Measured BRDF in Film Production - Realistic Cloth Appearance for "The Matrix Reloaded"

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Introduction

Traditionally, fairly simple analytical models have been used to approximate surface reflectance properties, but they work well only for a small set of materials like plastics or metals, which is why most computer graphics today still looks "plastic". On *The Matrix Reloaded* we were required to deliver fully computer generated "copies" of the principal actors for many scenes that are inter-cut with live-action footage. We wanted to escape from a "plastic" computer generated appearance and try to measure true reflectance of certain materials such as the actor's costumes.

Measurement Device

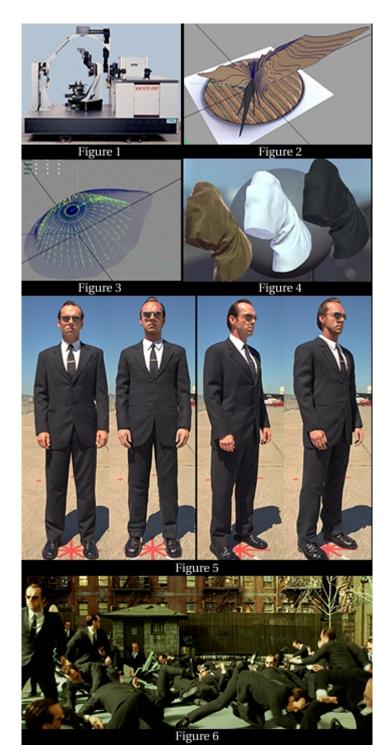
We collaborated with Surface Optics Corporation, a company that is a military and NASA contractor and among other things specializes in building Reflectometers. SOC-200 - the \$700,000 machine in Fig. 1 was built for Lockheed Martin and is used to design the paints of Stealth aircrafts, so they absorb and reflect waves in the "wrong" direction, making them invisible to radars. We were able to get access to the machine and measure the BRDF for some samples of the actor's clothing like Agent Smith's shirt, suit, tie, and lining, Neo's cassock, etc.

BRDF Visualization, Editing, Resampling, and Interpolation

The complexity of real-world BRDFs relative to analytical models is clearly illustrated by tools we built to interactively visualize the measured raw data. Fig. 2 shows the collected raw data at a given incident azimuth and polar angle for Agent Smith's lining which is a highly anisotropic silky material. The data contained some outliers and was not sampled on a regular grid of incident and outgoing directions. This required us to write software and tools for BRDF editing and resampling on a regular grid. The resampling was accomplished by first constructing NURBS curves along the constant azimuth raw samples. These curves were then used to create NURBS surfaces. We then generated sample points on a regular grid by shooting a virtual ray with varying outgoing azimuth and polar angle from the origin and finding the intersection with the surface. That point becomes the BRDF value for the outgoing azimuth and polar angles. The new grid-sampled data allowed us to use fast quadrilinear interpolation lookup to generate BRDF values for arbitrary angles. Fig. 3 shows the BRDF before (in green) and after outlier editing, resampling, and interpolation for incident light angles not present in the original measurement and a denser representation for outgoing angles.

Results

To use the data in computer generated renderings we wrote a material shader whose input was the resampled data file. For truly realistic renderings we combine these measurements with our real world Lighting Reconstruction technology and a highly programmable ray tracer - mental ray. Fig. 4 shows a rendering of the silk lining, cotton shirt, and woolen suit. We are capturing all the subtle appearance of these fabrics, which would have been very difficult to match using the existing reflectance models. Fig. 5 shows a pair of side-to-side comparisons of a photograph of Agent Smith (left) and a complete head to toe computer generated image (right). Fig. 6 shows a fully synthetic frame from *The Matrix Reloaded*.



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