Visual Identification of a Crystaline PUF

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Introduction

Many polymers when melted form spherical crystals called spherulites. Each crystaline structure forms randomly, with spherulite centers potentially occuring around single atoms of impurity in the polymer.
As the spherulites expand outwards from the center they encounter other crystals, halting their growth in that direction. The resulting structure is a Voronoi tesselation, with the size of the spherulite dependant on when it started to grow.

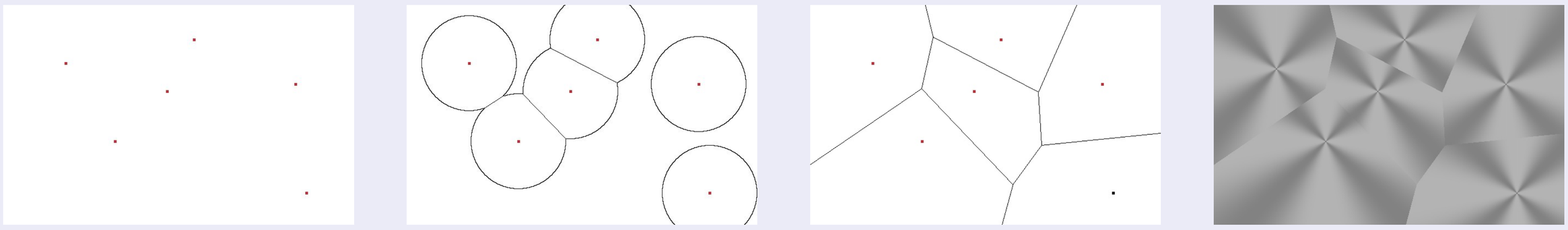

Figure: Growth of crystal structure and image produced through crossed polarising filters.

The random formation of spherulites and the effect that the entire structure of different center locations and growth start times means the structure cannot be practically duplicated. By viewing the spherulites between two crossed polarising filters the underlying structure can be determined and used as a Physical Unclonable Function.
The visual patterns produced are known as Maltese Crosses, and their orientation is dependant on the the angle of the crossed filters.

1. Initial Identification Method

A reader was constructed to get spherulite images and allow the adjustment of the angle of the crossed polarisers:

- Centers were identified by convolution with sample kernels
- Structure identified by comparison with database of center points
- Did not make use of knowledge about global crystal structure

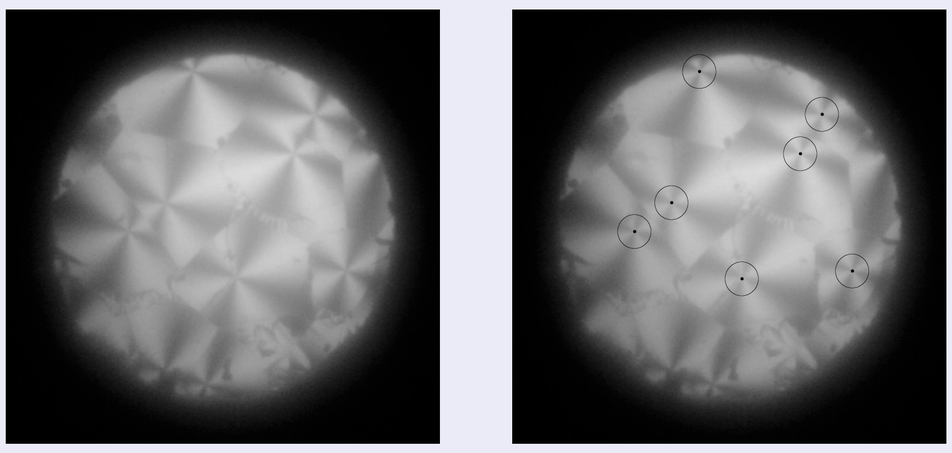

Figure: Sample Image from reader and detected points.

2. Vision Model

We started with the theoretical model for a spherulite image.
For each spherulite:

$$light \propto sin^2(2\theta)$$

Where θ is the angle between the optical axis and the polarisers. Key differences from real crystal images were studied to create a visual model of the crystal

- Global and local lighting. Illumination across the structure is not even and follows the graph shown below. Values for the range and average of light values were also determined from real images.
- Optics - limitations in equipment simulated using a Gaussian blur

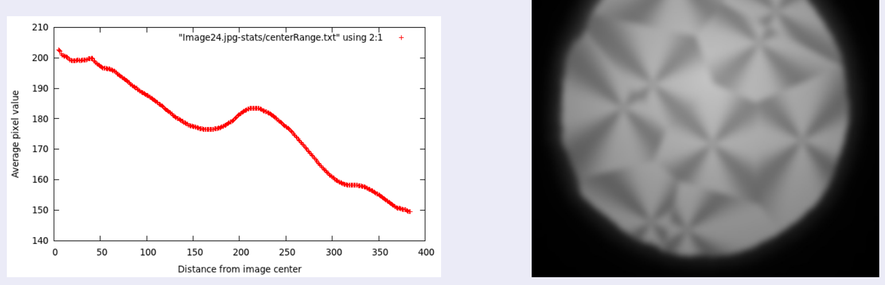

Figure: Illumination graph and final simulated crystaline structure

3. Spherulite edge detection

- Edge detection based on expanding outwards from points
- Revealed underlying difference in growth start times of points
- Sometimes edges are undetectable using a single orientation, giving an unconnected graph of time relationships

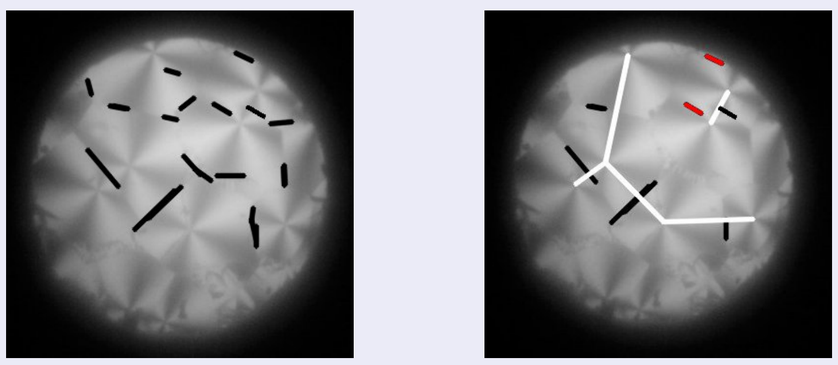

Figure: Edges detected and assigned to points

4. Local and Global Maximisation

- Simply carrying out one reading missed key features and did not make use of global structure.
- Center and edge detection methods were applied along with fitness measures for edges, centers and spherulite areas for the following algorithm:
  1. Find initial estimate of structure using edge and center detection. If edges not found assume those of voronoi tesselation
  2. Using previous measurements add, move or delete centers and edges to improve the estimate
  3. Repeat until estimate stabalises
  4. Verify crystaline structure with fitness functions, and if above threshold accept the reading. Different security applications can set different thresholds
- Currently developing and testing several fitness functions, based on the current visual model
- Spherulite structures are stored as a set of center points and the growth time relationships between them

5. Remaining Issues

- Finalisation of the fitness functions for edges, centers and spherulites
- Evaluating the security of the system, including metrics for comparison to other PUFs
- Testing of system using large number of simulated and real samples to optimise detection thresholds
- Possible testing of other scanner design?

6. Business Plan

- Currently partnering with Alpha Fox to produce id tags that can be scanned by a smart phone
- Predominantly targeting the consumer drugs market
- Exploring other potential markets including :
  - Credit/debit cards
  - Military equipment tracking
  - Anti-counterfeiting on electronic goods
- Currently testing a range of polymers to evaluate which is the most cost-effective for mass production

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