Characterization of a CCD camera for x-ray visibility spectroscopy

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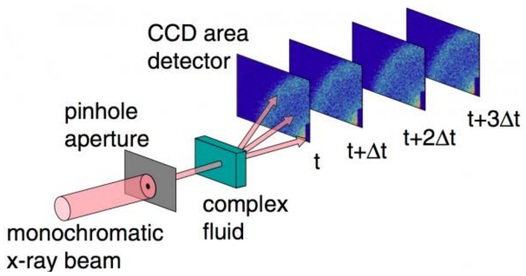
Introduction

- *CCD* (charge coupled device) camera is used to image scattered x-rays
- *X-ray speckle visibility spectroscopy* (XSVS) is a technique used to study the motion of small objects (e.g., proteins, lipids)
  - This is an extension of *x-ray photon correlation spectroscopy* (XPCS)
- XPCS commonly compares different frames taken by a CCD camera examining the time correlation of the photon intensity; this gives the dynamic structure factor of the sample (which provides information on the sample's dynamics)
  - However, given that CCD detectors take several milliseconds to capture and read out one measurement, a faster method is needed in order to study biomaterials
- This faster method is XSVS
  - Instead of finding frame-to-frame intensity correlation, the speckle visibility of each frame is determined
  - The exposure time of the frames is systematically varied in order to find time dependence of sample
  - Allows for faster measurements – the speed of measurements is only limited by the camera's shutter speed



- One frame exposed to x-rays typically has a few scattered photons – each photon is "seen" as a droplet of charge on the silicon of the CCD
  - A charge droplet is analyzed to find its center of mass and then replaced by an (x,y) point in order to process the data more efficiently

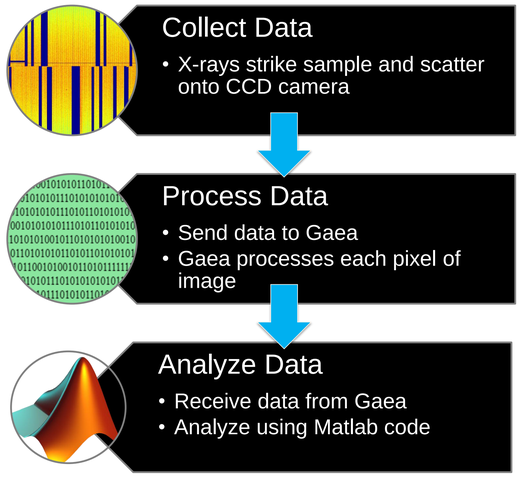
Aim

- Characterize CCD camera for use in XSVS
- This will provide a method to increase signal to noise ratio of x-ray data and improve the accuracy of measurements

Method

Data Collection:

1. Synchrotron x-rays from Argonne's Advanced Photon Source strike sample.
2. CCD images x-ray scatter pattern.
3. Data is sent to NIU's parallel computer cluster, Gaea, for processing.
4. Data is retrieved from Gaea for analysis.



Data Analysis:

1. Fig. 1 shows the distribution of photon-photon distances in units of pixels for photons within the same frame. The peak near 1 and 2 pixels displacements indicates that photons cluster together.
2. Fig. 2 shows the same data as fig. 1 except that the distances are calculated between photons in two *different* frames that have been offset in time by dt. The clustering of photons is still there but weaker. As the time offset is increased the correlations eventually disappear.

Results

- An example of the data analysis is shown below:

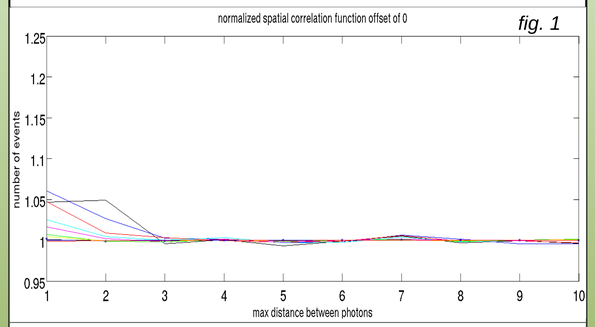


fig. 1

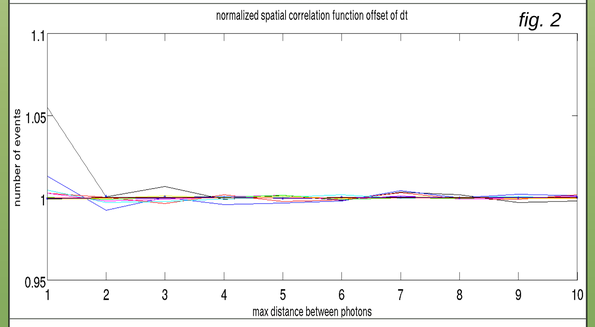


fig. 2

3. The green curve in fig. 3 shows the excess probability of photons occurring at a distance of 1 pixel or less as a function of the offset between frames. As can be seen, correlations disappear after ~200 ms. This indicates that the proteins diffuse away from their original positions within 200 ms, so that the scattering images are no longer related.
4. The black curve in fig. 3 shows the excess probability of photons occurring at a distance of 1 pixel or less when photon positions are correlated within the same frame. The time axis (in this case) represents the exposure time of the frame. As the exposure time increases, the correlations decrease, but more slowly than the green curve. Note that this method can measure down to much faster times (~10 ms) compared with correlations between different frames which are limited to 40 ms.

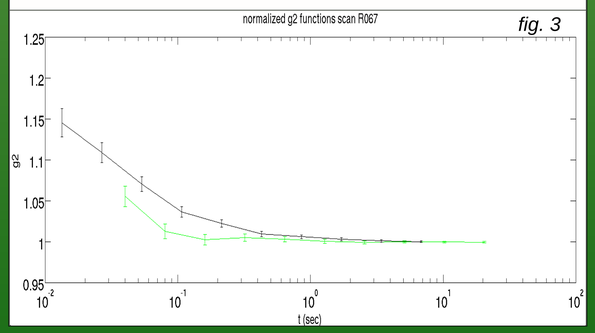
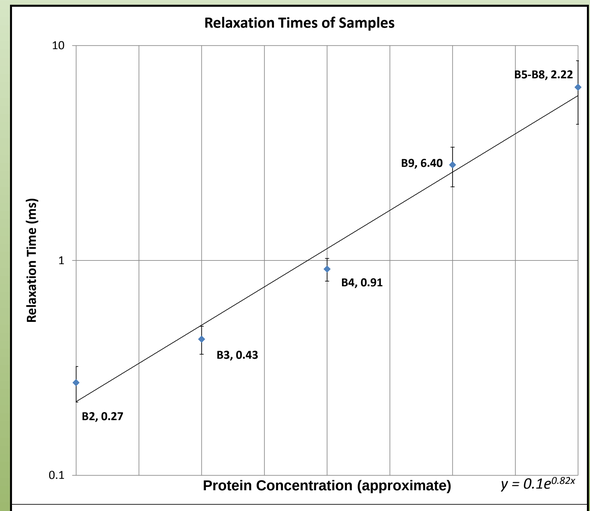


fig. 3



- The more concentrated the protein, the longer the relaxation time

Conclusions

- We expected photons to clump together, however the opposite was true – photons tended to spread away from each other
  - This was due to the spreading of charge in the camera; once this is accounted for and corrected then the clumping of photons is observed
- Perfecting XSVS will lead to a better understanding of protein dynamics (i.e., how proteins interact with other biomaterials)
  - Provides another tool to study diseases

Acknowledgments

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