Phase unwrapping using Reconfigurable Hardware

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Abstract

At Northeastern University, a coherent imaging process known as Optical Quadrature Microscopy (OQM) has been developed as one of the modalities of the Keck Microscope. This mode was designed for the purpose of non-invasively capturing the amplitude and phase data of an optically transparent sample. This can be used to reconstruct images of the original sample. However, current processing methods require several minutes for every frame of data produced by the microscope and our hope is to accelerate that process, so that phase unwrapping takes the same amount of time as image acquisition. To fully exploit the parallelism exposed in the algorithm, a sufficiently large FPGA with multiple banks of off-chip SRAM is needed. The Wildstar II Pro was selected as the reconfigurable solution that fulfills all these requirements.

The minimum L^p Norm algorithm as implemented here only finds a local minimum to the L^p Norm problem since a globally minimum solution is provably NP-Complete [2]. However, it is still the best solution to the phase-unwrap problem in the context of the images produced by the OQM microscope. An appropriate bitwidth was also selected, the hardware/software partition selected and the DCT algorithm specified. The next step is to implement the minimum L^p Norm algorithm on a reconfigurable platform, such as the Wildstar II Pro (shown to the left) in such a way as to make optimal use of bandwidth and memory. This work is currently underway.

Optical Quadrature Microscopy

Optical quadrature microscopy[3] was developed in 1987 based on techniques developed for coherent laser radar. A single coherent laser beam is split into two paths, one a reference and the other a signal path that passes through the sample under examination. Interference patterns are then captured by CCD cameras. Although the images could be taken with only two cameras, four are used to completely capture the entire signal including the conjugate intensities.

Results

• Selecting the best algorithm: Figures 1 to 6 depict the results of applying the various algorithms. The L^p Norm algorithm produces the solution that is the most discontinuity-free and has the lowest average background noise. The path-following algorithms have visible regions of discontinuities and the numerical minimization methods other than L^p Norm accumulate error or have high background noise. Note that the magnitude scales have been normalized.

• Selecting the right bit-width: Figure 7 shows the result of an L^p Norm phase unwrap using double precision arithmetic. Figures 8 to 10 show the same image but unwrapped with varying fixed-point formats. As can be seen in the figures, the 28 and 29 bit results provide close approximations to the original double-precision solution. The unnormalized magnitude scale also shifts, although covering the same range. This bitwidth result is being used to design a fixed-point hardware solution that will provide sufficiently accurate results.

• Selecting the right component to speed up: Through extensive timing analysis, it was noted that the most time consuming part of the kernel was the two-dimensional DCT and IDCT on the image. Thus this element was selected for hardware implementation.

• Selecting the right DCT algorithm: The ideal algorithm would be able to make use of publicly available cores, such as FFT components, and would be able to execute DCTs on large data arrays such as the images produced by an OQM microscope. The method outlined by Makhoul in [4] was selected since it was of a complexity comparable to that of a similarly sized FFT and also fulfilled the above requirements.

Conclusions and Future Work

The minimum L^p Norm algorithm as implemented here only finds a local minimum to the L^p Norm problem since a globally minimum solution is provably NP-Complete [2]. However, it is still the best solution to the phase-unwrap problem in the context of the images produced by the OQM microscope. An appropriate bitwidth was also selected, the hardware/software partition selection and the DCT algorithm specified.

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Optical Quadrature Microscopy

After the interference fringe pattern is taken, four further steps must be undertaken to produce the final image:

1) Phase evaluation: Produces a phase-map from the spatial distribution of the phase
2) Phase unwrapping: Assigns integer multiples to the phase values
3) Term elimination: Mathematical removal of setup irregularities
4) Rescaling: Converts phase to another criteria such as distance