Application of polarization for optical motion-registered SPECT functional imaging of tumors in mice

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ABSTRACT

The use of small animal models to investigate human diseases is an integral part of the development of new diagnostic and treatment regimens. Consequently, functional imaging modalities such as single photon emission computed tomography (SPECT) are increasingly being utilized to streamline the screening of animal phenotypes and to monitor disease states, progressions, and therapies. This paper focuses on the utilization of polarization filtering to minimize specular reflection from a glass tube used for holding live human-tumor-mice during functional imaging in a dedicated small animal SPECT system. The system presented is potentially useful for the real-time non-invasive investigation of diseases, such as cancer, and drug therapies in small animals because it utilizes optical motion-registered functional imaging that minimizes the effects of motion artifacts.

Keywords: microSPECT, functional imaging, polarization filter, specular reflection elimination

1. INTRODUCTION

Small animal imaging is becoming increasingly vital for investigating tumor development and therapies, neural mechanisms and pathways, and drug discovery, to name a few. Typically, this entails acquiring high resolution images of mouse models developed to study a specific human pathology, mechanism, pathway, and or metabolic response [1-14]. To accomplish this, single photon emission computed tomography (SPECT) imaging is becoming increasingly popular, primarily in dedicated systems that are optimized for small animal imaging; these are commonly referred to as microSPECT systems. One of the current thrusts of microSPECT imaging is its application for dynamic functional and quantification studies. For such studies, it is necessary to keep the animal alive, preferably without anesthesia (which sometimes interferes with the process or processes being studied).

As such, our focus is on the development of a real time non-anesthetized animal imaging system to facilitate SPECT functional imaging. This involves the concurrent recording of the radioactive emissions and position of a mouse, with the aid of fudicial markers, to enable the motion corrected reconstruction of its SPECT activity. The SPECT pose tracking system employed for this study has been described elsewhere [15-18] and employs two stereo configuration cameras to image three externally placed fudicial retroreflective markers illuminated by strobed IR LED light sources. Since the 3D position of the animal is based on determining the centroid of each marker in the camera images, we have discovered that specular reflections of the light source(s) that merge with the marker are a source of error. This paper presents a polarization filtration approach that was applied for the elimination of this problem.

Figure 1: Mouse, with glued on retroreflective markers, in glass tube holder. Multiple reflections of the fluorescent room lights are clearly visible on the curved front surface of the glass tube.

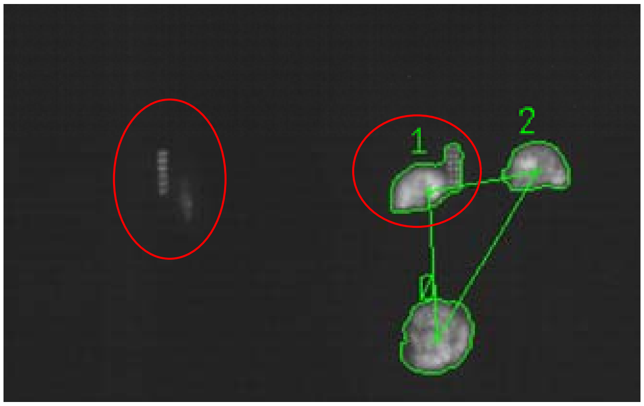

Figure 2: Images from a pose stereo camera showing the automated boundary recognition segmentation of the three retroreflective markers. The boundary defined for marker 1 includes the merged reflection of the strobed LED source with the actual semi-hemispehrical marker, thus skewing the location of the marker centroid. The image on the left half shows two reflections of the strobed light source off of the walls of the glass mouse holder.

2. THEORY

The basis for the experimental problem that this paper addresses is the specular reflection of light due to a refractive index interface. This accounts for the multiple reflections of the input light source picked up by the imaging camera, as illustrated in figures 1-3, which at times merge with the retroreflection from the fudicial marker(s) thus creating inaccuracies in their absolute position registration.

The basis for our approach to our experimental specular reflection problem is Maulus' law for determining polarized light intensity,

$$\mathrm{I}(\theta) = \mathrm{I}_0 \cos^2(\theta) \tag{1}$$

In Eqn. 1, $\mathrm{I}(\theta)$ is the detected intensity, which is a related to the input light intensity I_o by a cosine squared factor of the relative angle between the input light state-of-polarization (SOP) axis and the transmission axis of the preceding polarizer (polarization filter). This is illustrated in figure 4.

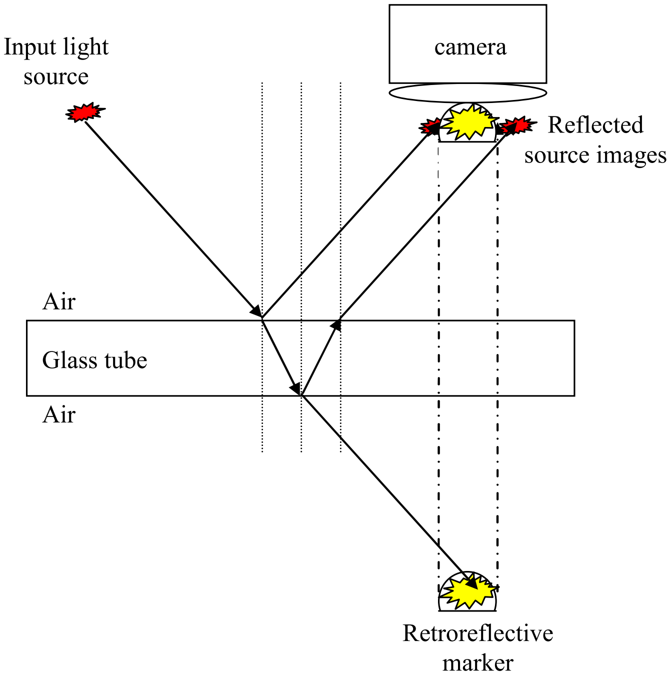

Figure 3: Illustration of input source specular reflections off of the walls of the glass tube mouse holder

In figure 4, an unpolarized light beam I_s is passed through a linear polarizer where it looses half of its original intensity. This can be explained phenomenologically by the following: an unpolarized light source can be decomposed into two orthogonal polarization vectors, which upon summation give a net polarization vector of zero; hence, the term unpolarized light can be construed to mean light that has no preferred polarization state. In the terms of Eqn. 1, half of the initial unpolarized light will be blocked because $\theta=90°$ for one of any two orthogonal polarization vectors used to characterize it. As the now polarized light beam I_o propagates through the system and encounters additional polarizer(s), the intensity is based on Eqn. 1 and the SOP is always coincident with the transmission axis of the preceding polarizer.

We can apply Maulus' law to develop a polarization filter by placing a polarizer that is aligned crossed polarized to the input SOP, i.e. $\theta=90°$, in front of the imaging camera. This results in total filtration of the input polarized image due to blocking of its polarization by the second polarizer. Figure 3 illustrates the application of this principle to the imaging setup. Note for the purpose of imaging the fudicial markers for tracking purposes, it is necessary for the retroreflective fudicial markers to either depolarize the incident SOP (this allows 50% of the retroreflected light through the polarization filter) or to rotate the plane of linear polarization ($0°<\theta<90°$ to allow for some of the retroreflected light to make it through the polarization filter) or alternatively the retroreflective fudicial markers can do both.

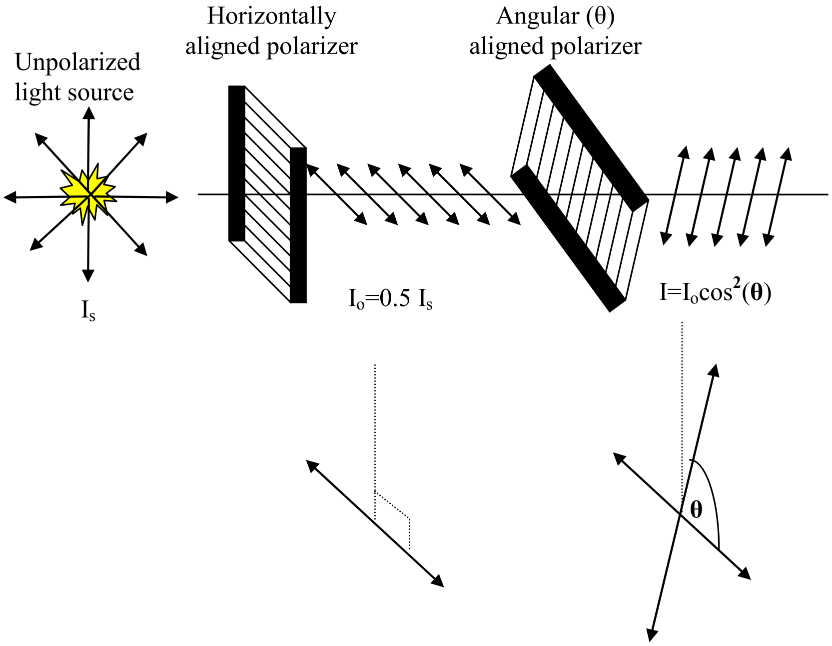

Figure 4: Illustration of Maulus' law for polarized light intensity

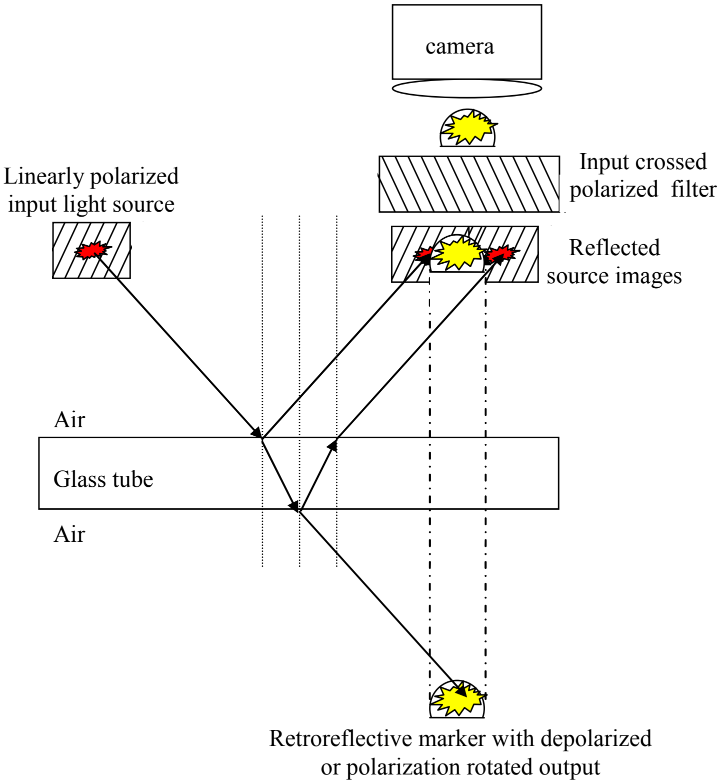

Figure 5: Illustration of the elimination of input source specular reflections off of the walls of the glass tube mouse holder by application of polarization filtering.

3. MATERIALS AND METHODS

The system employed is illustrated in Figure 5. It consists of additional components added to the system described in references [15-18]. The added components are two IR Polaroid sheet polarizers (Edmund Optics Inc., Barrington, NJ), the first is installed in front of the IR LED illumination light source to polarize the input light, and the second is installed in front of the camera lens with an alignment that is crossed to the first. All animal experiments where conducted under an approved animal use protocol.

4. RESULTS AND DISCUSSION

Figure 6 shows some preliminary results that we obtained with the aforementioned system. This demonstrates the ability to filter out the polarized right LED source reflection from the stereo camera image while the unpolarized left LED source reflection is, as expected, unfiltered. The appearance of the 3 retroreflective fudicial markers, labeled 1-3, in the original input SOP polarization filtered image is evidence of their ability to depolarize the input polarization and or rotate the plane of the linear input SOP.

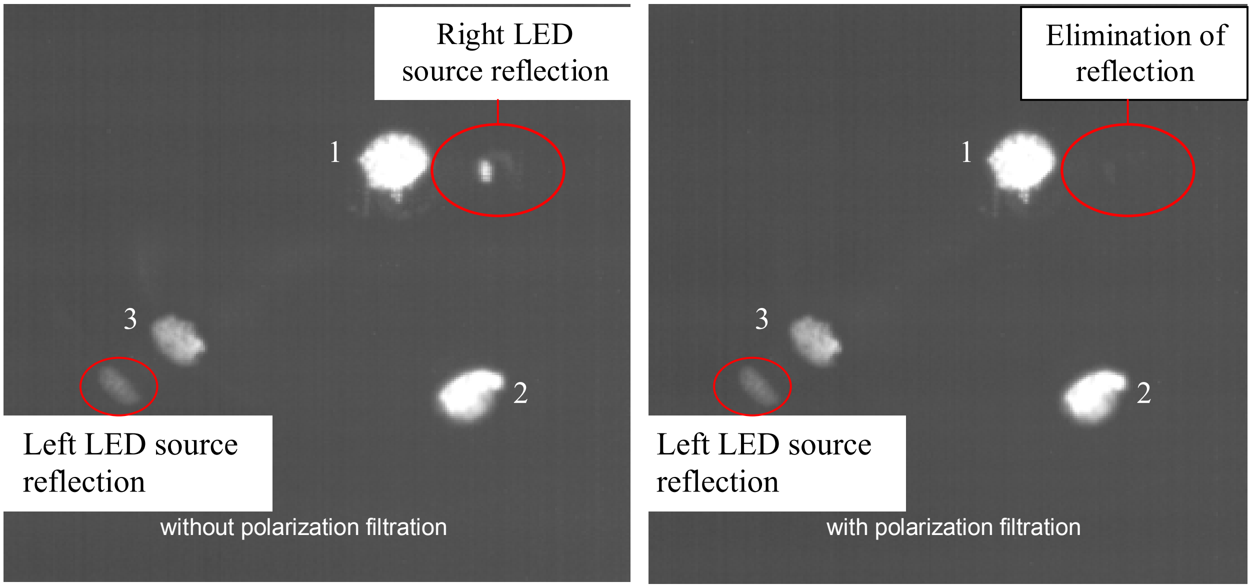

Figure 6: Experimental results from one of the stereo cameras showing the 3 retroreflective fudicial markers, labeled 1-3, and the polarization filtration of the image of the Right LED light source which was polarized while the left, unpolarized , LED light source is unfiltered.

5. CONCLUSION

By utilizing a polarization filtration system, we have demonstrated the ability to eliminate light source specular reflections, which are a source of noise for the absolute registration of retroreflective fudicial markers. This gives us the ability to increase the accuracy of registering the position of a live mouse during microSPECT functional imaging studies and will enhance our ability to improve the quality of motion corrected reconstruction of functional SPECT activity through more precise position tracking.

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