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Close Range Remote Sensing of Levitated Dust Particles

A.C. Cook (1), A.J. Higgs (1), and R.A. Pocock (1)
(1) Department of Mathematics and Physics, IMPACS, Aberystwyth University, UK. (atc@aber.ac.uk : Tel: +44 1970 622 754 Fax: +44 1970 622 826)

Abstract

A simple technique is highlighted to demonstrate how to detect and establish the coordinates of moving dust particles, in proximity to a single camera. This could be applied to planetary landers and rovers, or used from low orbit around comets and dusty asteroids. The only requirement would be the addition of a LED flash bulb close to the camera lens resulting in near zero phase illumination lighting conditions. Using this simple low cost, low mass setup, the 3D trajectory, colour, and other physical parameters of micron scale dust particles could be determined.

1. Introduction

Traditional dust particle detectors for planetary missions, function in a variety of ways[1-4], however they all lack the ability map particle trajectories in 3D space in situ. This would be an especially important issue in studying air motions in martian dust devils, or charged dust particle levitation on airless bodies. One novel solution, has already been partly demonstrated in the construction industry[5] for measuring dust particle densities in air. This utilizes circle of confusion imaging[6], or as is popularly known "orb photography". Orb artifacts (See Fig. 1) are optical defects that have become more noticeable in modern era digital cameras, and mobile phones, equipped with LED flash lights. They occur because the trend of placing camera flash lights closer to the lenses, of these small compact consumer devices, leads to small phase angle illumination of image scenes and enhanced back scatter. Any dust particles or atmospheric droplets present between the lens and the inner limit of the depth of focus will result in an out of focus disk (an "orb") centred on the particle concerned.

Figure 1: Example of "orb" artifacts from dust particles captured using a compact digital camera with a small camera/flash phase angle. Image taken inside an Icelandic lava tube.

2. Orb Geometry

As can be seen in Fig 2. the orb diameter scales linearly with ratio of the: difference between: where the camera is focused (S_2) and the object (S_1), and the object distance (S_1). The orb diameter is given by this simple circle of confusion equation:

$$C = Am(|S_2-S_1|)/S_2 \qquad (1)$$

Where:

c = Circle of Confusion i.e. orb diameter
A = Lens aperture diameter
M = Magnification
S_1 = Distance to where lens is focused
S_2 = Distance to object

Therefore if one has the camera model for a 2D camera, it should be possible to convert a measured orb diameter from pixels into metres, and given S_1, determine the distance to the object. However there are two solutions depending upon whether $S_1>S_2$ or $S_2>S_1$. Fortunately an intensity cross-sectional profile through an orb will provide the necessary information as to which solution is correct. If the intensity profile has a concave plateau then $S_1>S_2$, and if it is convex then $S_1>S_2$. The colour of the edge of the orb might also be used to discriminate which solution is correct for the distance to the object. Finally, given measurements of the image plane coordinates of the orb centre, this will yield a vector inside the camera model, from which a 3D real world coordinate of the particle could be calculated.

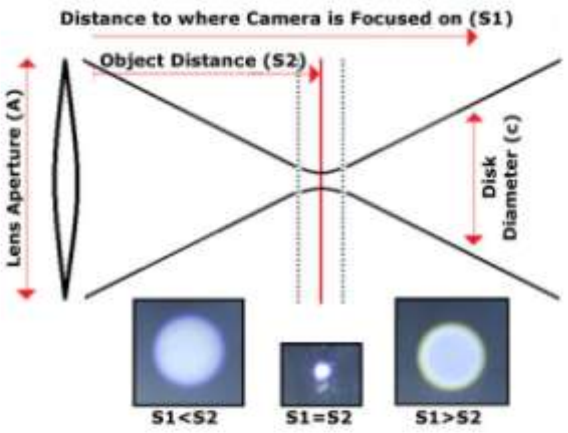

Figure 2: This diagram illustrates how the diameter of an orb is defined as seen from outside the camera.

3. Other Orb Properties

As can be seen from Fig 1. orbs can exhibit colour, which is related to the composition of the particles involved. The sizes of the particle sizes are more problematic to determine – if the particles had the same composition and reflectivity, and were at a fixed distance, then the relative brightness of one particle to another would be directly proportional to their cross-sectional areas. However for larger phase angles it is necessary to take into account the inverse square law to calculate illumination reaching the particle from the light source, and similarly for light reaching the camera.

4. Conclusion

We have shown that it is possible to determine distances to dust particles in the vicinity of a 2D camera. The colour of the particle can be measured, but the size of the particle is more problematic. Further research will be undertaken to see if the sharpness of the edges of the orb intensity profile can provide important clues on the particle sizes. It is expected that by using a strobe LED on a long exposure image, that trajectories and motions of dust particles could be determined. LEDs have been flight tested on previous missions[7].

Although an analogous technique of 3D by Depth of Field exists for mapping 3D structures, our technique is designed specifically for particles that are in front of the camera, and requires one image only. Our technique works best against a dark background, however it may be possible to use it under more conventional day light scenes, if two images were used, one with, and one without a flash, and the two results subtracted to capture any resulting orbs. It is possible that our technique will be especially suited to longer focal length cameras as this will permit a larger volume to be monitored, and at greater distance from the spacecraft.

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