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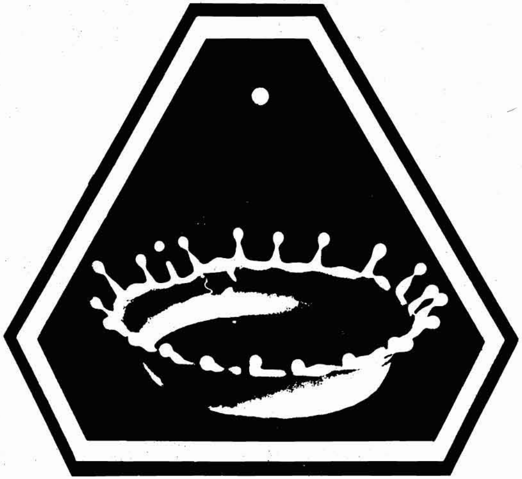

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PAPER SUMMARIES

3D IMAGE Acquisition BY DIFFRACTION PROFILOMETRY

Tom DeWitt
DeWitt Brothers Tool Company
New York City, New York, USA

A new method for profilometry has been invented, diffraction range finding. The method offers distinct advantages over triangulation in the near-field, because the diffraction method is monocular and works to point-of-contact. Moreover, when the grating parameters are tailored properly, the diffraction method magnifies the profile dimension, providing accuracy equal to the front-looking sensor. Implementations of the new method can take advantage of the emerging technologies of holographic optical elements (HOEs), including mass-produced embossed HOEs, as well as computer generated gratings produced by optical or electron beam lithography.

BACKGROUND

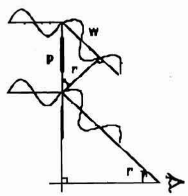
A profile is a side view. The profile contains the depth (range) coordinates for the corresponding front-on view. Profiles can be acquired through views off a normal, and profiles seen at the angle perpendicular to the normal will produce linear range data. However, it is rarely practical to place a ranging camera an angle perpendicular to the front-on view. More typically, the profiling camera will be at a placement of less than 45 degrees. Indeed, one biological model for stereo photogrammetry, our eyes, has a mere 5 degree rotation. In these cases, the range data acquired are not linear, because their accuracy is inversely proportional to distance. The accuracy of 3D ranging in human vision is much less than the two-dimensional resolution of the eye itself. Moreover, at ranges closest to the eyes, where triangulation accuracy would be theoretically the highest, there is an unavoidable blind area between the two views.

THEORY

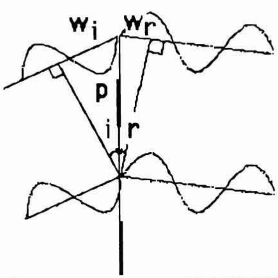
A diffraction grating re-radiates incident energy as a large number of new point source radiators. To an observer looking at the grating, only those wave fronts that arrive in phase at the point of observation will be detected. The remainder are eliminated by phase cancellation. For a point source radiator at infinity, the intensity maxima will be perceived at angles off the normal according to the basic equation:

$$\sin(r) = \frac{w}{p} n$$

Where w = the wave length of the incident radiation
p = the pitch of the grating
r = the angle of the perceived maxima
n = the diffraction order, an integer



This equation is based on a physical model at the scale of the grating grooves shown in the figure to the right. Adjacent grooves will radiate in phase along the observer's line of sight, when the inscribed right triangle made along the viewing axis has an opposite leg equal to the wave length, w. This is a similar triangle to the right triangle made along the normal line of view and the view of the diffraction image.
They share angle r. Constructive interference of waves from adjacent grooves will occur at integral multiples of the wavelength. These are the diffraction orders, n.



However, when a point source radiator is at a finite distance from a planar grating, the incident wave front strikes the grating out of phase with itself.

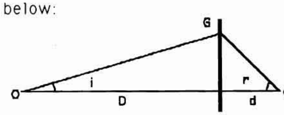
As illustrated in the figure to the left, the angle i can be inscribed on the incident face of the grating. The opposite legs of angles i and r sum to the wavelength., that is : wi + wr = w. The two triangles share the hypotenuse, p. The condition of additive construction between in-phase waves across adjacent grating grooves is maintained when:

$$\frac{wi + wr}{p} = \frac{w}{p} n$$

We can now say:

(1) $$\sin(i) + \sin(r) = \frac{w}{p} n$$

Consider the model below:



A point source radiator at O is viewed through grating G at the perspective center C. Equation 1 can be rewritten as:

(2) $$D = \frac{\tan(r)\ (1 - (\frac{n\ w}{p} - \sin(r))^2\ )^{(.5)}}{(\frac{n\ w}{p} - \sin(r))\ d}$$

Given d, p, w, and n the range distance D can be found by measuring r, the angle of the higher order diffraction spectra perceived by an observer at point C. This is a hyperbolic dependency. The angle r is asymptotically limited as distance D approaches infinity.

At distances approaching the grating, the diffraction maxima shift rapidly. Profile views can be magnified in near-field cases when appropriate choices are made for grating pitch, wavelength of illumination, observer-to-grating distance and the considerable width of the grating.

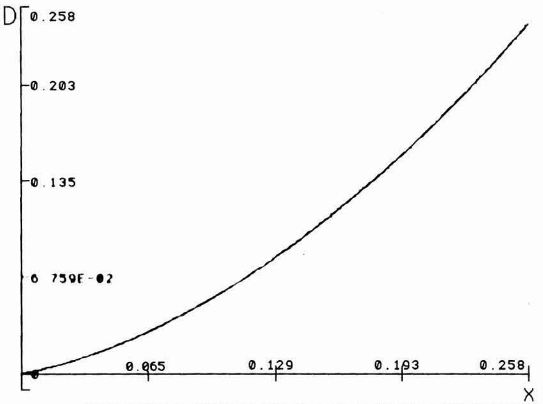
PRACTICE

Profilometry by the diffraction method can be implemented following practices commonly used in triangulation. Structured illumination can be used to designate the target. A camera or other photogrammetric sensor records the diffraction pattern for analysis. With linear gratings and stripe illumination, the patterns are simple, and may be measured by a micro- computer in real time. The author has built a prototype system using a television camera and an Apple II computer for image processing.

The diffraction method is sensitive to wavelength, so monochromatic illumination or bandpass filtering at the sensor is required. However, the method has no dependence on source coherence, notwithstanding that the directionality and monchromaticity of the laser make it a favored illuminant.

The scale of the measurements that can be made by the diffraction method is broad. With short wave length illumination and gratings of near equivalent pitch, microscopic profiles can be detected. Long wave length radiation and large scale gratings would permit ranging at kilometer distances, although with some sacrifice in accuracy.

The author's particular interest has been in the digitization of the human face and figure. An initial experiment with a holographic grating and HeNe laser stripe illumination has produced accurate profiles of a head. The experiment confirmed predictions based on equation 2. Relating the distance to the target (D) as a function of the displacement across the face of the grating (X), the following graph can be made:



Range (D) vs. Displacement Across Grating (X) in Meters

The graph predicts profile ranging suitable for the human bust. The ranging accuracy is better than 1:1 throughout the entire region.

The diffraction method of profilometry has no prior citation in the literature other than by the author, although the grating interference principles are well known. Further experimental evaluation is warranted.