Determination of the orientation of ice crystals based on 3D image analysis: a tentative method

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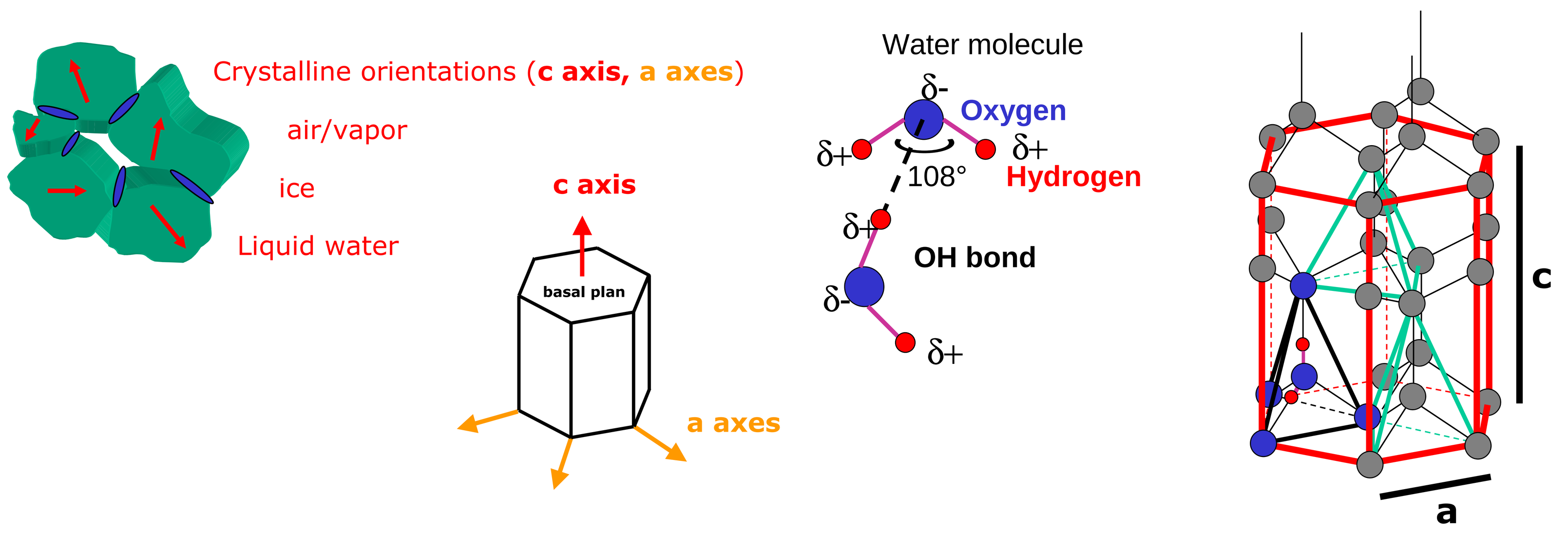
Crystallographic orientations of grains in 3D images of polycrystalline materials are often required for modeling purposes. However, such information may be difficult to obtain, as it generally involves diffraction measurements. For ice samples, we propose an approach that is solely based on X-ray tomography: the main idea consists in obtaining etch pits by sublimation of the ice surface (Knight, 1966) and interpreting the geometry of the 3D-imaged etch pits to determine the crystallographic axes of the crystals.

In this work, we focus on the applicability of the method to ice single crystals. After briefly describing the experimental method that leads to 3D images of etch-pits structures, we present a three-step algorithm that provides the crystalline orientations from a considered etch pit: the etch pit is first localized by a curvature-driven segmentation algorithm. Then, the main facets are identified thanks to their normal and curvature fields. Facets orientations are then checked to fulfill the hexagonal symmetry of the ice crystal and crystallographic orientations are finally computed.

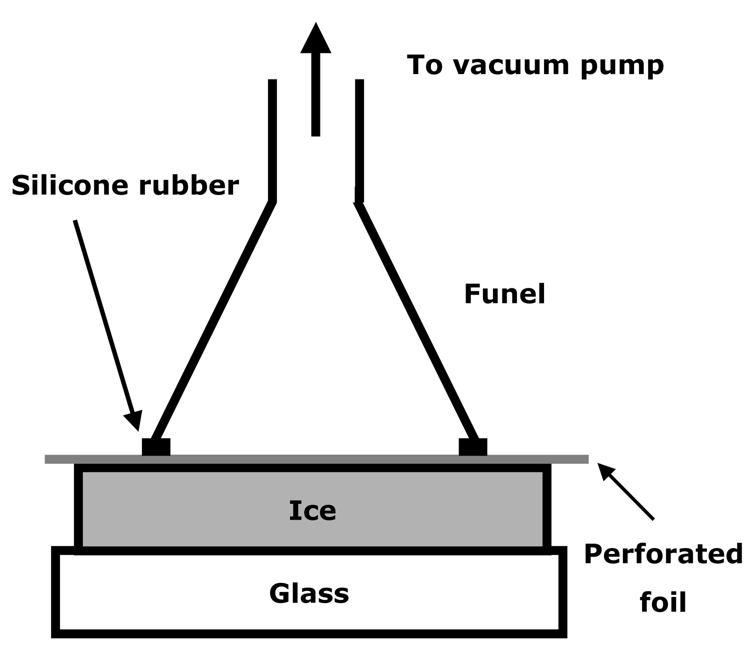
The algorithm was tested on two kinds of data: numerically generated images, and tomographies obtained from single crystals. It provides encouraging results for its extension to ice polycrystals.

1. Introduction

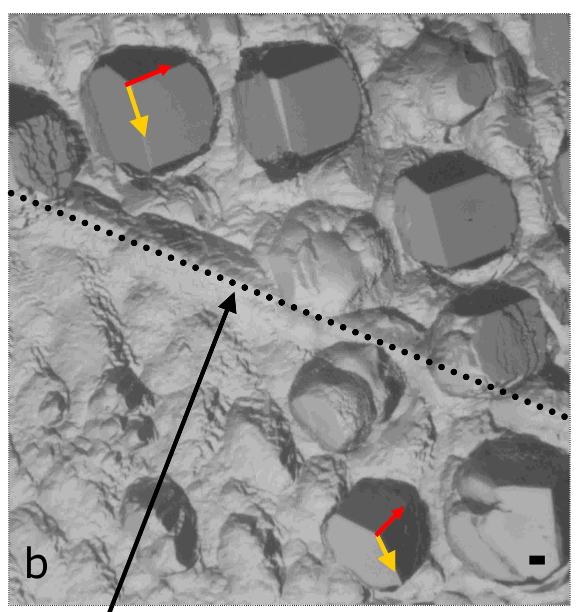
1. Key Parameter: crystalline orientations



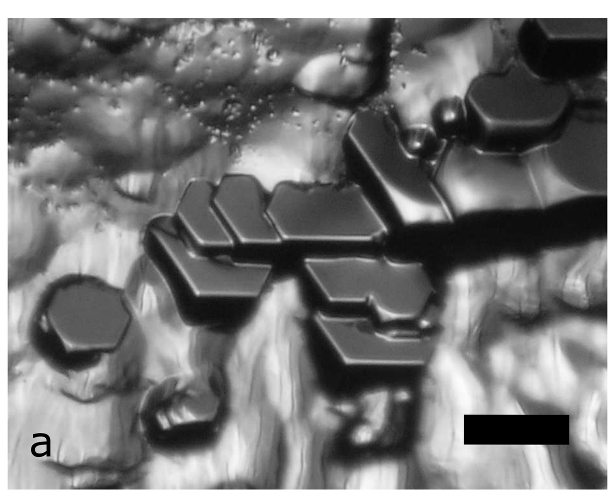
2. Thermal etching of ice : an old experimental method



Obtaining etch pits (Knight, 1966)



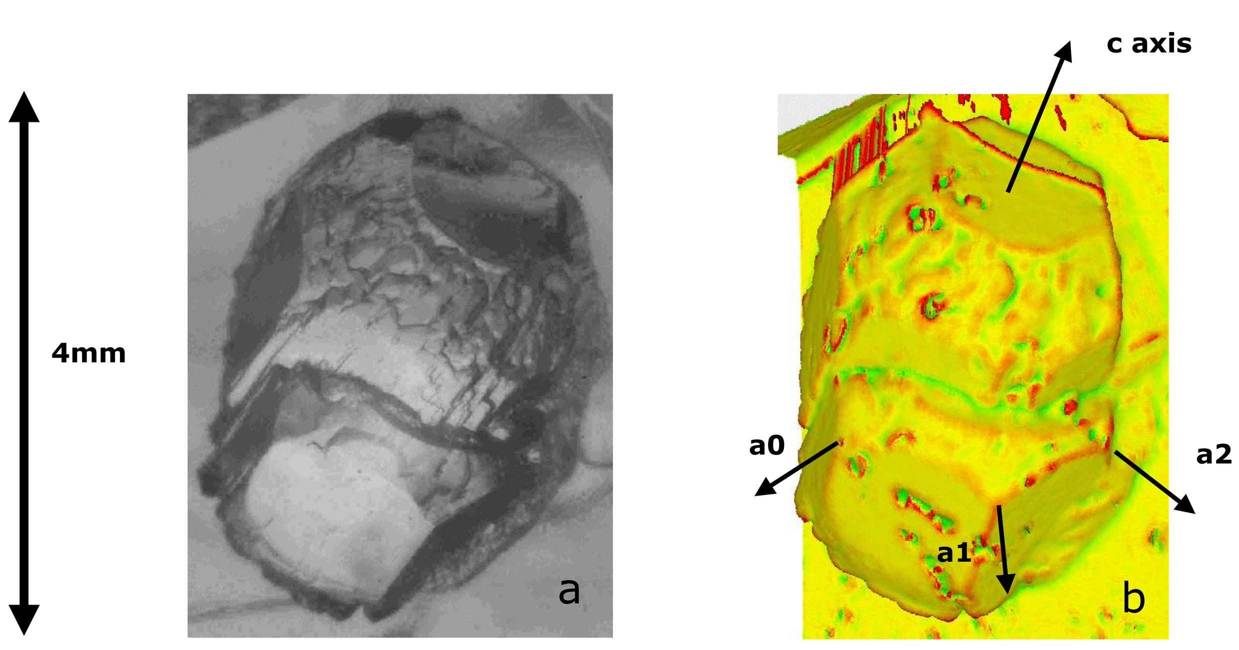
Grain boundary



Photographs of a single crystal (a) and a bicrystal (b) after etching by sublimation with a vacuum pump in cold room. Typical facets and edges of the hexagonal system are clearly visible.

The scale bars are 200 micron long.

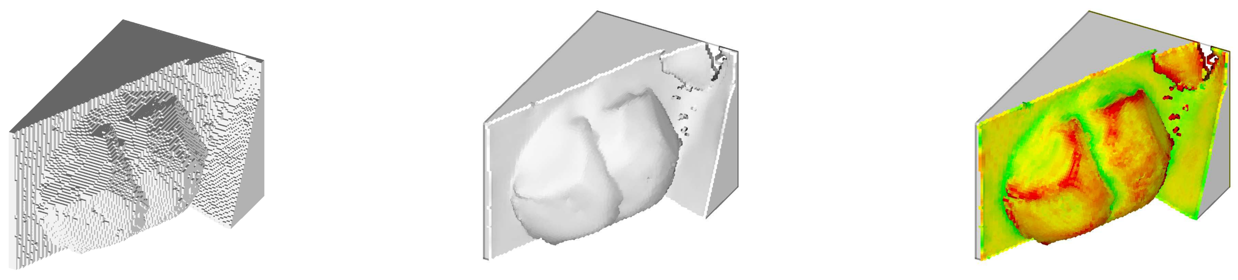
2. Experimentation



Photograph of an etch pit (a) and the replica of the same etch pit after a classical tomographic acquisition (b). The porous space was filled with 1-chloronaphthalene to preserve the figure from sublimation. Local curvature of the interface is represented to emphasize the edges and facets location (red corresponds to convex shapes of the replica, green to concaves ones).

3. Image Analysis

0. Obtention of normal (Flin et al, 2005) and curvature (Flin et al., 2004) fields



An example on the etch-pit's complement

1. Curvature-driven segmentation (Gillibert et al, 2010)

-Detection of surface zones where the lowest principal curvature < 0

-Volume extension of the boundaries with a Voronoi-based algorithm

2. Identification of main directions

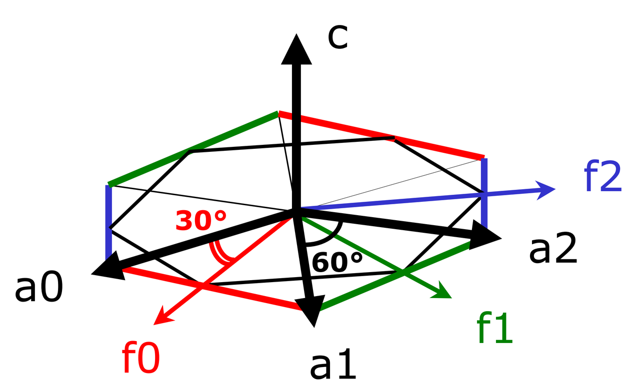
Existing methods rely on the detection of digital planes: sensitivity to noise

-Normals are projected on the **Gaussian sphere**

-High-density zones of the sphere are listed

-Similar orientations (within 30°) are averaged

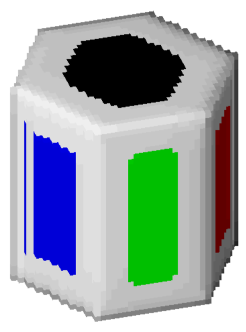
3. Orientation check



The **facet orientations** should fulfill the hexagonal symmetry:

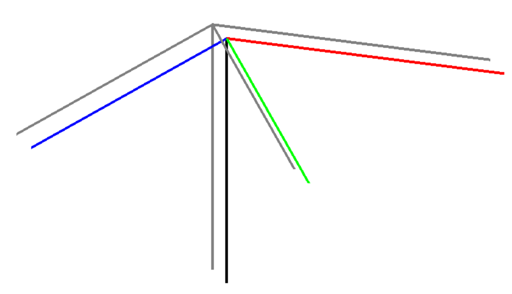
- **c** orthogonal to f0, f1, f2
- (f0, f1) = (f1, f2) = 60°

4. Validation of the algorithm

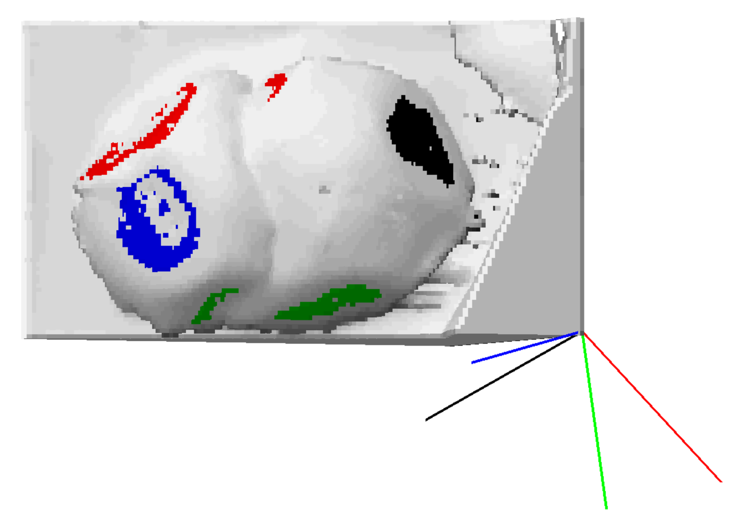


Facet identification:

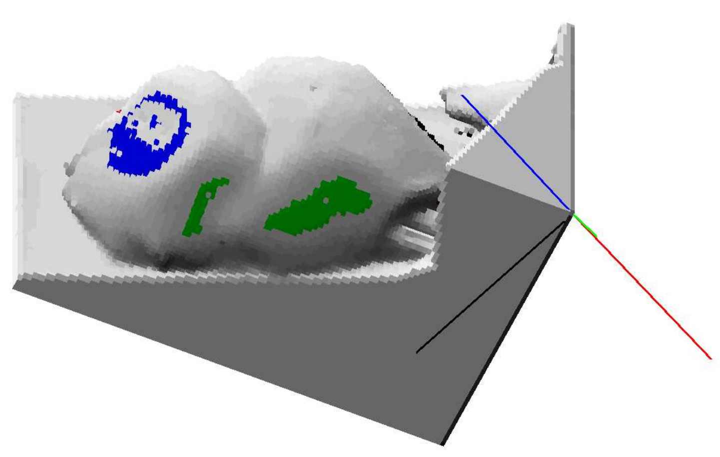
(c, f0, f1, f2)



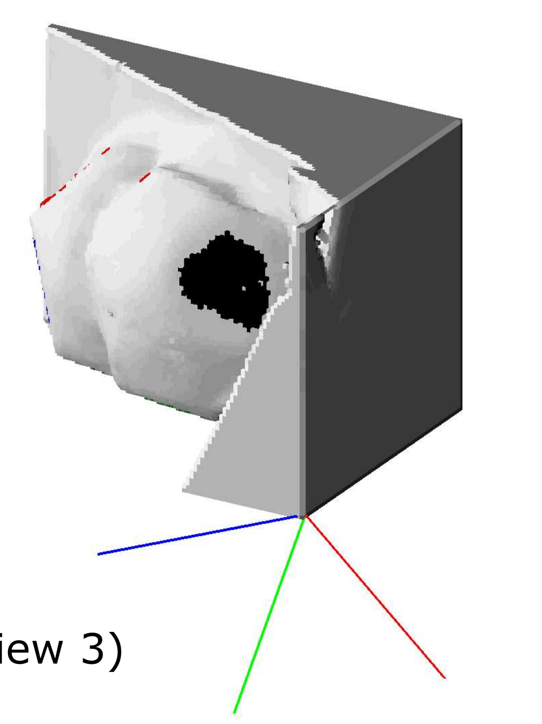
Hexagonal prism: the detected orientations (in color) correspond to theoretical axes (in gray) with an error below 1°.



etch-pit (view 1): the detected orientations correspond to the orientation of the colored surface with an error below 2°



etch-pit (view 2)



etch-pit (view 3)

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