Image Transformation and Calibration Using System FOTOM

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The key point of here described image transformation is to convert the image coordinate system into the world space coordinates. The related image calibration is used to correct the distorted projection and to make the measurement of various objects possible. The described calibration is also capable of measurement of objects which are lying on the inner side of the cone-shaped cavities. Developed method also removes the object distortion and provides the rectangular view of the measured area. Methods are implemented as a one module for system FOTOM^{NG} and the goal of this work is to extend the calibration capabilities of this system and to spread the area of possible use in this way. The system FOTOM is continuously developed at the Department of Computer Science, VŠB-TU Ostrava.

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Introduction

In this paper we deal with development and application of modern methods used for image processing and measuring the depicted objects. The image coordinates of aerial, satellite, mine and the other images are transformed into the world or object coordinates [1]. Described calibration process support also the transformation of the coordinates of the object placed on the inner wall of the cylinder from the image plane. The developed method is also applicable in the area of medical images and mine pit images as well. In the case of medical images we focus on calibration of images acquired by flexible endoscope with sliding arm. The arm used for collection of tissue samples is moving towards the field of view and the described method is utilizing the presence of this arm in the image. The output of the calibration is represented by rectangular top view of the region of interest.

The rest of this paper is organized as follows. In the following section we deal with basic principles of coordinates transformation. Further we discuss the calibration of plane and cavity images. Last section bears final thoughts and conclusion.

Transformation of Aerial, Satellite and Mining Images

The method used in diagnosis of mines represents a single-image photogrammetry [2, 3, 4, 5, 6, 7, 8, 9]. This means that we can only determine 2D coordinates in the plane of the captured object based on the relative position of the camera and the object plane. In our case, these objects are the light-marks on the mine pit (Fig. 1). If we observe the lit places (bright points), belonging to the light-marks, we can clearly identify their positions in the global coordinate system.

Now we need to determine the transformation relations, which will transfer coordinates from a local image space to the global coordinate system. These transformations belong to the category of planar affine transformations. If the image is captured as described, the following conditions are met:

- The circular shaped light-marks lie in the plane parallel to the projection plane.
- Camera axis is perpendicular to both planes.
- Camera lens has very low geometric distortion.

The desired transformation of points coordinates is expressed by the following equation

$$\bar{\mathbf{x}} = \mathbf{x} \cdot \mathbf{M}, \tag{1}$$

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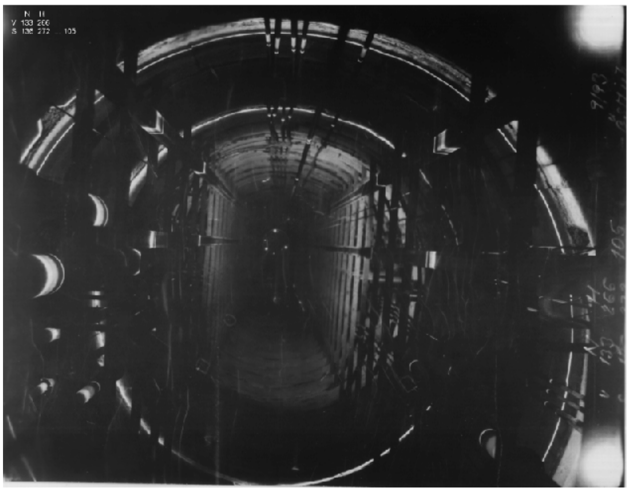


Fig. 1: Example of the mine pit image.

where the row vector $\mathbf{x}$ represents the original point's image coordinates, row vector $\bar{\mathbf{x}}$ contains the resulting transformed coordinates and $\mathbf{M}$ denotes the transformation matrix. Transformation matrix consists of the following three 3×3 matrices

$$
\begin{aligned}
&\text{rotation} && \mathbf{R} = \begin{pmatrix} r_x & r_y & 0 \\ -r_y & r_x & 0 \\ 0 & 0 & 1 \end{pmatrix}, \\
&\text{translation} && \mathbf{T} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ t_x & t_y & 1 \end{pmatrix}, \\
&\text{scaling} && \mathbf{S} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1/s \end{pmatrix},
\end{aligned}
\tag{2}
$$

representing rotation around the origin, translation by vector (t_x, t_y) and scaling by factor s. Then the overall transformation matrix $\mathbf{M}$ is represented as

$$
\mathbf{M} = \mathbf{R} \cdot \mathbf{S} \cdot \mathbf{T} = \begin{pmatrix} r_x & r_y & 0 \\ -r_y & r_x & 0 \\ t_x/s & t_y/s & 1/s \end{pmatrix}. \tag{3}
$$

Now we need to determine the coefficients r_x, r_y, t_x, t_y and s. Let us set an auxiliary function of the two variables $\arctan2(y,x)$. For any real arguments x and y returns the angle in radians between the positive x-axis of a plane and the point (x,y) on it. The angle is positive for counter-clockwise angles (i.e. $y > 0$), and negative for clockwise angles (i.e. $y < 0$). The transformation is derived from the knowledge of the two pairs of corresponding 2D control points. Local control points are designate as $\mathbf{l}_1$ and $\mathbf{l}_2$ and the corresponding global control points are labelled $\mathbf{g}_1$ and $\mathbf{g}_2$. Let us introduce $\Delta\mathbf{l}$ as the Euclidean distance between points $\mathbf{l}_1$ and $\mathbf{l}_2$ and the same apply to $\mathbf{g}_1$ and $\mathbf{g}_2$. The rotation angle is denoted by ψ and obtained as follows

$$
\psi = \arctan2\left(\mathbf{g}_{2_y} - \mathbf{g}_{1_y}, \mathbf{g}_{2_x} - \mathbf{g}_{1_x}\right) - \arctan2\left(\mathbf{l}_{2_y} - \mathbf{l}_{1_y}, \mathbf{l}_{2_x} - \mathbf{l}_{1_x}\right). \tag{4}
$$

Then the transformation coefficients are

$$
s = \Delta\mathbf{g}/\Delta\mathbf{l}, \quad \mathbf{r} = (\cos(\psi), \sin(\psi)), \quad \mathbf{t} = \left(\mathbf{g}_{1_x} - s\left(\mathbf{l}_{1_x}\mathbf{r}_x - \mathbf{l}_{1_y}\mathbf{r}_y\right), \mathbf{g}_{1_y} - s\left(\mathbf{l}_{1_y}\mathbf{r}_x + \mathbf{l}_{1_x}\mathbf{r}_y\right)\right). \tag{5}
$$

There are lot of factors affecting the measurement accuracy. We limit ourselves on the most important one. The most critical part is to set a plumb line for the exact location of control points. Also the deviation of object plane from

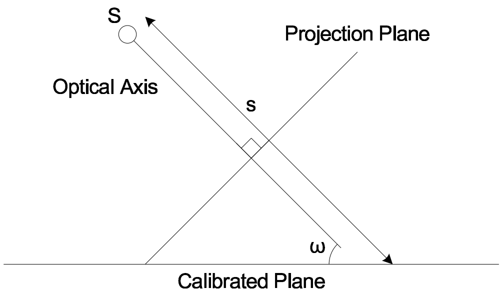


Fig. 2: Tilt and distance of calibrated plane.

projection plane can be the source of significant errors. Ideally, both the planes should be horizontal. Other factor affecting the resulting accuracy includes the lens geometric distortion.

Calibration of Plane and Cavity Images

In the following section we will discuss the calibration process for planes and cavities in more details.

Calibration of plane

During the calibration of images captured by the endoscopy we take in account the following properties of this device [10].

- Endoscope lens is placed at the end of the device.
- Arm cannot be rotated to the sides (i.e. the angle between optical axis and arm is fixed).

Estimation of the distance between lens and plane of interest is obtained by touching arm to the plane of interest. In this case the distance is equal to the length of the extended arm. Lateral tilt is measured with the aim of small pincers at the end of endoscope. The spikes can be used to define single direction vector. The second one is obtained by estimation of the angle ω between optical axis represented by the arm and the calibrated plane (see Fig. 2).

Identification of calibrated area of cavity

The method for cavity calibration assumes that the cavity has cylindrical shape. It is necessary that the optical axis goes through the center of the cavity. Approximation of the whole cavity by single cylinder is often not possible, thus delimitation of approximation boundaries is incorporated.

Method for plane calibration

At first we remove the optical distortion of image, then the perspective projection model is estimated and finally the plane image is generated. Process of calibration is divided into three parts (Fig. 3):

1. Optical distortion removal (centering and radial distortion removal).
2. Image pre-processing (removal of lateral lilt).
3. Removal of perspective distortion.

Method for cavity calibration

In this case we also remove the optical distortion of image and compensate the perspective projection. The calibration process differs only in the second step:

1. Optical distortion removal (centering and radial distortion removal).
2. Inner surface of cylinder unrolling.
3. Removal of perspective distortion.

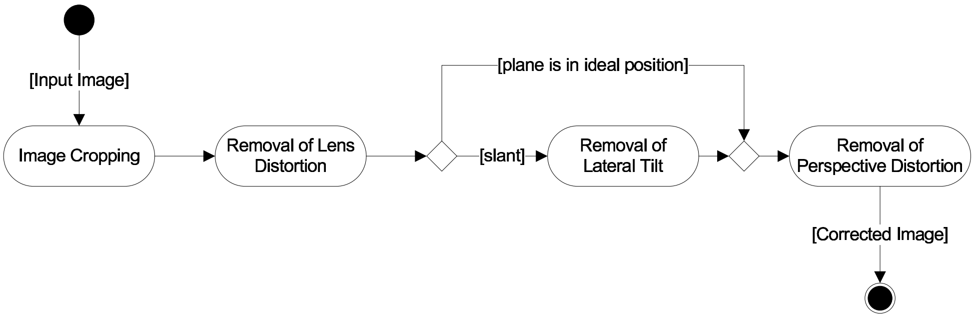
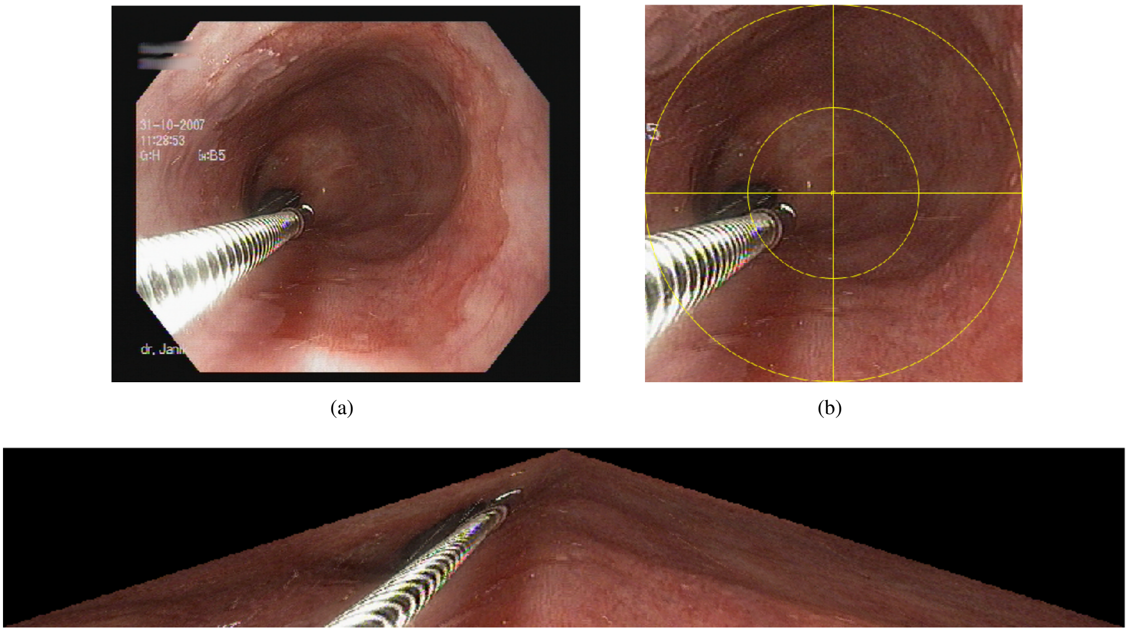


Fig. 3: The plane calibration process overview.



(a) (b)

(c)

Fig. 4: (a) Original image of cavity. (c) Example of unrolling of the cavity image.

Optical distortion removal

The main purpose of this step is to reduce the negative influence of optical effects caused by the camera lens. Every wide-angle lens exhibits some degree of barrel distortion. Both cases of radial distortions are depicted in Fig. 6(b) and 6(c). We have used the following radial distortion model [11, 12]

$$\mathbf{x}_u = \mathbf{x}_d + (\mathbf{x}_d - \mathbf{x}_c)\,(K_1^2 + K_2^4)\,Z\,, \qquad (6)$$

where vector $\mathbf{x}_u$ represents coordinates of undistorted pixel, $\mathbf{x}_d$ stands for coordinates of distorted pixel, $\mathbf{x}_c$ is the image center, K_1, K_2 are distortion coefficients and Z is zoom factor.

Image preprocessing

After the lens distortion removal we obtain image with straight lines, i.e. rectilinear. Next step is to reduce the effect of perspective distortion. There are three basic types of perspective projection; one-point, two-point, and three-point perspective. Three-point perspective exists when the perspective is a view of a Cartesian scene where the picture plane is not parallel to any of the scene's three axes. As we are interested in calibration of only one plane the problem turns in two-point perspective model. In the next step we remove the lateral tilt. The normal of calibrated plane is perpendicular to the horizon vector. In this way we further reduce the perspective model and we obtain just one-point perspective.

Perpective correction

Assessment of perspective projection includes parameters like center of projection, field of view, focal length or aperture. The plane has to be defined by:

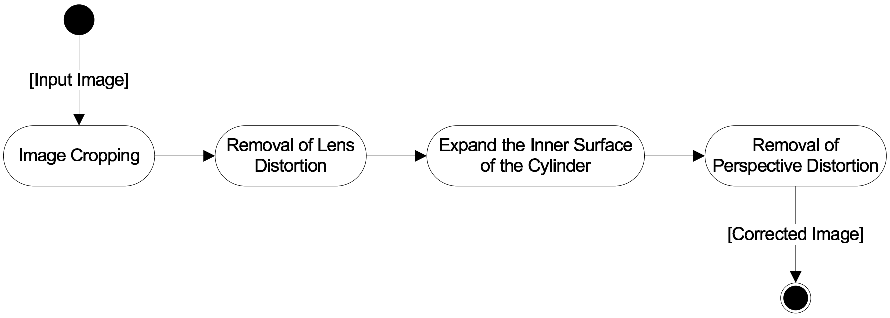
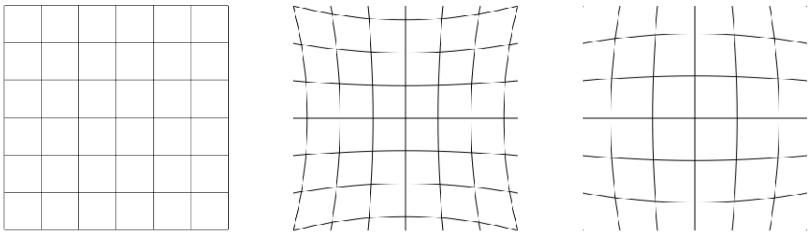


Fig. 5: The cavity calibration process overview.



(a) (b) (c)

Fig. 6: (a) Regular raster, (b) pincushion distortion and (c) barrel distortion

- Distance between of projection center and the intersection of calibrated plane with optical axis.
- Two direction vectors or one normal vector.

Process of model estimation contains following parts and is depicted in Fig. 8(a).

1. We choose arbitrary center of projection **S** representing the position of the lens.
2. Te distance of the projection plane from the center of projection is given by $s = A/2\tan(\mathrm{FOV}/2)$, where A is image width in pixels, FOV is field of view.
3. Calculated distance s is applied to the optical axis from center of projection **S** in the direction to the point **H**.
4. With the aim of FOV we define the width of the image.
5. Finally we evaluate the base line and the horizon.

To reverse the projective transformation we have to estimate the nine parameters stored in 3×3 matrix **M**. To do so we need to know at least four points in the source image and their desired location in the transformed image (see Fig. 8(b)).

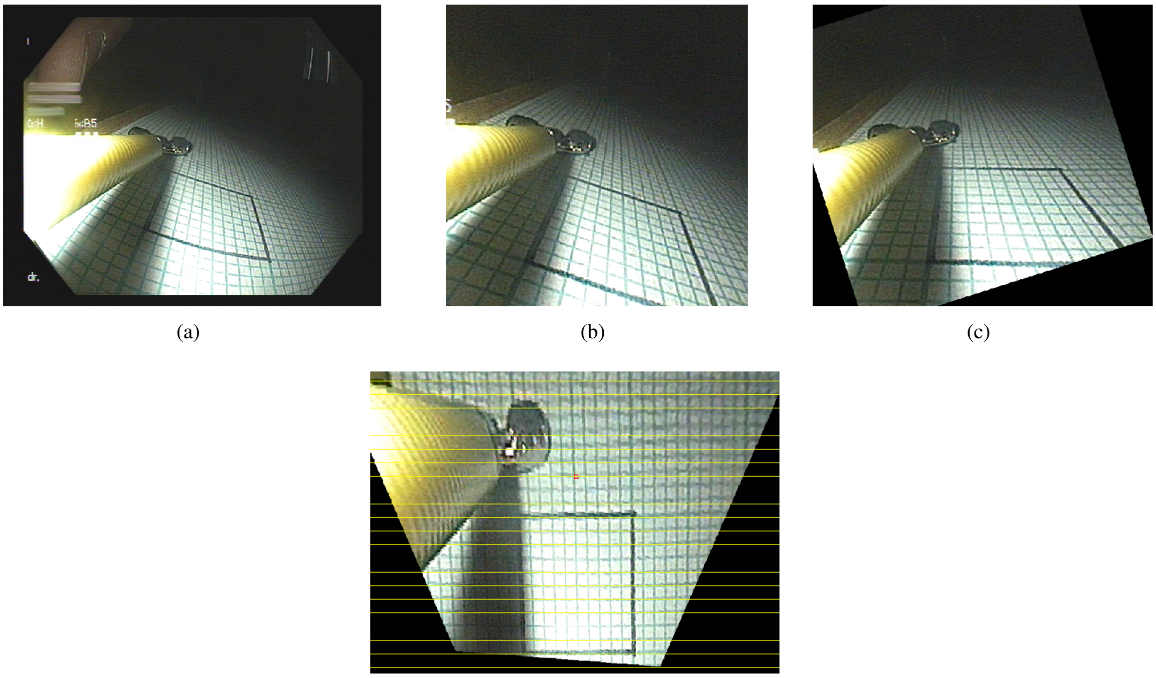
Unrolling of the inner side of the cone

The input image shows cavity which we want to estimate the coordinates of objects of interest located on the inner side of the cylinder. The output image contains the unrolled view of cylinder surface. We use two concentric circles as the markers of top and bottom side of cylinder (Fig. 10(a)).

Conclusion

With mine images, transformations involve the conversion of a captured image to a planar coordinate system. Calibration enables easier and correct measurement of observed objects on the inner side of cylindrical-shaped objects like mining pits or oesophagus. In this way the technicians can inspect the condition of pits to ensure safe operation.

Measurement of endoscopic images brings the possibility to refine the estimation of finding sizes (e.g. size of Barrett's oesophagus, neoplasia size before the resection, the extent of inflamed mucosa etc.). The described method was used for evaluation of therapy effectiveness in trials and clinical practice. Presented method has a few limitations. Procedure does not eliminate completely the role of human factor. Minimizing the human factor is the subject to



(a) (b) (c)

(d)

Fig. 7: (a) The original image before the lens distortion removal and (b) corrected image. (c) The image after tilt removal procedure. (d) The resulting image prepared for measuring.

further development. New methods should be able to automatically resemble the probe orientation. In this way one can achieve of repeatable quality level of calibration without the presence of problematic human intervention.

In this paper we have described two methods for measuring the sizes of objects of interests. methods are specialized for the measurement of objects in cavity and planar formation images. In close cooperation with Ostrava–Vítkovice hospital we explore the specific characteristics of endoscopes. The resulting methods can cope with images of planar objects and cylindrical pits. Both methods also incorporate the lens optical distortion removal as well as the perspective correction. The main application areas are the medical images of cavities like oesophagus and also the images of mining pits.

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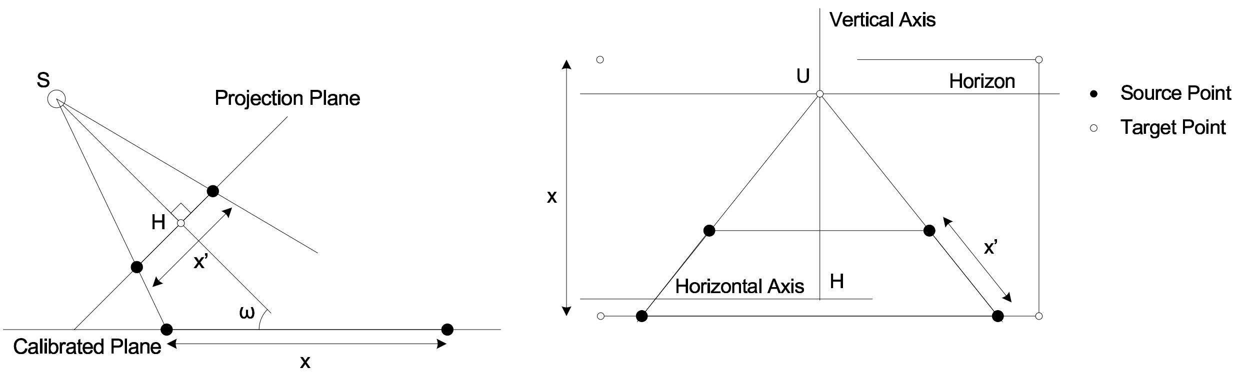


Fig. 8: (a) Method for estimation of original dimensions of general image area. (b) Example of the layout of the four calibration points.

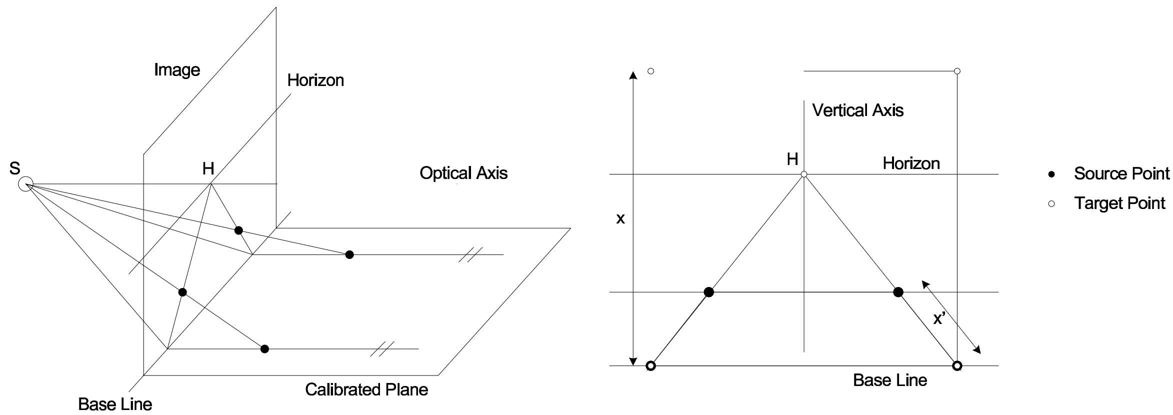
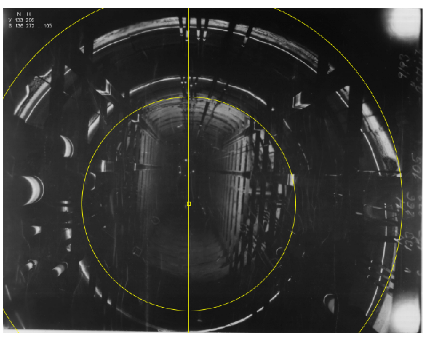
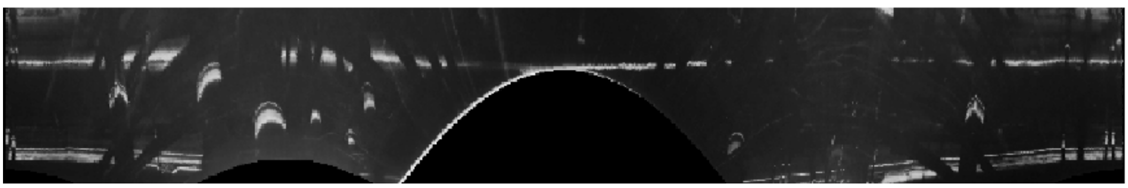


Fig. 9: (a) Perspective projection. (b) Calibration.



(a)



(b)

Fig. 10: Example of original mine image (a) calibration (b).