An overview of the Algorithm and Software Description for OLA, ALTWG and Stereo-Photoclinometry [SPC] products are described in the ALTWG SIS ODOCS -> 9.4.2 -> SISs -> UA_DD_9.4.4-307.

A brief overview of how SPC will work during the OSIRIS-REx encounter with Bennu is also captured in the following SPC tutorial slide set:

Greater detail is provided in the following published manuscript:

OLA processing:

Kahn, E.G. et al., 2015. Reconstruction of the Eros Shape Model Using NEAR Laser Rangefinder Data. 46th Lunar and Planetary Science Conference, 46, p.2874.

ALTWG manuscript and user guide forth coming.

SPC processing:

Gaskell, R.W., 2011. Optical Navigation Near Small Bodies. Proceedings of the 21st AAS/AIAA Space Flight Mechancis Meeting, 140(11-220), p.13pp.

Gaskell, R.W. et al., 2008. Characterizing and navigating small bodies with imaging data. Meteoritics and Planetary Science, 43(6), pp.1049–1061.

SPC User guide forthcoming.

A QUARTER CENTURY OF SPC

Digital Identification of Cartographic Control Points

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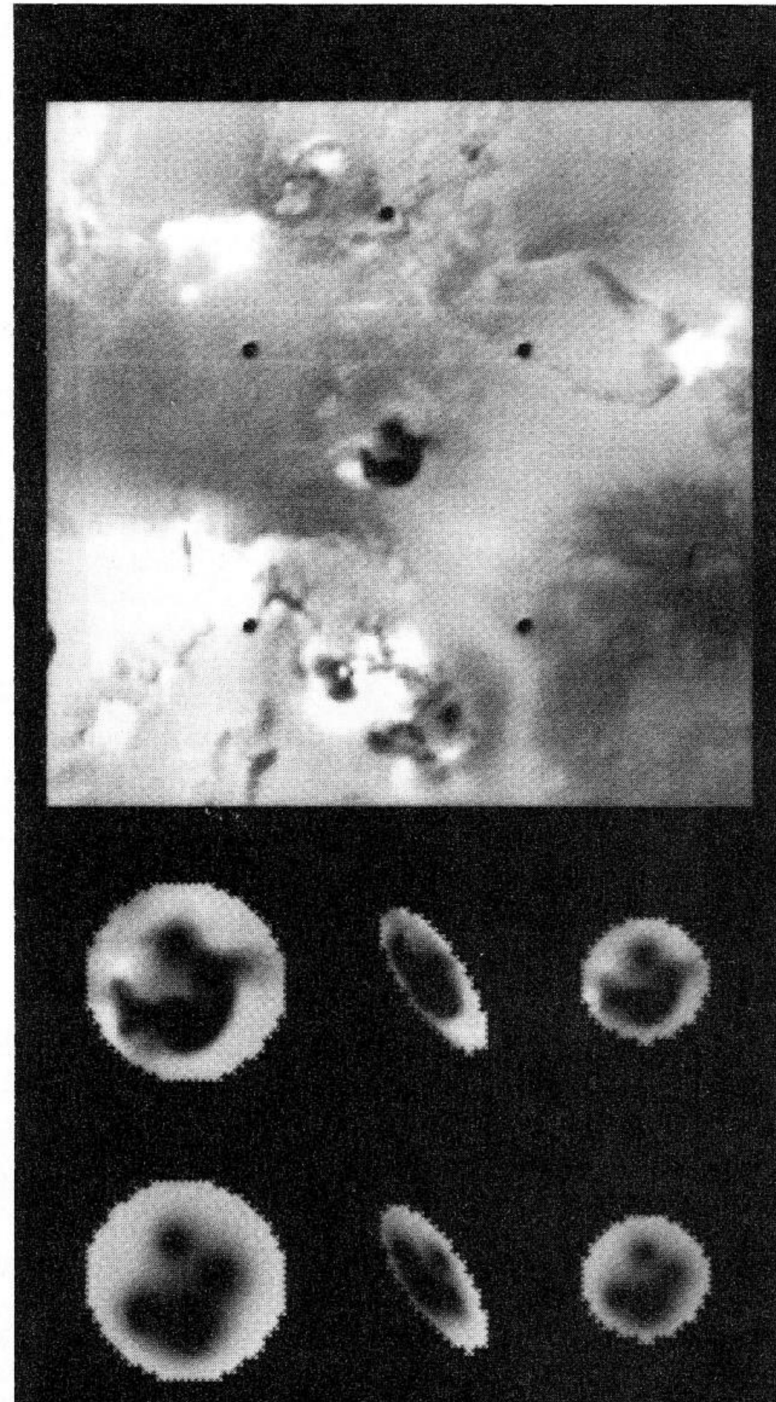
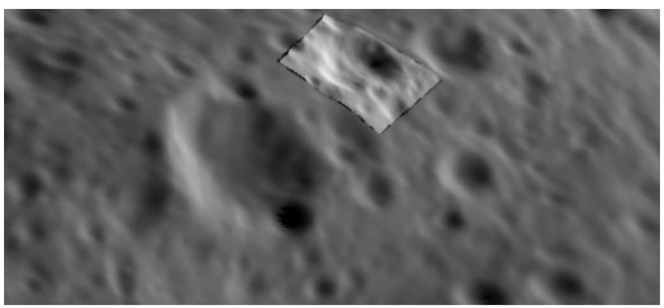


GOAL: To design an object (template) that can be identified and located in an image under any observation conditions.

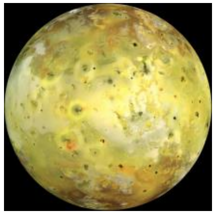
CONCEPT: Construct topo/albedo maps of surface patches with control point at center.

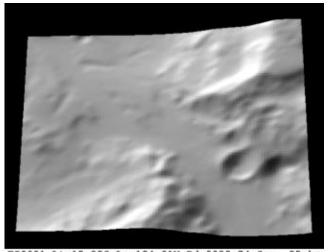


RESULT: Stereo on steroids. Precise control point location from huge stereo separation over multiple trajectories and even multiple spacecraft.

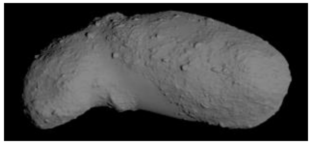
SPC HERITAGE

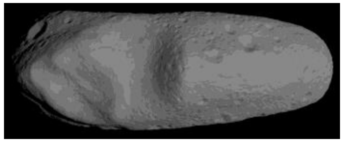
1985 1990 1995 2000 2005 2010 2015

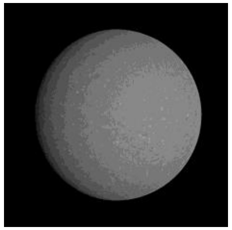


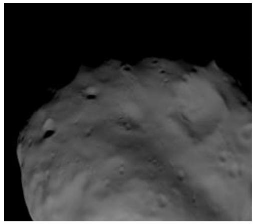


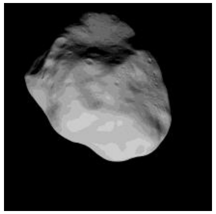
FI0031 Lt=15.95S Ln=184.01W Rd=3392.74 Sz= 25 km

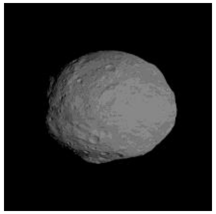


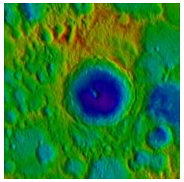


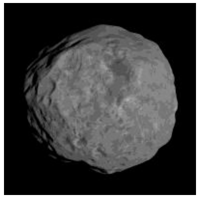


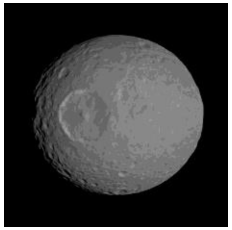


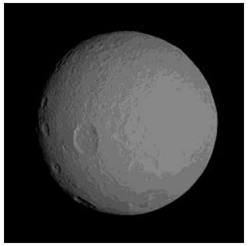


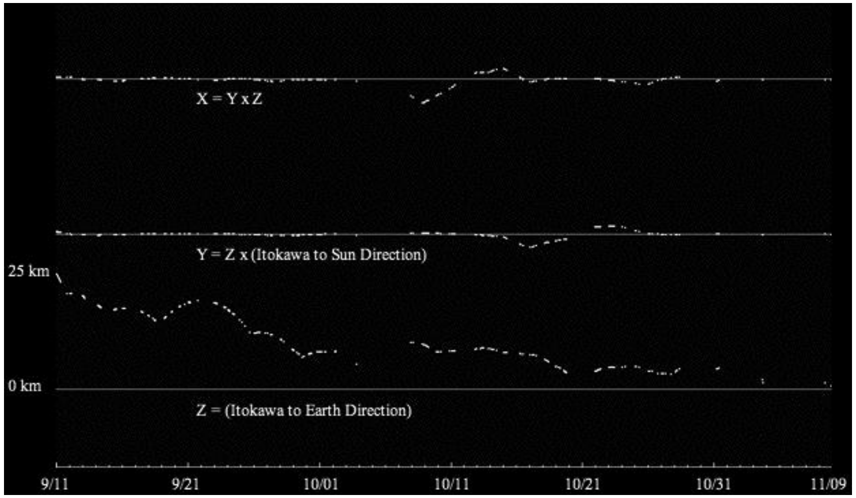












NEAR LANDING

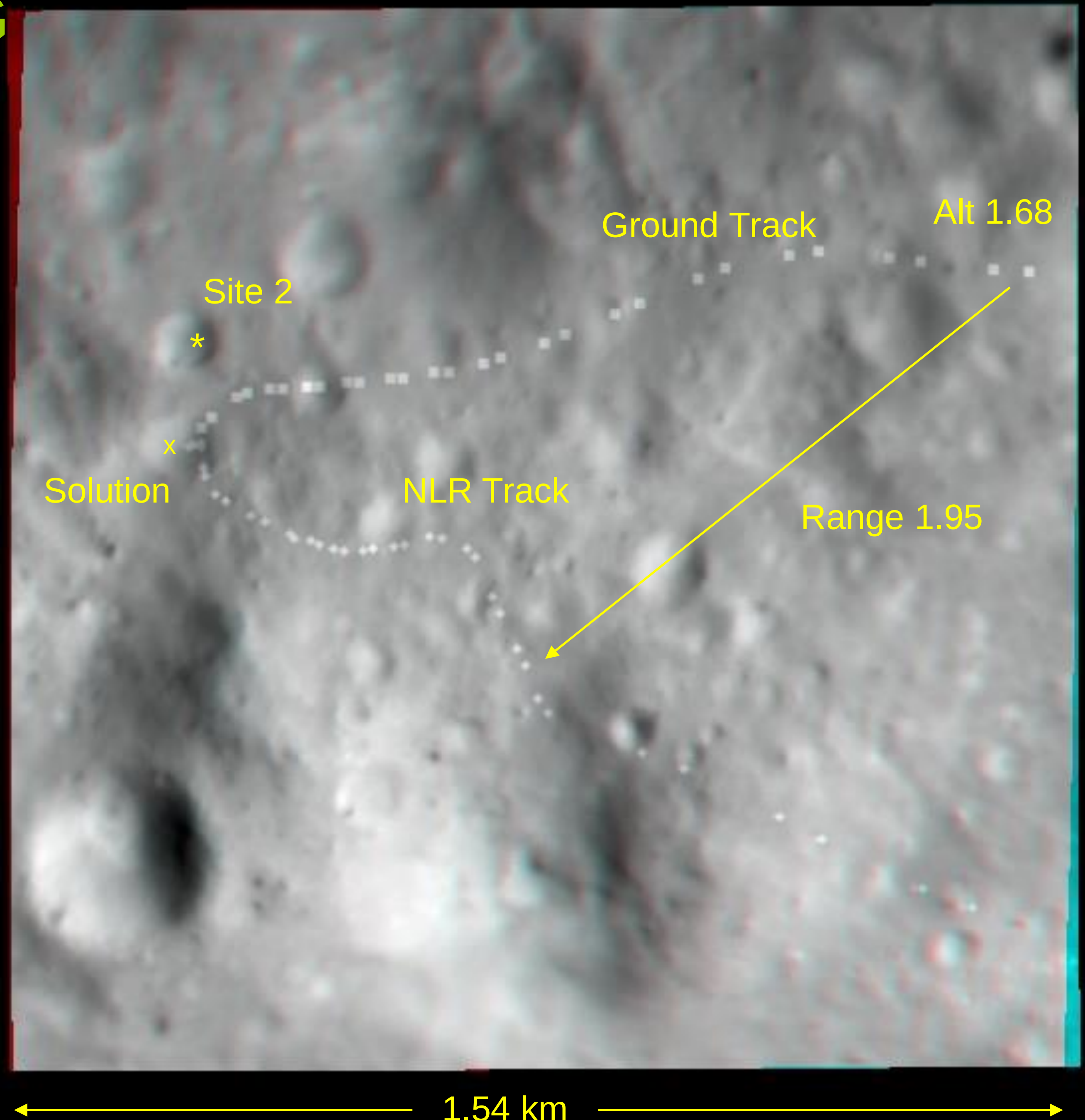
This solution:

x = 0.818 ± 0.01
y = 4.849 ± 0.01
z = -4.370 ± 0.01
Lat =   41.626 S
Lon = 80.421 E

*Site 2:

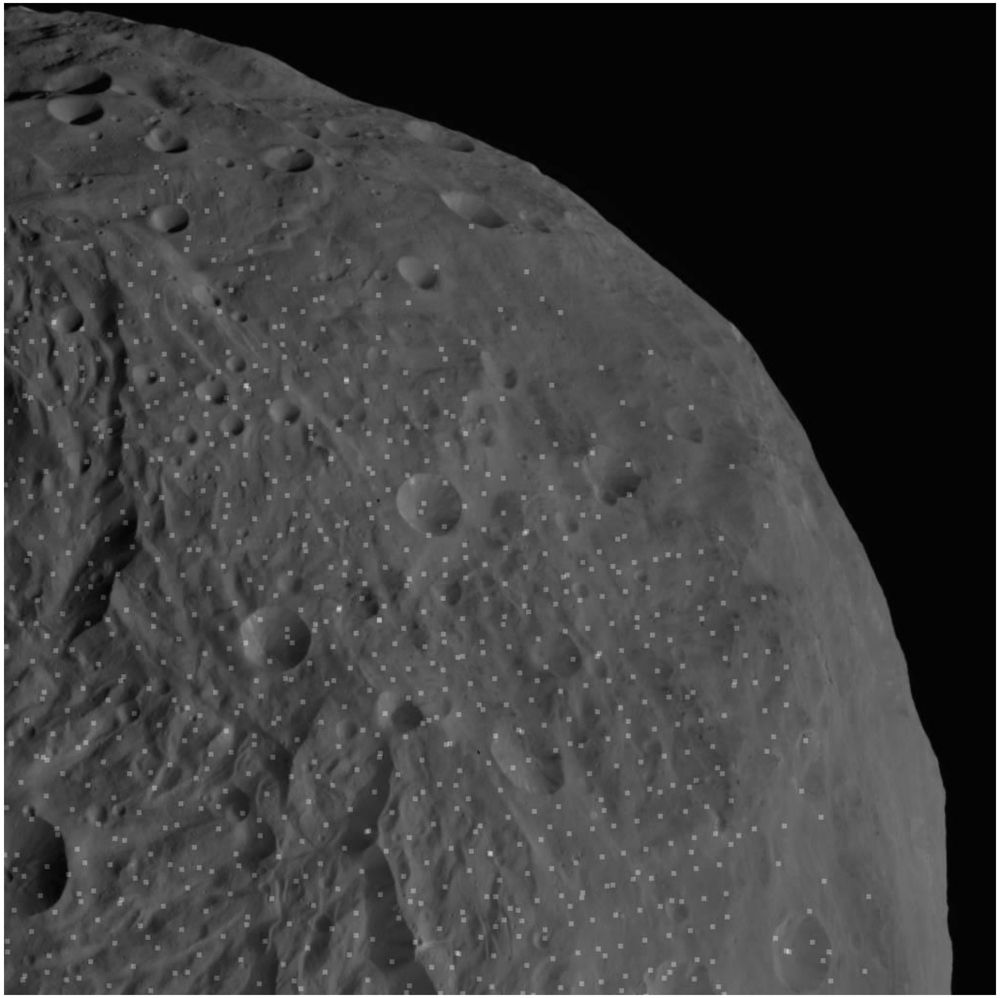
x = 0.802 ± 0.05
y = 4.872 ± 0.01
z = -4.147 ± 0.15
Lat =   40.03 S
Lon = 80.66 E

*Antreasian, et al. 2001
(AAS 01-372)



DISTANT NAVIGATION

Positions of landmarks in this image change in a unique way under changes in camera pointing and spacecraft position (six degrees of freedom)



If we know where the landmarks are, and if we know the orientation of the body, we can completely determine the s/c state.

BUT we don.t know where they are, we don’t know s/c state and we don’t know asteroid’s rotation.

We face a huge estimation, simplified in part by taking many images on approach, with its simple, nearly linear trajectory.

UP CLOSE NAVIGATION

Positions of landmarks in this relatively flat image change in a not quite unique way under changes in camera pointing and spacecraft position since all points are at about the same distance. If L is the number of landmarks and σ is LMK position uncertainty relative to FOV, range and twist are:

$$\delta V_z/V \sim \delta R_z \sim 3\sigma/\sqrt{L}$$

but for cross line of sight

$$\delta V_x/V \sim \delta V_y/V \sim \delta R_x \sim \delta R_y \sim 5\sigma \mathrm{ctn}(\theta)/\sqrt{L}$$

where θ ~ larger of slant angle or FOV/2. Most modern spacecraft have pointing uncertainties of ~ 100 μr that helps break the degeneracy.

BUILDING MAPLETS

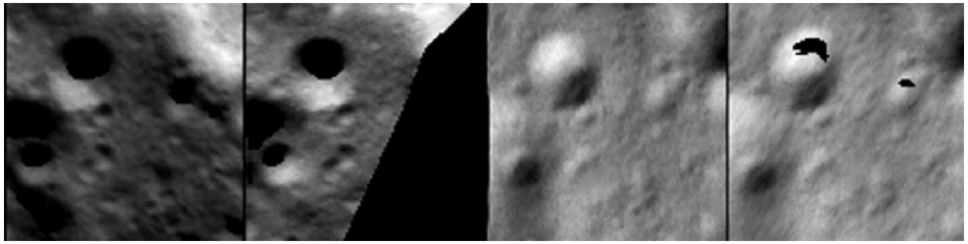


Image data is extracted from the pictures and projected on the initial maplet topography. The brightness (dn) at each map pixel for each image is

$$dn \sim \lambda(1+t_3)R(\cos i, \cos e, \alpha) + \chi$$

where

$t_1 = -\partial h/\partial x$, $t_2 = -\partial h/\partial y$, $1+t_3 \sim$ albedo

$\cos i = (s_1 t_1 + s_2 t_2 + s_3)/\sqrt{(1+t_1^2+t_2^2)}$

$\cos e = (e_1 t_1 + e_2 t_2 + e_3)/\sqrt{(1+t_1^2+t_2^2)}$

λ sets the scale for the brightness variations. A large λ means slope variations are smaller, so we need initial topography to fix λ.The first landmarks must be large, so the curvature of the body provides known topography. Template parameters t_1, t_2 and t_3 are estimated at each map pixel by minimizing sum square residuals of measured and predicted dn.

χ models background brightness and is currently unused.

GETTING HEIGHTS FROM SLOPES

Remember that $t_1(x,y) = -\partial h/\partial x$, $t_2(x,y) = -\partial h/\partial y$

So $t_1(x+s/2,y) \sim [t_1(x,y)+t_1(x+s,y)]/2 \sim [h(x,y)-h(x+s,y)]/s$, etc.

This leads to the tautological relationship in the first two lines:

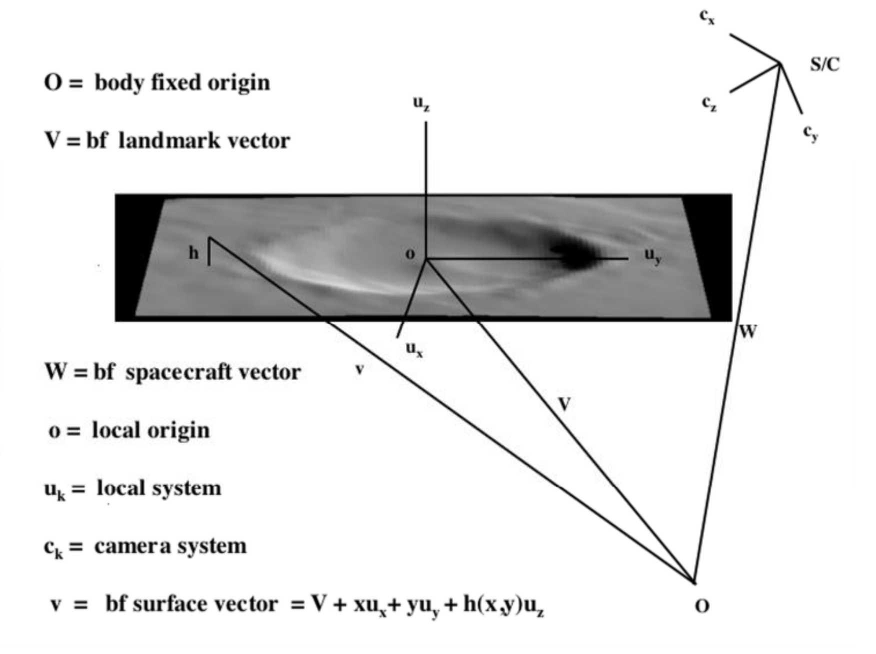
$$
\begin{aligned}
h(x,y) = \; & [h(x+s,y)+s(t_1(x,y)+t_1(x+s,y))/2+h(x-s,y)-s(t_1(x,y)+t_1(x-s,y))/2 \\
& +h(x,y+s)+s(t_2(x,y)+t_2(x,y+s))/2+h(x,y-s)-s(t_2(x,y)+t_2(x,y-s))/2 \\
& +w_c h_c(x,y)]/(w_c+4)
\end{aligned}
$$

To this we occasionally average in a constraining height w_c to set the scale of a Monte Carlo relaxation process. This occurs in the slope to height (slp2hgt) process in LITHOS. The constraints come from several sources. The initial topography itself, topography from overlapping maplets or external maps (eg from lidar data), heights from differential stereo and heights from limbs are the most used. The same procedure is used in the program BIGMAP. Maplet heights and slopes are initially averaged at each bigmap pixel. The slp2hgt process is carried out, with randomly selected average heights used as constraints.

EXTRACTING IMAGING DATA

We need to extract imaging data to the right pixel on the maplet display.

If we are looking obliquely and there is significant topography, there may be distortions if the topography is not correct. Practically, this means that initially we should restrict emission angles to smaller values, say < 40°.



With $M_{ij}=\mathbf{c}_i\bullet\mathbf{u}_j$,

$$X = f((\mathbf{V}-\mathbf{W})\bullet\mathbf{c}_1+M_{11}x+M_{12}y+M_{13}h)/((\mathbf{V}-\mathbf{W})\bullet\mathbf{c}_3+M_{31}x+M_{32}y+M_{33}h)$$
$$Y = f((\mathbf{V}-\mathbf{W})\bullet\mathbf{c}_2+M_{21}x+M_{22}y+M_{23}h)/((\mathbf{V}-\mathbf{W})\bullet\mathbf{c}_3+M_{31}x+M_{32}y+M_{33}h)$$

where X,Y are the focal plane positions in a pinhole camera. A distortion model takes these to the true positions and a K-matrix transforms to pixel space.