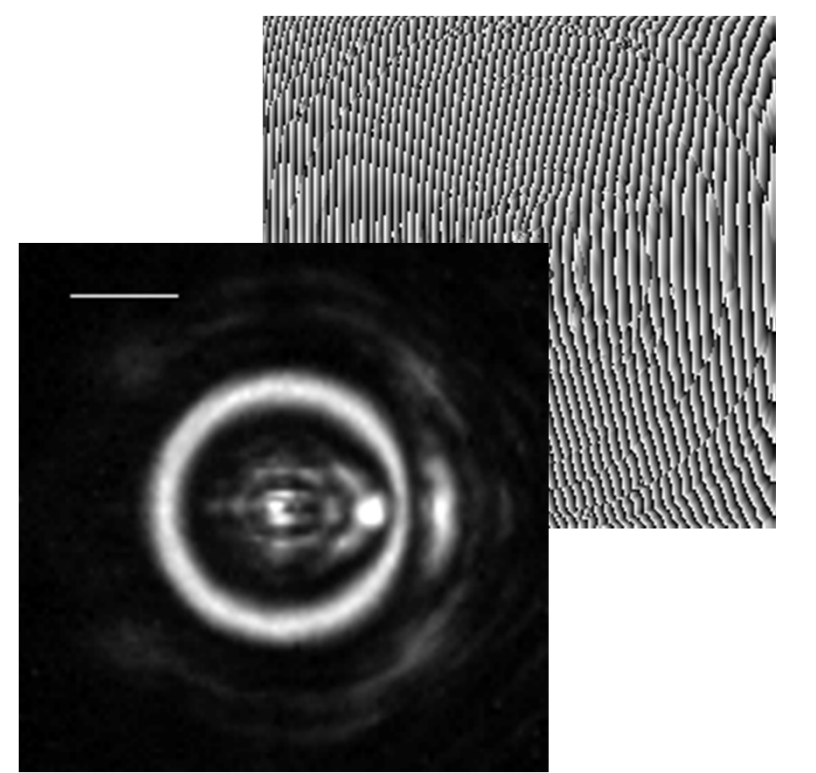


A Feedback Algorithm for the Optimisation of Holographic Cold-Atom Traps

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Summary:

Optical holography is a method of representing a light intensity profile with a phase grating. We do this with a Spatial Light Modulator (SLM), which affects the phase of light incident on it. By programming different phase profiles for the SLM, traps of any shape can be accurately reproduced using Iterative Fourier Transform (IFTA) methods. However the hologram is never 100% accurate in a real optical system. We propose a feedback method to correct real discrepancies in the hologram. The difference between the image and the target is added onto the original target to create a new target, and another IFTA run to produce an equivalent phase profile. This process is repeated until most errors are suppressed. We have been able to reduce errors in real holograms by up to 75% using this method.

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Background and Aims:

For truly flexible ultra-cold atom experiments, techniques for the creation of laser traps of arbitrary shape must be developed. Conventionally, many of these patterns (like ring-traps, flat-tops and twin-welled Gaussians) are difficult to create. Methods of holographically creating these traps using a Spatial-Light-Modulator (SLM) that affects only the phase of the light that passes across it have been computationally reproduced with very high accuracies. This is done using an Iterative Fourier Transform Method (IFTA). The IFTA takes a target pattern and transforms the coordinates of a 'guess phase' between a real/image plane and the Fourier, or phase plane which represents the programmable retardation the SLM pixels apply to light, all the while keeping the input and target intensities constant. After several iterations of this, the phase profile now produces an image of the target pattern with incredible accuracy.

However when placed on an optical setup the results are far from their computer cousins, instead errors up to 40% can be observed in the pattern. To correct for these errors, we have developed a 'Feedback' algorithm. Some previous work has already been carried out, but only for traps of specific shape. The aim of this project was then to develop a generalised code that will work with any shape, and to gain a fuller understanding of the underlying principles of the Feedback progression.

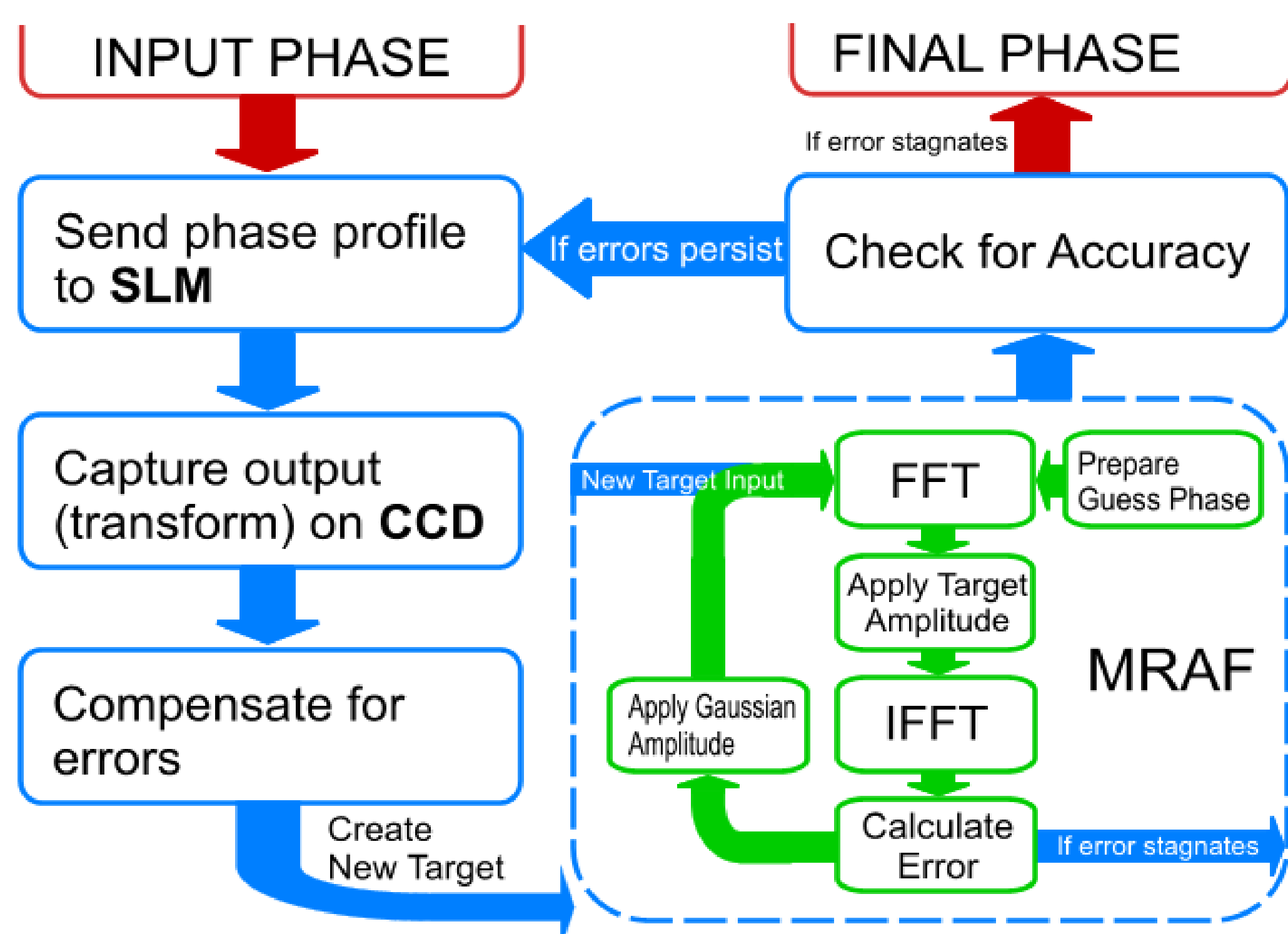


BNS Phase-Only SLM
(256x256 pixels)

Basic Principles and Setup:

The basic setup to create Optical Holograms via phase-only SLM modulation is to have a laser output a Gaussian beam profile, and focus this to slightly overfill the active area of the SLM, and then focus the beam onto a CCD camera to capture the result. We use a Boulder Non-linear Systems (BNS) XY-series P256 phase-only SLM and a 1060nm diode laser. The laser output is non-Gaussian to begin with, which we correct with a set of anamorphic prisms and cylindrical lenses. The active area of the SLM is 6.14mm in diameter. The laser is then focused onto a CCD camera for imaging.

Taking the predicted phase-profile from an IFTA and applying it to any real optical setup results in a hologram with intensity errors with up to 40% RMS error. Reasons for this may include focusing errors, neglect of the 0th order in computation, non-Gaussian inputs, elliptical polarisation and others. All these issues are common in optical setups and even with considerable effort and expense, prove difficult to completely remove. Feedback provides a simpler way to compensate for pattern errors.



Flow-Chart Diagram showing the basic operation of feedback

The basic principle of Feedback is to take the measured output (S), and to add the discrepancy between it and the target (T_i) pattern to the previous target (T_p) and perform another IFTA on it. The amount added is worked out by the relationship:

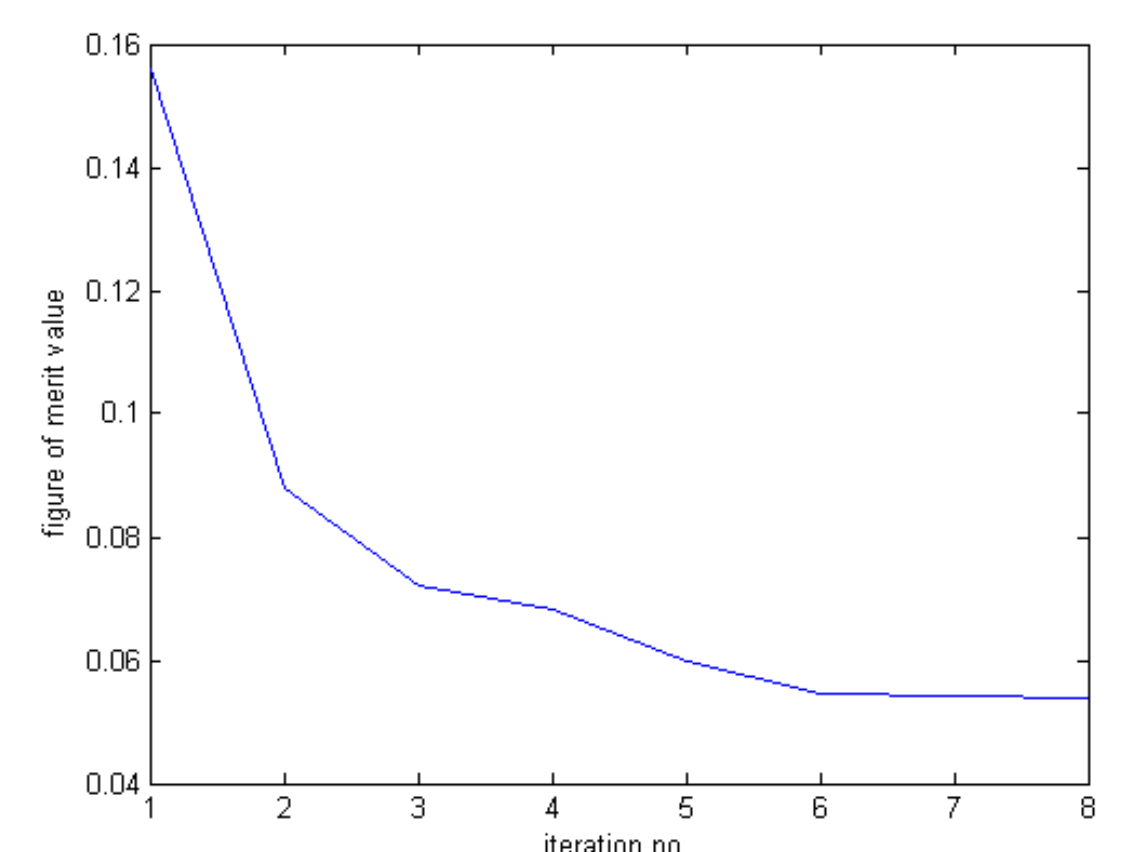
$$T_{new} = T_{prev} + \lambda(T_{initial} - S)^{\alpha}$$

Lambda and Alpha are multiplication and power factors that are set for each pattern. Values of lambda range typically from 0.3-0.6, and alpha may be any positive integer, typically 1. These values seem to affect the speed at which feedback converges to a steady error value, and are pattern independent.

- This 'filmstrip' depicts the step-by-step evolution of an **indented ring** pattern undergoing feedback. All of these images are of the **actual output** captured using a CCD camera, with red being areas of high laser-intensity.

- Each image corresponds to one iteration of the feedback loop. For each iteration, the light-intensity RMS error (difference from the initial target) is calculated.

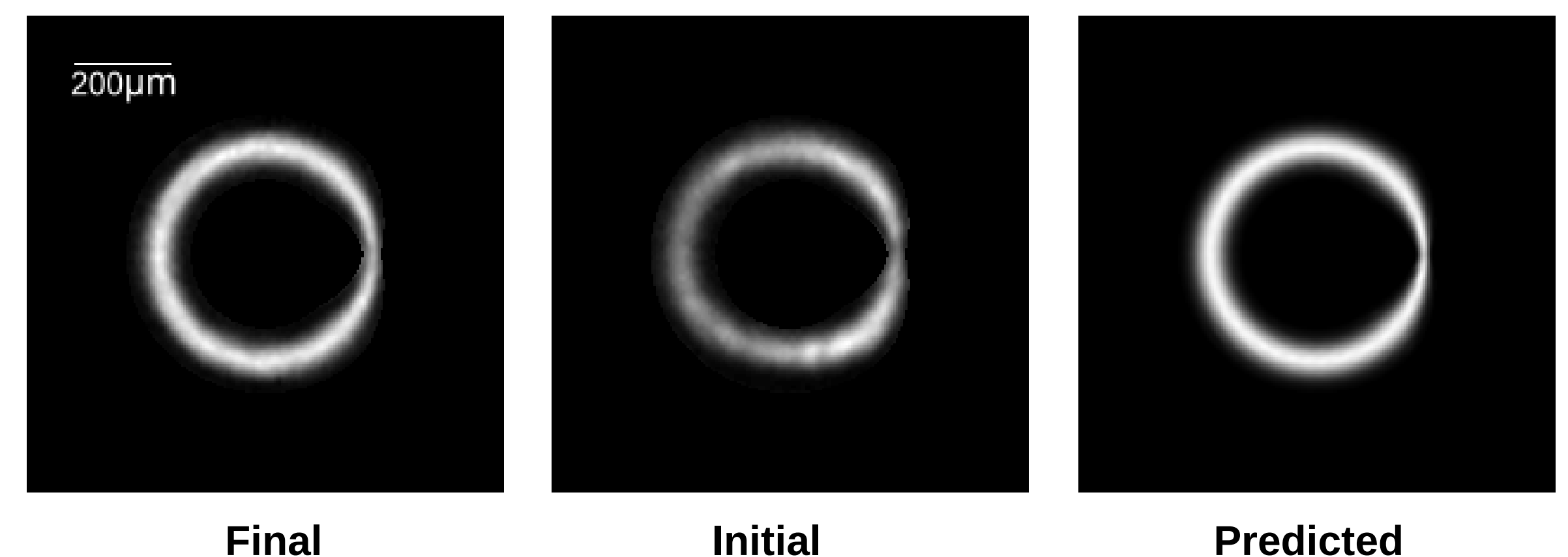
When the light intensity RMS error stagnates the code terminates and the final phase-profile is saved. Plotting this error against iteration number produces a downwards curve. The speed at which stagnation occurs is seemingly pattern dependant and can vary between 7-15 iterations.



RMS Error vs Iteration Plot

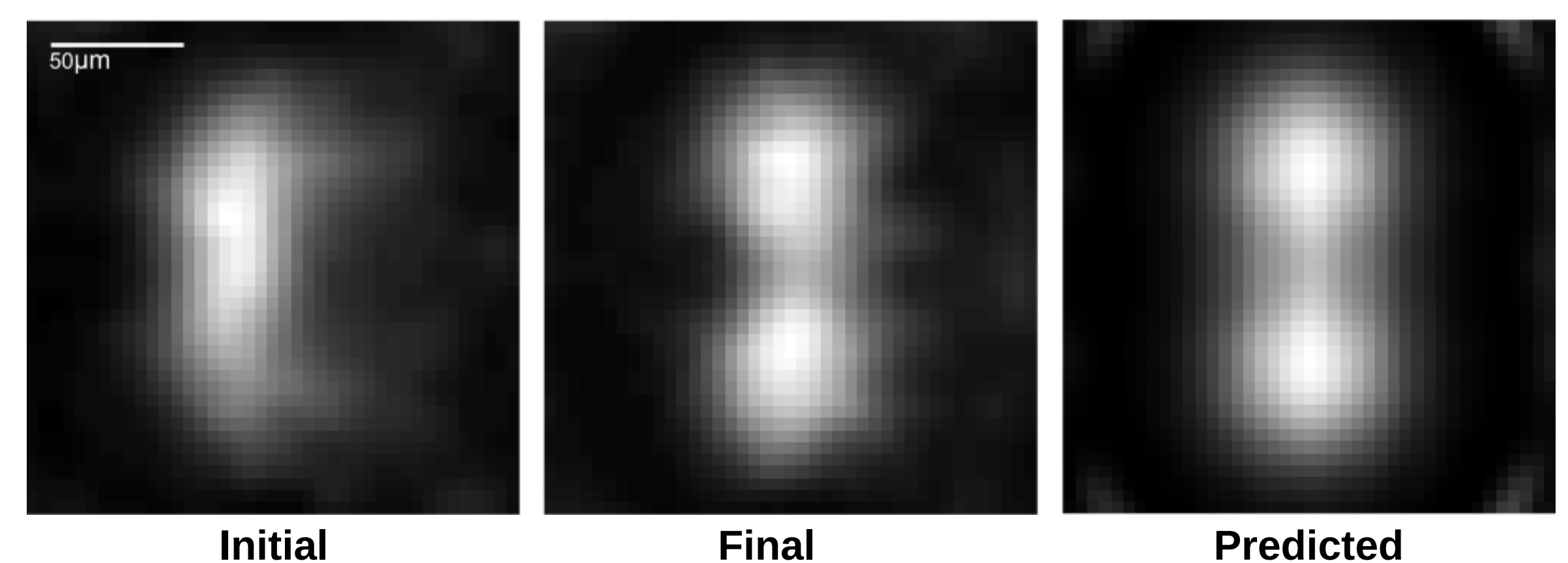
- To demonstrate the flexibility of the IFTA and the performance of Feedback, two patterns - an 'indented' ring and a twin-welled Gaussian - were chosen. Of note, the indented ring is circularly asymmetric, and is conventionally difficult to produce, as the IFTA copes better with symmetric patterns.

INDENTED RING



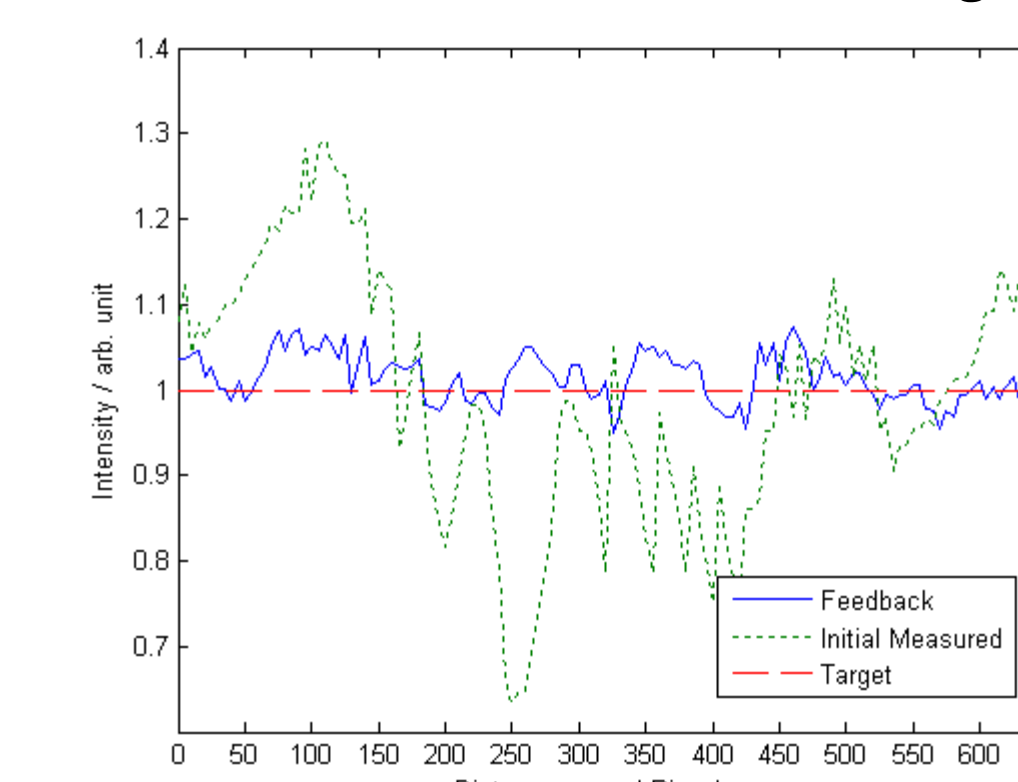
Feedback reduced the errors in the Indented Ring from 24.70% to 6.08% (RMS). The Twin-Peak pattern performed equally as well, from 36.65% to 4.28% (RMS).

TWIN-PEAK GAUSSIAN

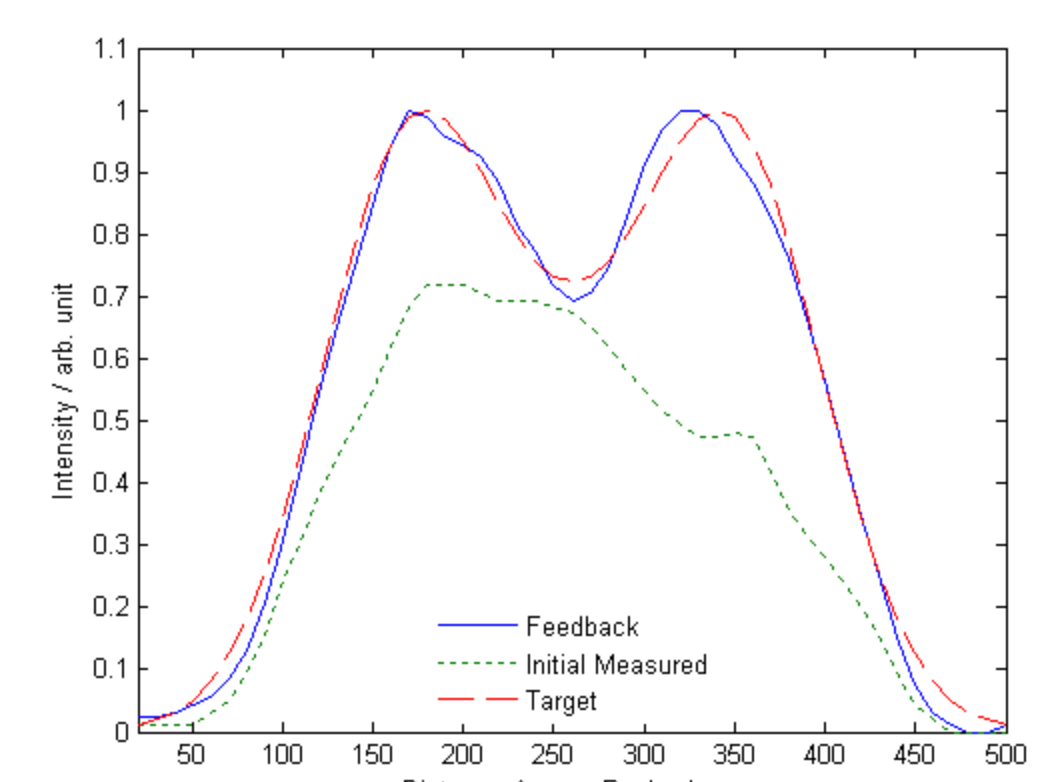


- The RMS values are calculated along a 'cut' along the arc of the ring or across the centre of the wells. The plots below show the target and the output before and after feedback along each cut.

Indented Ring



Twin-Peak



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