

A NOVEL ALGORITHM FOR TRIDIMENSIONAL RECONSTRUCTION USING DATA FROM LOW-COST SENSORS

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ABSTRACT

A novel algorithm to generate a tridimensional reconstruction of an object using a series of images obtained with sensors within low-cost cameras is proposed. As a matter of particular study, this paper presents the methodology employed to set an array of sensors to extract the necessary information from a particular group of acquired images surrounding the sample, the processing schema for its interpretation and its mapping, in order to approximate a tridimensional model with the use of real data. The simulation results can verify the efficiency of the proposed approach, showing an application where it could be a useful tool for decision support or resource management.

Index Terms — Image Processing, Optical Sensor, Array Signal Processing, Remote Monitoring

1. INTRODUCTION

A camera sensor is, in essence, an optical system for light acquisition [1]. The sensor installed within a photography camera is known as active pixel sensor, which is responsible for the detection of light levels through an electrical current that varies depending on the light intensity that is received. This is achieved through the photo-sites, which are photodiodes with a level of sensibility to the light received, and each one represents a pixel in the formed image. This technology is based in a complementary metal oxide semiconductor (CMOS). Most of the modern security cameras use CMOS sensors. A digital camera incorporates filters that allow it to acquire red, green and blue (RGB) light, where the combination of the three bands produces a real color image [2]. Moreover, some cameras use an infrared sensor above the CMOS sensor to allow the generation of images under low-light conditions. Some cameras using CMOS and infrared sensors can be obtained at a very low price.

The aim of this project is to define an array of sensors that will surround a physical sample (PS) of a particular granular material (wheat, sorghum, corn, etc.) contained in a volume without a predefined form, which will be reconstructed within a tridimensional space (3DS) using only the data provided by the cameras, in order to estimate the contained volume.

2. CAMERA CHARACTERISTICS

The requirements for the selection of the camera should have some fundamental elements in order to guarantee a more precise acquisition of data and, therefore, a more precise estimation of the contained volume. The minimum characteristics are:

- Compact design and lightweight.
- CMOS-based sensor (2mm minimum).
- Infrared sensor (for nocturnal capture).
- Pan & Tilt movement.
- Image size of 640x480 pixels.
- Wireless connection to Internet (*IEEE std. 802.11*).

Lets assume a large space filled with certain PS, which will be 3DS modeled in order to calculate its characteristics (measurements, weight, volume, distribution, among others). The arrangement of the cameras will provide the information for an algorithm that will reconstruct the 3DS of the PS.

3. SENSOR ARRAY

Considering the physical limitations of a low-cost camera (sensor) with the required specifications that were previously described, it is necessary that each camera that will be part of the sensor array (SA) is set with a location radio that can vary between 10 and 14 meters (according to the depth range of its infrared sensor [2]).

The Figure 1 shows the top view of the experimental SA. The objective is to increase the accuracy of the SA and decrease (or avoid) dead points in the sight of each camera. For this particular sample, the radio of sight for each camera is set to 12 meters.

Each sensor is positioned with its sight towards its front plane (perpendicular to its position plane); this provides a wide vision area for each sensor and performs an adequate triangulation of the space to be acquired.

The vertical position of the SA is set according to the radio of sight of each camera as well. For this experimental SA, the vertical position is set with a similar value to the radio of sight (12 meters).

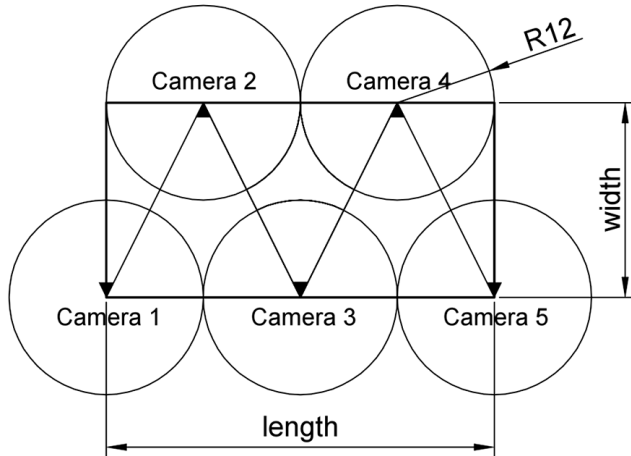


Figure 1 – Top view of the experimental SA.

The Figure 2 shows the top view of the experimental SA with the infrared images acquired by each camera at its respective positions throughout the physical conformation of the space containing the PS.

4. METHODOLOGY

The methodology implemented for 3DS reconstruction is based on an image classification algorithm [3] that performs the following process:

1. Acquisition of the data from the cameras that conforms the SA. The data are images of 640x480 pixels in JPEG compressed format, containing only one spectral band (infrared) with gray-level data [1].
2. Synthetic images composed by the individual images acquired by each camera of the SA, using the physical conformation of the space containing the PS (one for each side through the length of the space).
3. Mapping of the intensity level for each pixel contained in both synthetic images in relation to the camera position, respectively. This process employs the calculation of the normal vector of the surface (intensity vectors) [4] for each pixel in order to determine the theoretical distance between the camera and the sample within the image. The intensity maps obtained from the synthetic images are shown in Figure 3.
4. Determination of the theoretical distances using a reconstruction algorithm [3].
5. Application of the 3DS method for the reconstruction of the sample [5].
6. Determination of the theoretical volume of the sample [6].

5. SIMULATION AND PARAMETERS

In order to obtain an accurate estimation of the volume conformed by the PS contained in the space, it is necessary that each installed camera on the SA are using some operational and calibration parameters. Those parameters will allow that both, the 3DS and volume algorithms, can reduce the error in its respective estimations. The values to be employed by those parameters are described as follows:

- **Image capture mode:** Because of the light conditions that will be present in most of the cases where the SA will be installed, it is necessary that the capture mode is set only to infrared. Independently of the camera model or brand, this feature should be set always to this particular image mode. The use of only one spectral band (infrared) from four possible bands (red, green, blue and infrared) available by the camera will reduce the accuracy on the estimation [7], however the use of all four bands is a topic for a further study.
- **Acquisition schedule:** To avoid that the physical limitations associated to the depth range of the infrared sensor of each camera can cause a shortage of data and reduce the accuracy on the estimation (considering that this could happen under very low levels of visible light surrounding the SA), the desirable scheduling for image acquisition should be during the morning or the evening only, avoiding excessive exposure of light that could lead to an over-exposition of the sensors.
- **Image size:** Most of the cameras available at a low cost and based on CMOS sensors can produce images of 640x480 pixels in JPEG compressed format. This size provides the required balance between its spatial resolution and a small-size file that can be sent through low-speed Internet connections.
- **Predetermined position of each camera:** Once the SA is installed, the particular capabilities of movement of each camera will assist for the necessary calibration of their positions. For the horizontal view (pan), each camera should have a sight view perpendicularly oriented to the installation plane. For the vertical view (tilt), each camera should have a complete sight of the opposite vertical plane of the space containing the PS.

Once all the operational and calibration parameters are set, the methodology previously described can be performed to estimate the tridimensional reconstruction of the PS contained within the space surrounded by the SA, and its volume. The Figure 4 shows the 3DS reconstruction obtained for the experimental SA. In order to validate the accuracy of the proposed methodology, the calculation of the theoretical volume is compared with the real measurement, where it is possible to quantify its accuracy (an error less than 3%).

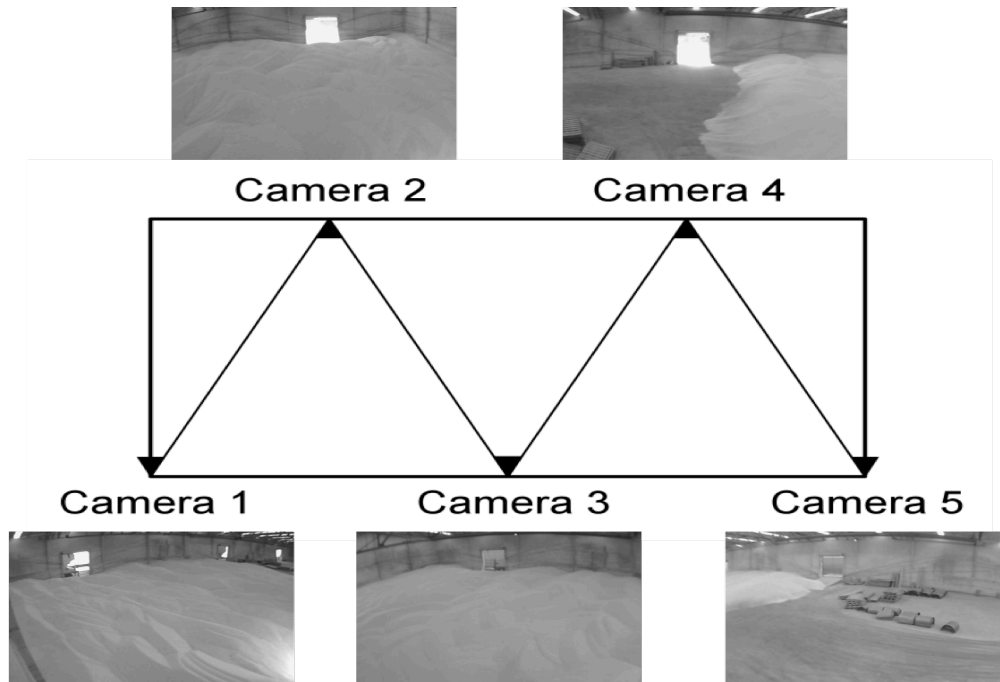


Figure 2 – Top view of the experimental SA with the infrared images acquired by each camera at its respective positions throughout the physical conformation of the space containing the PS.

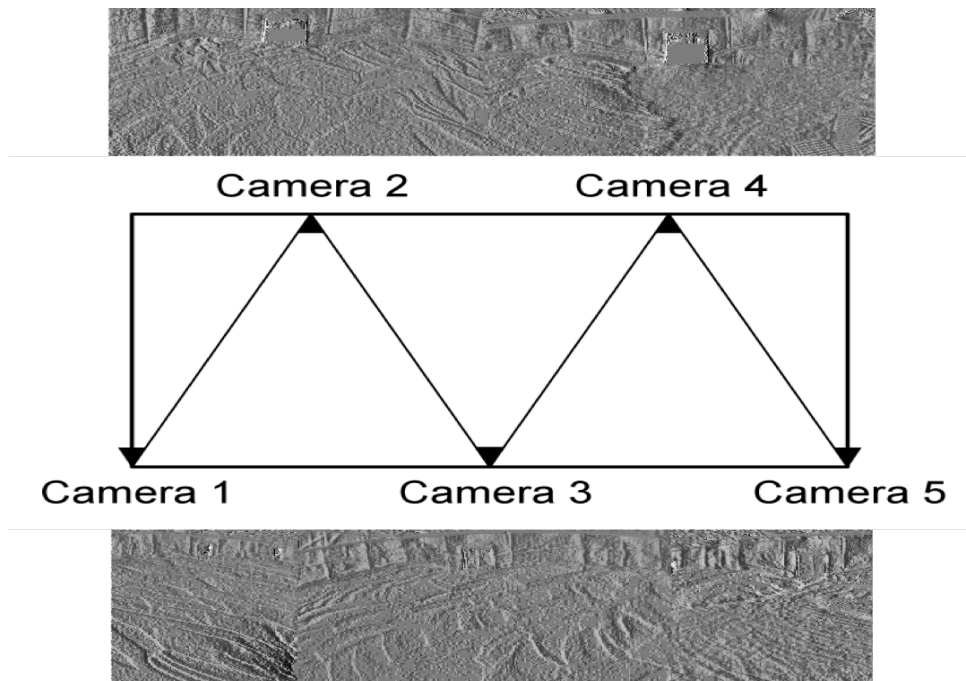


Figure 3 – Top view of the experimental SA showing the intensity maps obtained from the synthetic images throughout the physical conformation of the space containing the PS.

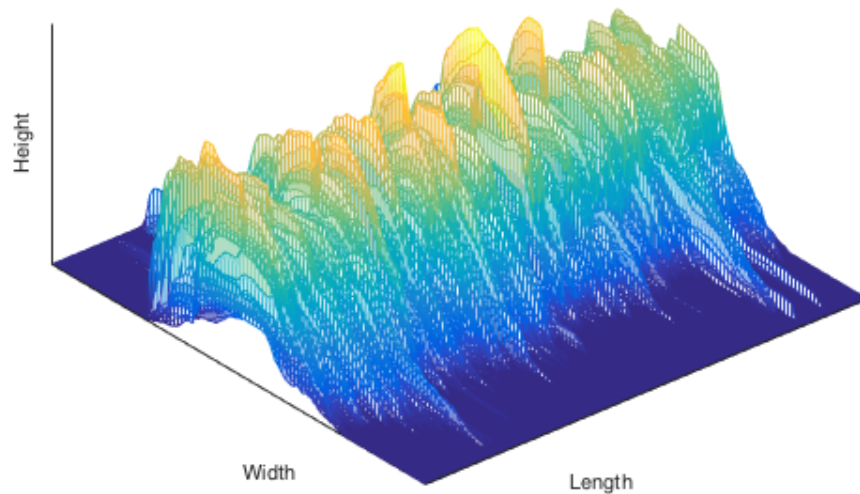


Figure 4 – 3DS reconstruction. The volume measurement and error obtained are:

$$\textit{Theoretical Volume} = 1317.07\text{m}^3$$

$$\textit{Real Volume} = 1285\text{m}^3$$

$$\textit{Error} = 2.49\%$$

6. CONCLUDING REMARKS

The developed model for theoretical approximation of the three-dimensional PS of a particular granular material contained within a space employing the 3DS reconstruction and volume estimation is a novel methodology with the main characteristic of using low-cost cameras as a SA. A more extensive validation of the results is needed in order to improve the accuracy of the model for different scenarios, space sizes and samples. Moreover, the use of more than one spectral band for the intensity mapping will increase the overall performance, although it might lead to an increased computational processing time. However, the results provided are an indicative of the performance gain using this proposed approach and will be a reference for a more extensive research.

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