A technical overview of the Fuel3D system.

FUEL3D™

Fire up your creativity.

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Introduction

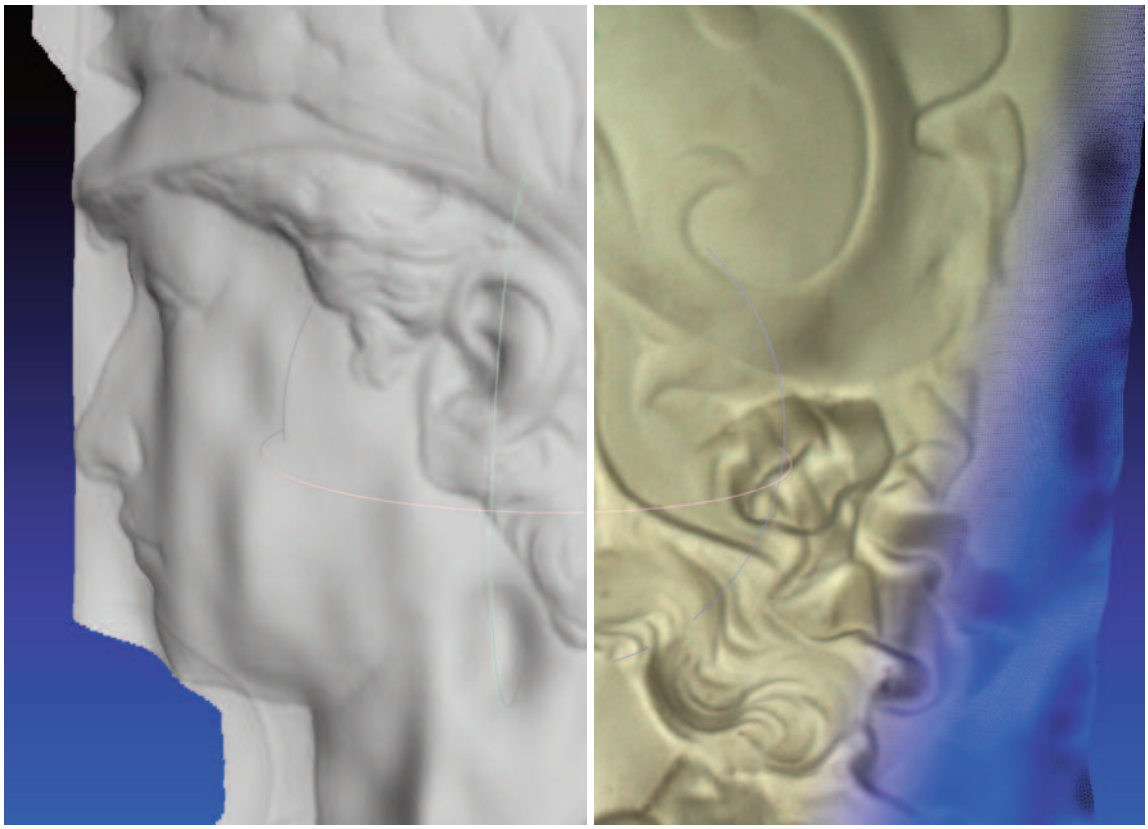
The Fuel3D scanner brings handheld 3D imaging technology, originally developed for high-end medical applications, into the professional and consumer marketplace at a dramatically lower cost than comparable solutions. Whether you are a game developer, designer, artist, maker or any kind of 3D enthusiast, Fuel3D can help you easily capture, archive and manipulate detailed, full color 3D images.

Fuel3D has three components:

- A handheld camera unit which connects to your PC or Mac via a USB connection, in a similar manner to a webcam
- Software which runs on your PC or Mac and works in conjunction with the scanner
- Optical targets, which are used to allow the scanner to track its motion during image capture

Working together, these components allow rapid capture of color 3D images, which can then be edited and exported into a number of different 3D formats, including .STL for 3D printing, .OBJ for impoirting textured images into games, and .PLY for full color on-screen rendering.

So how did we manage to achieve this? Well, it wasn't easy and took a lot of sweat and some long days. So read on to find out more about how Fuel3D has been developed to help you fire up your creativity!



Integrated image showing combined different scan views

How does Fuel3D actually work?

When taking an image, the Fuel3D scanner rapidly acquires a series of stereoscopic 2D photographs with several lighting directions. These are then processed by software to resolve a single 3D image. Under the hood, Fuel3D combines a number of image processing technologies to allow on-the-spot acquisition of high quality 3D images:

- Photometric imaging is used to acquire color and high-frequency 3D detail from the subject
- Optical localization is used to determine the position of the imaging device during the acquisition process
- Geometric imaging is used to acquire accurate underlying 3D shape information from the subject
- Data fusion is performed to combine the data output of the photometric and geometric processes to produce a single 3D image

Photometric imaging for high-resolution surface detail

Photometry is the science of the measurement of light. The principle behind photometric imaging is that the image of a subject observed by a camera depends on both the shape and material properties of the subject, and the lighting conditions under which it is illuminated.

When carrying out photometric imaging, several images are taken of the subject illuminated by a single dominant light source from a number of different directions. Image processing techniques examine how the observed illumination levels across the subject vary with the change in lighting direction, calculating the direction of the "normal" to the surface of the subject for each pixel in the image, alongside maps of reflectivity, such as color. The resulting "normal map" is then integrated to provide a highly detailed 3D "range map" of the surface.

Traditional photometric systems are bulky, requiring many light sources and careful calibration. They are not portable and are generally regarded as inappropriate for capture of live subjects. A key component of the Fuel3D technology is the optical target…

Optical localization to track movement during acquisition

The Fuel3D system is handheld, and so moves during acquisition of the subject. By placing a simple optical target next to or (in the case of live subjects) onto the subject, parameters describing this motion can be resolved (see diagram 1 on page 7). The principle behind this is that the system knows the size and layout of the optical target, and by looking for the target in the image, Fuel3D can accurately estimate the relative position and orientation of the scanner with respect to the target.

The target allows the Fuel3D software to calculate the position of the camera and the light for each image. This eliminates the need for many of the functions of traditional system calibration and allows a practical hand-held system to be produced, which can compensate for small movements during photometric imaging.

The optical target allows accurate measurements (within limitations of resolution and noise) to be recovered in the X and Y dimensions of the 3D data output from photometric imaging. Z data will be subject to a degree of low-frequency distortion, and thus is not highly accurate. This is a fundamental limitation of photometric imaging techniques, which is overcome by incorporating geometric 3D imaging…

Geometric imaging for accurate underlying shape

Geometric 3D imaging resolves depth using optical triangulation, which involves resolving distance from parallax. With the Fuel3D system this is achieved by using stereoscopic imaging (two cameras and lenses) to acquire a matched pair of images of the subject, then identifying and correlating the location of features between the two images to sub-pixel accuracy. For this to be possible the subject must have a degree of random surface texture, either from variation in color, or from having a rough or wrinkled surface. The output from the geometric imaging technique is a 2D range map analogous to that provided by photometric imaging, with

better underlying accuracy but lower resolution. Geometric 3D imaging gives accurate measurements of bulk shape in all three dimensions.

Data fusion to combining geometric and photometric data

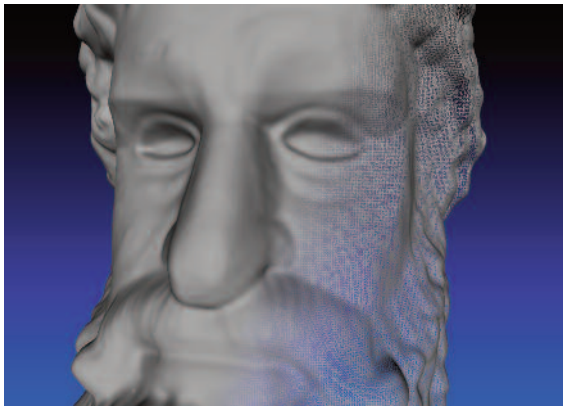
The Fuel3D software incorporates proprietary algorithms to combine the data from its photometric and geometric 3D imaging systems to produce a single 3D model that is both accurate and has high resolution of surface detail. In essence, the high-accuracy, low-resolution geometric 3D data is used as a skeleton on which the higher resolution photometric 3D data is overlaid. The resulting 3D images consist of a large number (several hundred thousand) of samples, each having XYZ geometry (surface location in millimeters) and material properties (color) in 8 bit RGB.

How accurate is the data from Fuel3D?

Output resolution from Fuel3D varies with the distance of the system to the subject. The best achievable resolution is approximately a 250 micron sampling. To provide an indication of data accuracy, an object known to be flat (-/+ 0.25mm) was imaged several times at the minimum achievable resolution (i.e. the greatest distance from the Fuel3D scanner). A synthetic plane was then fitted to the data and error bounds calculated as distances from the plane. Results were as follows:

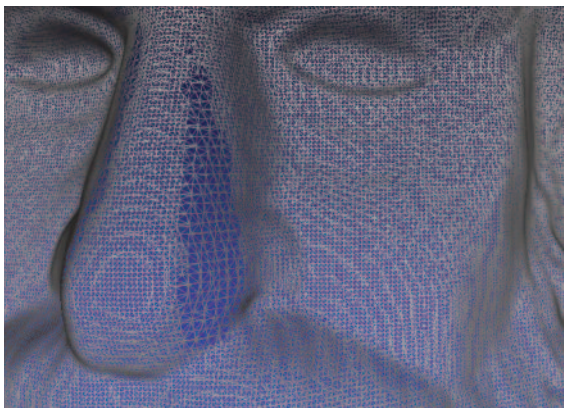
Inter-sample spacing (X)	500 microns nominal
Inter-sample spacing (Y)	500 microns nominal
Minimum per-sample error	2.07e-7mm
Maximum per-sample error	2.50mm
Average per-sample error	0.30mm
Number of samples	234780

Original of a plaster portrait reproduction



3D Scan of a sculpture showing introduction of wireframe

3D Scan of a sculpture showing details and relief



Display of full 3D wireframe

What kinds of things can be imaged with Fuel3D?

Fuel3D is a combination of hardware and software which can resolve 3D information from subjects, whether people or inanimate objects. It is important to understand that there are some scenarios in which the system will resolve data better than in others, and also some ways to maximize the effectiveness of the system.

Some examples of subjects which work well with Fuel3D

- Skin, e.g. faces and body parts
- Fabrics
- Organic subjects e.g. plants, leaves
- Stone, masonry, brick
- Food
- Artwork, e.g. paintings, statutes

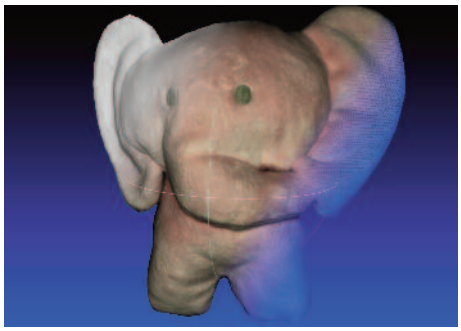
...and some examples of subjects which are more challenging

- Glassware, and reflective objects e.g. mirrors
- Jewelry
- Metal objects, e.g. knifes & forks
- Plain objects e.g. cups and saucers
- Animate objects, e.g. things which are deforming
- Hair, e.g. hairy animals or body parts

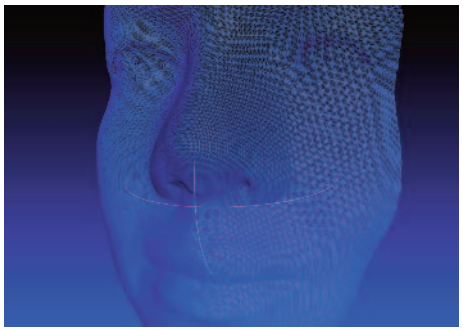
Key points to note:

- Fuel3D has fixed focus. It resolves a maximum size of about 35cm diagonal in a single image.
- Reflective, transparent or shiny objects are more complex to capture.
- Textured objects are better, ideally randomly. This is because the system has to correlate pixels between stereoscopic views of the subject. Textured can mean one or both of having varying colour, or surface roughness meaning illumination from an angle (as with the Fuel3D scanner) results in surface detail being visible.
- Fuel3D needs to be able to see a point on a subject with both cameras in order to resolve it. Subjects with deep holes or crevices can be difficult for the camera to see into.
- Fuel3D can only resolve what it can see from a single viewpoint. Acquiring e.g. a whole human head will require multiple shots and third-party software to register and "stitch" the shots together.

Hybrid 3D scan of a sunflower (color image, relief and wireframe)



Hybrid 3D scan of a soft toy (color image, relief and wireframe)



3D wireframe of a female face

Using Fuel3D

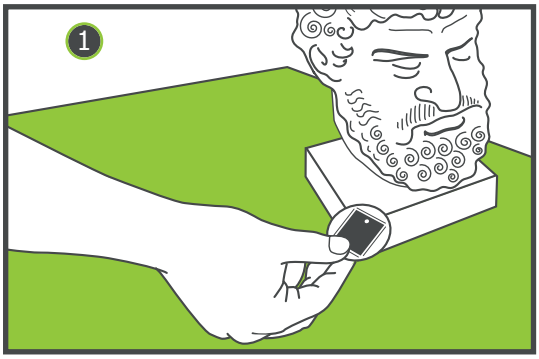
Acquiring 3D images with Fuel3D is straightforward. You will need a Fuel3D scanner, a computer running the Fuel3D software, a Fuel3D target, and, of course, something to image!

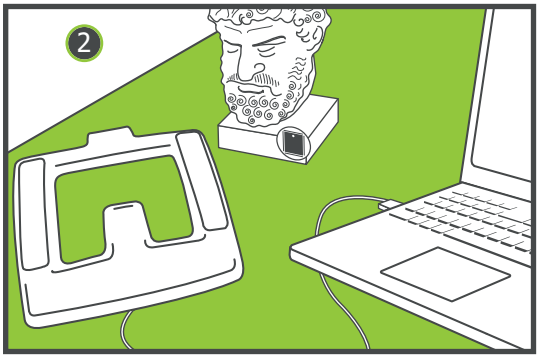
The Fuel3D software can be installed on both Mac and PC. The required minimum specification is as follows:

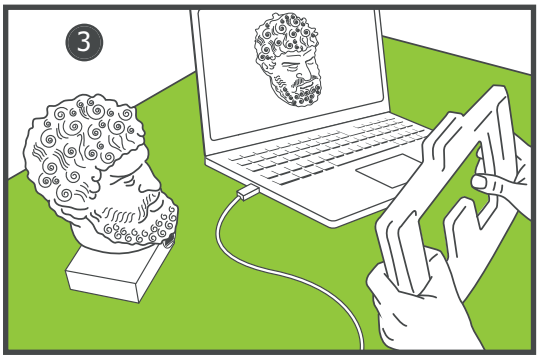
- Mac, Windows 7 or Windows 8 Pro
- 2GB RAM, 1GB hard disk space
- Dual-core processor

To start taking 3D images, here's all you need to know:

1. (Illustrated) Prepare the subject to be imaged. For a live subject, e.g. a person, you will need to attach a target onto them. For an inanimate object, place the target nearby so it can be viewed alongside the subject. The target needs to be placed so that it is approximately facing the scanner when you will be taking the image, not facing away.
2. (Illustrated) Attach the Fuel3D scanner to your computer, and start the Fuel3D software. The software will display a live viewfinder on your computer so you can aim the scanner at the subject to be imaged.
3. (Illustrated) Line up the Fuel3D scanner using the viewfinder on your computer screen, so that you can see both the subject and the target in the viewfinder. The viewfinder will indicate when you are the right distance to take the shot.
4. (Illustrated) Press the button to take the shot. The scanner will rapidly flash several times and acquire the image.
5. The image will be transferred to your computer and will enter the inbox for processing. The scanner will automatically recharge its flash units and the viewfinder will indicate when the scanner is ready to take another shot.
6. Depending on the speed of your computer, the image should pass through the inbox in about 20 seconds. Once processing is complete you can then view the image in the 3D view.
7. The 3D view allows you to interactively view and manipulate the image, cropping out the region of interest and then exporting to common 3D file formats.







Getting the best out of Fuel3D

- Minimise background clutter. When imaging people, try to isolate the body in space, away from walls or the floor. When imaging objects, place against a dark, textured background e.g. carpet or fabric.
- Avoid overexposure. Highly reflective (e.g. bright white) subjects may result in overexposure. The Fuel3D scanner has an operating distance of about 40cm +/- 5cm. If your images appear overexposed, try to move the scanner further away from the subject when imaging.
- Avoid direct sunlight, or very bright overhead lighting. Again this may result in overexposure. The Fuel3D system is best used in normal office or home conditions.
- Acquire featureless objects by speckling the surface of the object to add texture.
- Image faces viewing "upwards" into the face. The Fuel3D scanner has two sensors in a vertical orientation, and both sensors must be able to see the surface of the subject in order to resolve. Noses "overhang", so you will do better with imaging faces if you are imaging from a lower position, looking upwards.

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* Please note that the front cover image is a graphic render of the proposed Fuel3D product design.