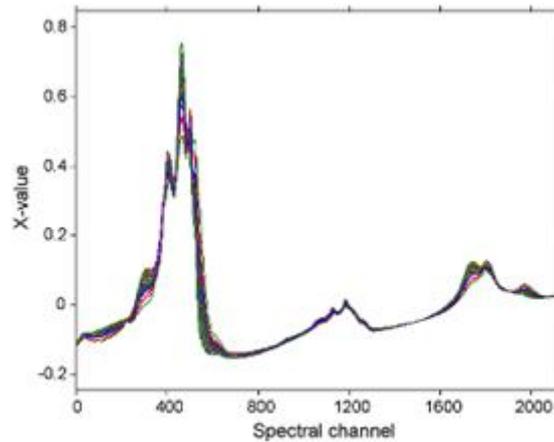


Figure 7. This figure shows the improvement on the signal based on the proposed method.

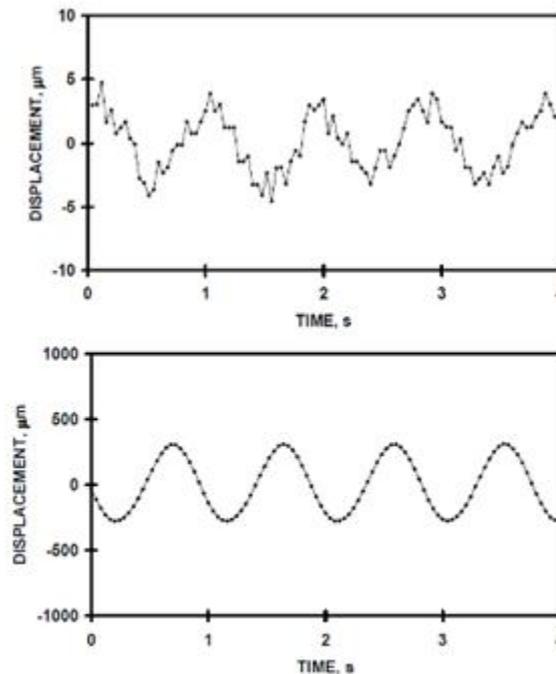


Figure 8. The final improvement of the noise associated with the system is shown and the proposed method has significantly improved the tracking.

#### IV. CONCLUSION

This research presents our proposed method of improving the precision of the PSD system. It was shown through the simulation and the actual implementation of the system that the noise associated with overall system was significantly reduced. The main scientific contribution of the paper comprises these modifications the most important of which are the methods and constructions that can be used to improve measurement precision in the performance of a PSD. Overall, the simulation and actual result show a very significant improvement in the precision of the PSD system.

#### V. ACKNOWLEDGMENTS

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#### VI. DECLARATION

Authors have disclosed no conflicts of interests.

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