Respected Reviewer,

Thank you for reviewing my thesis.

- **Thesis Title: Wide Dynamic Range CMOS Image Sensor for Star Tracking Applications**

Firstly, I would like to thank you for your insightful comments. These excellent comments have helped significantly improve my thesis. This letter addresses each of the raised points and notes precisely how I have responded and included the comments into my revised manuscript.

Sincerely yours,

Xinyuan Qian

Reviewer: 1

General comments:

- There are several minor mistakes in the Reference List, for example:

Page 127: should be Publications

Page 127-140: the format and position of the month and year should be consistent

Page 127-140: format for the publications and papers are non IEEE

Page 127-140: there are many other apparent mistakes and should be proof read carefully before submission

A few other errors are highlighted in the thesis.

Reply: Thanks for pointing these out. As of these two Sections, I have changed all the items into IEEE format and accordingly correct these errors in the manuscript.

Chapter 1

Page 3: Proposal, design … In star trackers. This is not proper sentence. Similar mistake for in (i) and (iii)

Page 4: Characterizations … increase. This is not a proper sentence. It should be for example: Characterization … increase due to …

Reply: Thanks. These improper sentences have been revised.

Chapter 2

Fig. 2.8 and others: It may be better use the symbol of the transistor with an arrow sign. It could be confusing whether the transistors are NMOS or PMOS, since there is only one type of transistor. In addition, the position of the source and drain are not illustrated.

Reply: These figures have been redrawn to avoid confusion.

In this chapter, many high dynamic range CMOS image sensors are described. A qualitative table of comparison between these high dynamic range CMOS image sensors should be given instead at the end of the chapter in terms of important parameters.

Reply: Thank you for the suggestion. I have appended a table with three important parameters (SNR, pixel complexity, system complexity) for comparison at the end of the chapter.

Chapter 3

In this chapter, several pixel configurations have been introduced. However, no other literature works were provided. Please explain if there is any related works in literature. If yes, please include those works for proper comparison.

Reply: The radiation effects on the CMOS image sensors depend highly on the process selection and chip fabrication (e.g. process parameters, etc.). So it is not applicable to simply port the radiation tolerant techniques from one process node to another. The way to verify the radiation tolerance is to make comparison between pixels applying these techniques within one specific process node.

The methodology has long been established since [1] where four different pixels with different pixel parameters have been proposed and compared. More recently, the study in [2] characterizes fourteen types of image sensors fabricated and characterized using a commercial 0.18-µm CMOS image sensor technology. Other examples include [3], where the radiation tolerance of thirteen photodiode layouts has been studied using a deep submicron CMOS image sensor process.

The related works in literature have been included as background study in Section 2.4.1.3.

Chapter 4

For Fig. 4.27, it should be compared to the simulated results.

Reply: The characterization of photocurrent and the dynamic range takes the incident light intensity as input. During the measurement, the sensor is illuminated by a uniform light source, such as an integrating sphere.

However, It is unlikely to get the simulated result because it requires pixel device models which include a number of optical (e.g. quantum efficiency) and physical (e.g. photodiode dimension) parameters. Unfortunately, most foundries do not provide the support of such models in their PDK, not even for TSMC's 018um CIS process, which is the imaging specialized process I used to fabricate the radiation-tolerant image sensor.

Chapter 5

In this chapter, it is mentioned that the relative centroiding performance with limited integration time compared to commercial image sensor is 1% higher. Please explain on possible measurement error and its contribution in percentage.

Reply: The measurement attempts to measure the distance (AB and BC) of three simulated "stars" spots (A, B and C) from an LCD screen as shown in Fig. 1. This is for the purpose of evaluating the centroiding performance. The measurement result is represented as relative error (AB/BC-1) in percentage in comparison with the "ground truth" equidistance (AB=BC=12 LCD pixels). To make it a fair comparison between my sensor and the commercial image sensor, this measurement setup was unchanged throughout the test.

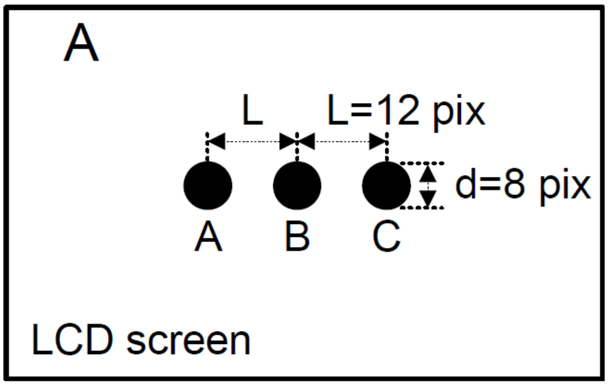

Fig. 1 Measurement setup.

Possible sources of the measurement error can come from the LCD screen. The LCD screen is not a perfect light source. It has bad black emissivity and ill-controlled bright emission so that within each spot, the “ground truth” can deviate from its designed position, which adds to the measurement error in the sensors. From the sensors’ perspective, the SNR (signal quality and noise performance) also determines the accuracy. The commercial has rather low sensitivity. With limited integration time, the obtained signal magnitude is not sufficient to lead to fair centroiding accuracy. Other possible erroneous source may be in the optical system, such as, lens aberration and the extent of the focusing.

Reference:

[1] E.-S. Eid, T. Chan, E. Fossurn, R. Tsai, R. Spagnuolo, J. Deily, J. Byers, W.B., and J. Peden, “Design and characterization of ionizing radiation-tolerant CMOS APS image sensors up to 30 Mrd (Si) total dose,” IEEE Trans. on Nuclear Science, vol. 48, no. 6, pp. 1796–1806, Dec. 2001.

[2] V. Goiffon, M. Estribeau, and P. Magnan, “Overview of Ionizing Radiation Effects in Image Sensors Fabricated in a Deep-Submicrometer CMOS Imaging Technology,”
IEEE Trans. Electron Devices, vol. 56, no. 11, pp. 2594–2601, Nov. 2009.

[3] V. Goiffon, P. Cervantes, C. Virmontois, F. Corbiere, P. Magnan, and M. Estribeau, “Generic Radiation Hardened Photodiode Layouts for Deep Submicron CMOS Image Sensor Processes,” IEEE Transactions on Nuclear Science, vol. 58, no. 6, pp. 3076–3084, Dec. 2011.