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Phosphorescent spherical marker for precise image measurements

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Abstract

In this paper, we propose a phosphorescent spherical marker to improve precision of detecting the marker position in captured images, which leads to precise image measurements. The phosphorescent spherical marker is excited by a UV light source to emit phosphorescence from the marker. Only phosphorescence emitted from the marker is captured by a camera without any other light source. In the captured images, the intensity contrast between the marker and background is high because the images contain only the intensity information of phosphorescence emitted from the marker instead of the reflected UV light. This high contrast leads to success of edge detection of the marker contour with high precision. The phosphorescent spherical marker of 25.4 mm in diameter has high sphericity less than 100 µm. The marker position in the captured images can be detected with high precision by fitting a circle to detected edge points on the marker contour because of the precise edge detection and the high sphericity. Standard deviation of detected position of the phosphorescent spherical marker was evaluated as an index of precision of marker detection. The marker placed 500 mm in front of a camera was captured 30 times. The camera was Nikon D800E which resolution was 7360 x 4912 pixels. The lens installed in the camera was AF-S NIKKOR 50mm f/1.8G. In the captured images, the diameter of the marker was about 690 pixels. The precision of detecting the phosphorescent spherical marker was 0.0084 pixels in standard deviation, which corresponded to 0.31 µm. The relative precision were 1.1×10^{-6} and 1.7×10^{-6} in horizontal and vertical directions respectively. These results show a possibility of applying image measurements with the phosphorescent spherical marker to precise motion of machines.

Phosphorescence, Spherical Marker, Image Measurement, Precise Detection

1. Introduction

Image measurements have two important advantages: (1) contactless measurement, (2) simultaneous measurement of multiple points. One of the most successful applications of image measurements is motion capture system for measuring human and robot motion. In general, the relative precision of motion capture systems is from 10^{-4} to 10^{-5} [1], which means that the measurement precision corresponding to measurement range of 1 m is from 100 µm to 10 µm. For more precise applications of measuring motion of precision mechanical systems, it is necessary to improve the relative precision of image measurement from 10^{-5} to 10^{-6}.

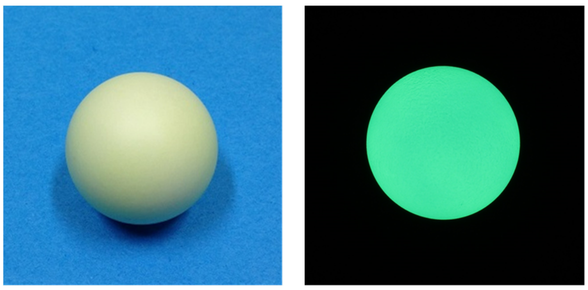
In motion capture systems, retroreflective spherical markers are mainly used for detecting measurement points. The precision of detecting retroreflective spherical marker with weighted centroid method is from 0.05 pixels to 0.02 pixels [1-2]. Fluorescent spherical markers can be detected more precisely than retroreflective ones with edge-based detection method [3]. Image measurement with fluorescent spherical makers requires UV-cut filters to make high contrast between the marker and background.

In this paper, we propose a phosphorescent spherical marker which can be detected precisely without UV-cut filters. The followings describe the difference of shooting method between phosphorescent and fluorescent spherical makers, and precision of detecting phosphorescent spherical makers.

2. Phosphorescent spherical marker

A phosphorescent spherical marker is a novel optical marker for precise image measurement without any UV-cut filter. The phosphorescent spherical marker is made by coating with phosphorescent paint on a soda glass sphere with high sphericity. Figure 1 (a) shows an appearance of the marker under fluorescent light. Figure 1 (b) is an example of captured image of the marker excited by UV light source. The shooting procedure is described in section 2.1.

The phosphorescent spherical marker has two important features for high-precision detection: (1) high sphericity, (2) high contrast between the marker and background. The phosphorescent spherical marker of 25.4 mm in diameter has high sphericity less than 100 µm.



(a) (b)

Figure 1. Phosphorescent spherical marker: (a) appearance of a phosphorescent spherical marker under fluorescent light, (b) captured image of a phosphorescent spherical marker after excitation by UV light source

2.1. Shooting procedure for high-contrast images

Phosphorescent spherical markers are captured after excitation by UV light source. Figure 2 shows the temporal relationship between exposure of a shooting camera and excitation lighting. These shooting procedure makes the captured image high-contrast between the marker and background like shown in Figure 1 (b).

In capturing a fluorescent spherical marker as high-contrast images, UV-cut filters are required to remove reflected excitation light [3]. In contrast, a phosphorescent spherical marker can be captured as high-contrast images without any UV-cut filter because there is no reflected light in the time of exposure.

2.2. Marker detection with high accuracy

The position of a phosphorescent spherical marker in a captured image is measured by fitting a circle to edge points detected by [4]. These edge points can be detected precisely because of high-contrast images which leads to high intensity gradient around the edge. The relationship between precision of edge detection and intensity gradient is shown in Figure 3.

Fitting a circle to the precisely detected edge points results in high-precision detection of the marker. In addition, high sphericity of the marker leads to high trueness of marker detection.

3. Experiments

Appropriate excitation time and precision of marker detection were examined. Shown in Figure 4, a phosphorescent spherical marker placed 500 mm in front of a camera was captured with two UV light sources. The camera was Nikon D800E which resolution was 7360 x 4912 pixels. The lens installed in the camera was AF-S NIKKOR 50mm f/1.8G. In the captured images, the diameter of the marker was about 690 pixels.

3.1. Excitation time for high-contrast images

The excitation time was varied from 0.5 s to 60 s. The horizontal profile of marker intensity is shown in Figure 5. This graph shows that excitation time more than 5 s was enough to be high intensity gradient around the marker edge.

3.2. Precision of marker detection

The marker was captured 30 times. The precision of detecting the phosphorescent spherical marker was 0.0084 pixels in standard deviation, which corresponded to 0.31 µm. The relative precision were 1.1 x 10^{-6} and 1.7 x 10^{-6} in horizontal and vertical directions respectively.

4. Conclusion

This paper proposes a phosphorescent spherical marker which can be detected with relative precision of about 10^{-6}.

Acknowledgment

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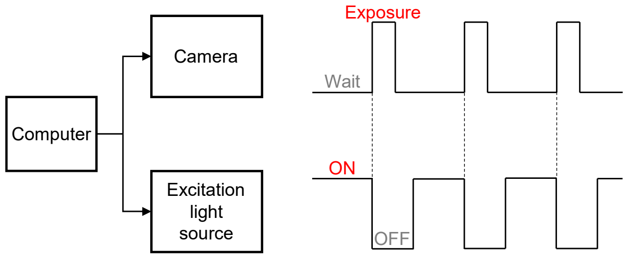
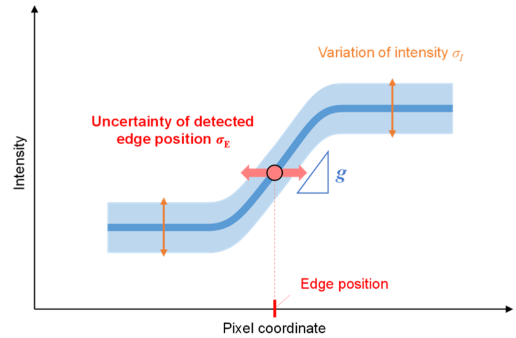
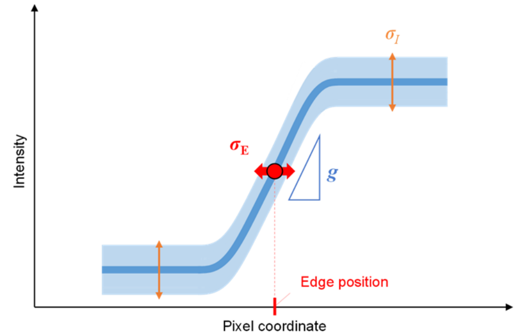


Figure 2. Timing control of exposure and excitation lighting



(a) Low intensity gradient g



(b) High intensity gradient g

Figure 3. Relationship between uncertainty of edge detection σ_E and intensity gradient g under condition of intensity variation σ_I

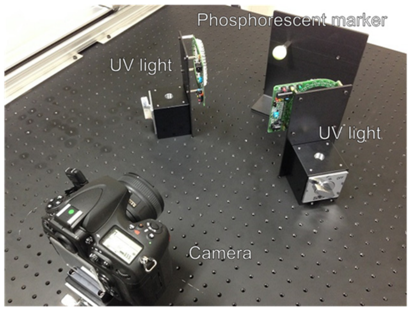


Figure 4. Experimental setup

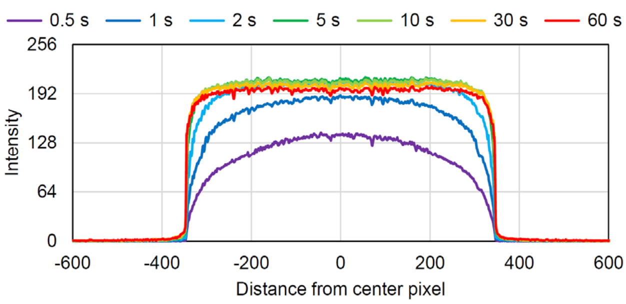


Figure 5. Intensity distribution of a phosphorescent spherical marker in various excitation time