September 23, 2019

AUTOCALIBRATION OF CAMERAS FOR 3D PRINTING PROCESS MONITORING

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Invention Title

Autocalibration of cameras for 3D printing process monitoring

Short Title

3D Printing camera autocalibration

This disclosure relates to the field of camera calibration for additive manufacturing devices. Additive manufacturing is a lengthy process spanning several hours even for small-scale 3D printing devices. The capability of a 3D printer to detect any defect in the printing process can save money in terms of materials, agents and energy. In addition to monitorize the build process, in-printer cameras can be used to augment the information or detect build errors. To accurately use these functions, cameras must be calibrated.

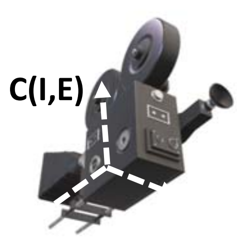
A method is disclosed that allows to calibrate the camera installed in the build chamber of 3D printers that uses the landmarks present in the build bed to perform without user intervention.

Some commercial 3D printers include cameras inside the build chamber, primarily to be used with the purpose of build monitoring. Other advanced uses of the camera include detection of printing errors or augmented reality monitorization. These advanced uses typically involve the use of the camera image and the data coming from the printer to mix both sources of information.

Typically, the camera is not located in the direct zenithal position of the build chamber, since usually there are heating elements located there. Also, it might be mounted in the top cover of the printer and the camera position might have small variations due to the physical tolerances of the cover hinge and locking mechanisms. In addition, in systems with a removable build bed such as the Multi Jet Fusion 4200 and 5200 printer series, variances in the final position might also be introduced due to tolerances inherent to the locking mechanisms of the build unit. The combination of a non-zenithal camera with several variance factors, might result in noticeable errors when trying to use raw (uncalibrated) image data. This effect generated by the perspective is especially noticeable in areas near the edge of the image and far from the camera, when trying to match build geometry to the image that can result in alignment errors noticeable by the user.

Camera calibration is a key step in many image processing algorithms, used to estimate both lens specific (Intrinsic) and position (Extrinsic) camera parameters typically involving the use of landmark selection on a series of checker patterns placed in front of the camera. A solution to remove the necessity of this step is to use a set of known landmarks present in the build area to perform automatically a camera calibration each time a build process starts.

Let be a 3D printer system consisting (as depicted in **Error! Reference source not found.**, left) in a build area surface (S), and a camera (C(E,I)) with extrinsic and intrinsic parameters E and I. If the origin (O) of 3D coordinates is set in one of the edges of the build area S, the calibration of the camera allows to compute E and I of C with respect to O.



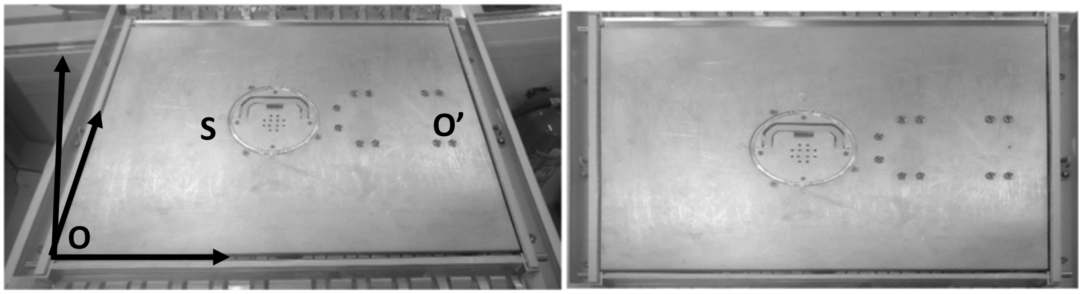


Figure 1: Left: Setup of the system with the Build Surface S, the camera C and the world origin of coordinates O (solid axes) and the camera origin of coordinates (dashed axes). Right: Flattened image of the build area.

Intrinsic parameters are the characterization of the optical and digital parameters of the camera and can be assumed to be constant over the entire series of printer or at least in every device. They can be captured using traditional calibration methods once and the data used to save computation time in the process. Extrinsic parameters define the pose (position and orientation) of the camera in the world, and they can be assumed to be within some fixed values (camera position is the same in all printers), where any variability is due to mechanical tolerance of any movable element between S and C. Since Intrinsic parameters are constant within the lifetime of the camera, the autocalibration system has only to compute E, the Extrinsic parameters of C, that are described by a transformation matrix with translation and rotation information from the world origin of coordinates O to the camera coordinates originated at O'.

The method is executed in the initial warming up of the printer, before any powder is deposited in the build bed surface, and uses the landmarks present in the surface. The surface has many fiducials landmarks in fixed and known position such as screw holes, powder sink holes or edges (Figure 1, left) that can be used to compute the world to camera transformation.

This part of the process is performed with the initial images from the camera using standard feature detectors for corners, blobs, lines and / or circle [1]. This information is compared to the known positions of the landmarks and the camera position and orientation computed from one of the many single image camera calibration algorithms.

Camera calibration also enables the user to turn the non-zenithal image into a virtual zenithal image. For the user this results in a much more natural view and ease of use (Figure 1, right).

Figure 2 shows the block diagram of the process:

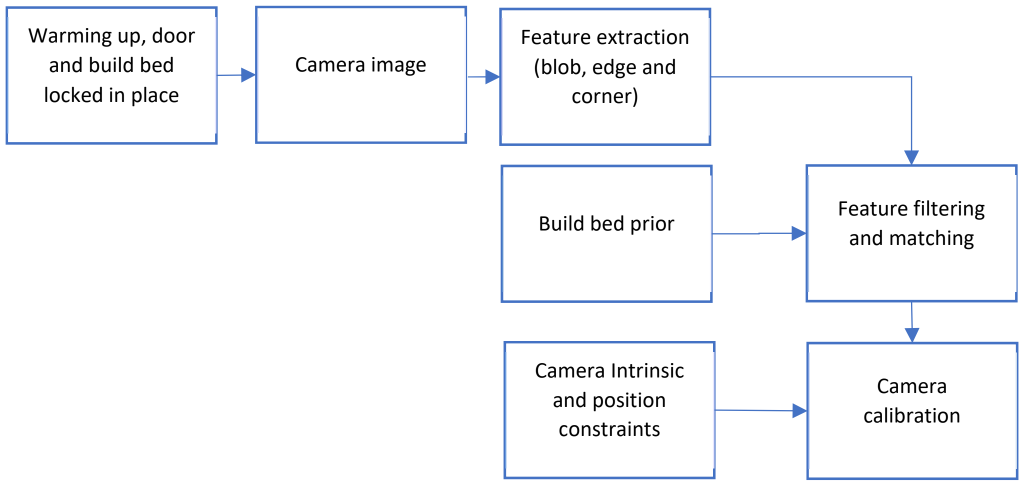


Figure 2: Block diagram of the autocalibration of the camera

Both the Build bed landmark positions and the precomputed intrinsic parameters of the camera are used to save computation time and to calibrate with a single image. Additionally, since the camera is mounted in the same location for all the printers, the algorithm has an initial estimation of the camera extrinsic parameters, so the computation is also constrained to this initial estimation with some variance in the position [2].

The calibration is process is a key step for enabling many other advanced camera-based contents for the device. Without it, the camera can only function as mere view to the interior of the printer. Traditional calibrations require the placement of predefined patterns in front of the camera. This disclosure presents a system that uses an internal part of the printer as calibration pattern. This process requires no interaction from the user and computations are not expensive and can be done while the printers is warming up and hence it does not require extra time in front of the printer for the operator. Benefits for the user include the availability of the zenithal mode and increased performance when processing parts of the camera image far from the camera.

References

[1] Lindeberg, Tony. "Feature Detection with Automatic Scale Selection", International Journal of Computer Vision, Volume 30 Issue 2, pp 79-116, 1998.

[2] Zhengyou, Zhang. "A Flexible New Technique for Camera Calibration", IEEE Transactions on Pattern Analysis and Machine Intelligence, Volume 22 Issue 11, pp. 1330-1334, 2000

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