01	02	03	04	05
				
Front neutral expression	Facing 45° up	Facing 45° down	Happy expression	Eyes closed
06	07	08	09	10
				
Angry expression	2nd Neutral	Eyebrows raised	3rd Neutral	Farther from camera

Fig. 5. Example face models taken from a 3D face database

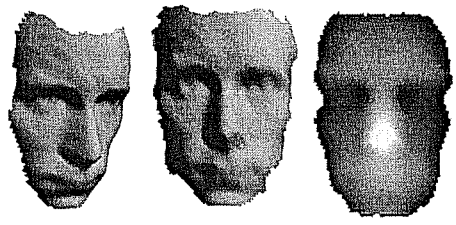


Fig. 6. Orientation of a raw 3D face model (*left*) to a frontal pose (*middle*) and facial surface depth map (*right*)

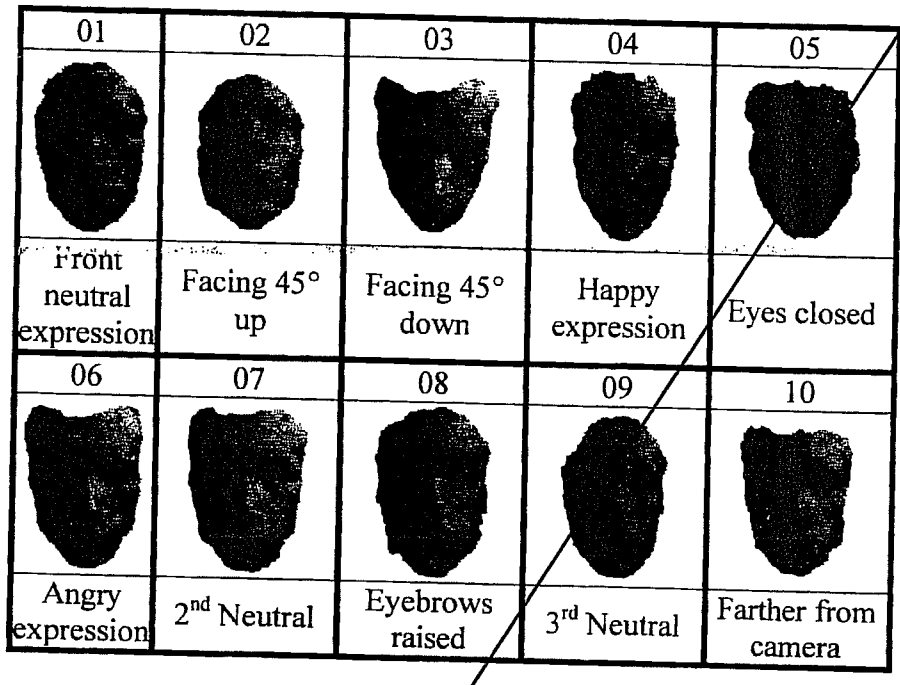


Fig. 5. Example face models taken from a 3D face database



Fig. 6. Orientation of a raw 3D face model (*left*) to a frontal pose (*middle*) and facial surface depth map (*right*)



Fig. 7. Average depth map (*left most*) and first eight eigensurfaces

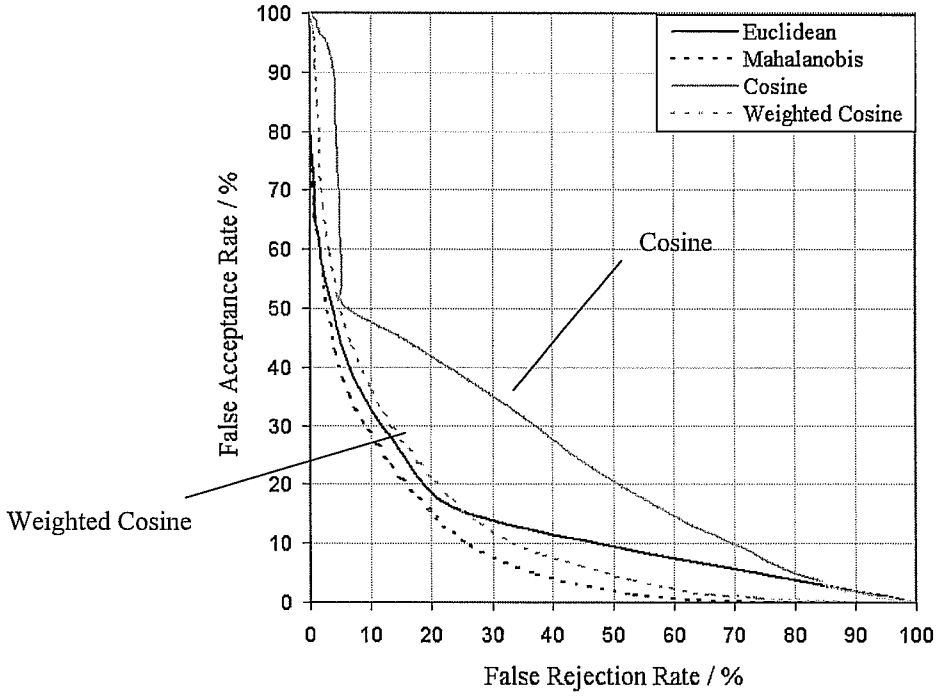


Fig. 8. Results from previous 3D face recognition systems using facial surface depth maps and a range of distance metrics

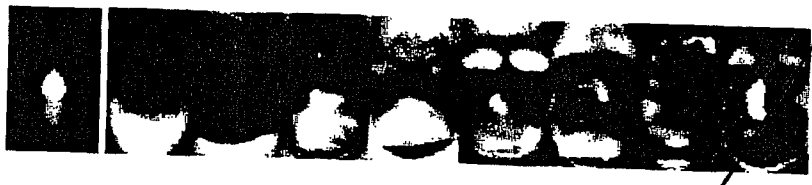


Fig. 7. Average depth map (*left most*) and first eight eigensurfaces

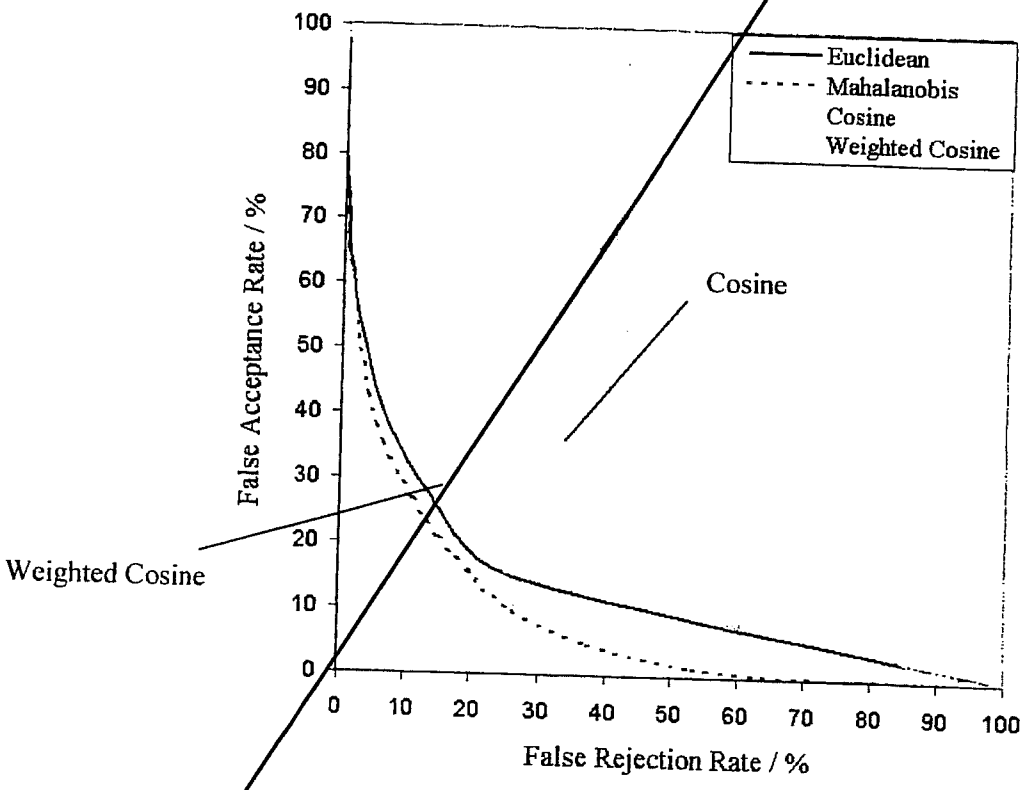


Fig. 8. Results from previous 3D face recognition systems using facial surface depth maps and a range of distance metrics

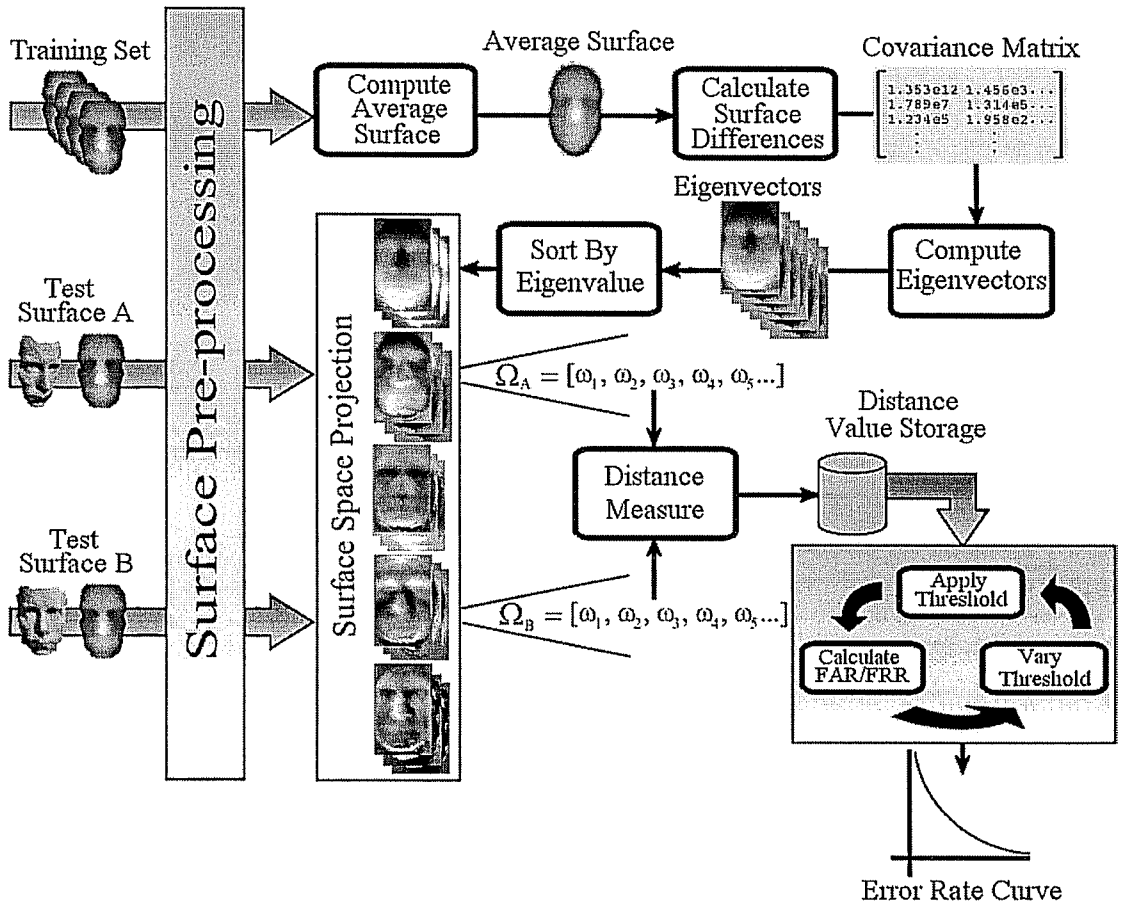


Fig. 9. Experimental framework for evaluating verification systems

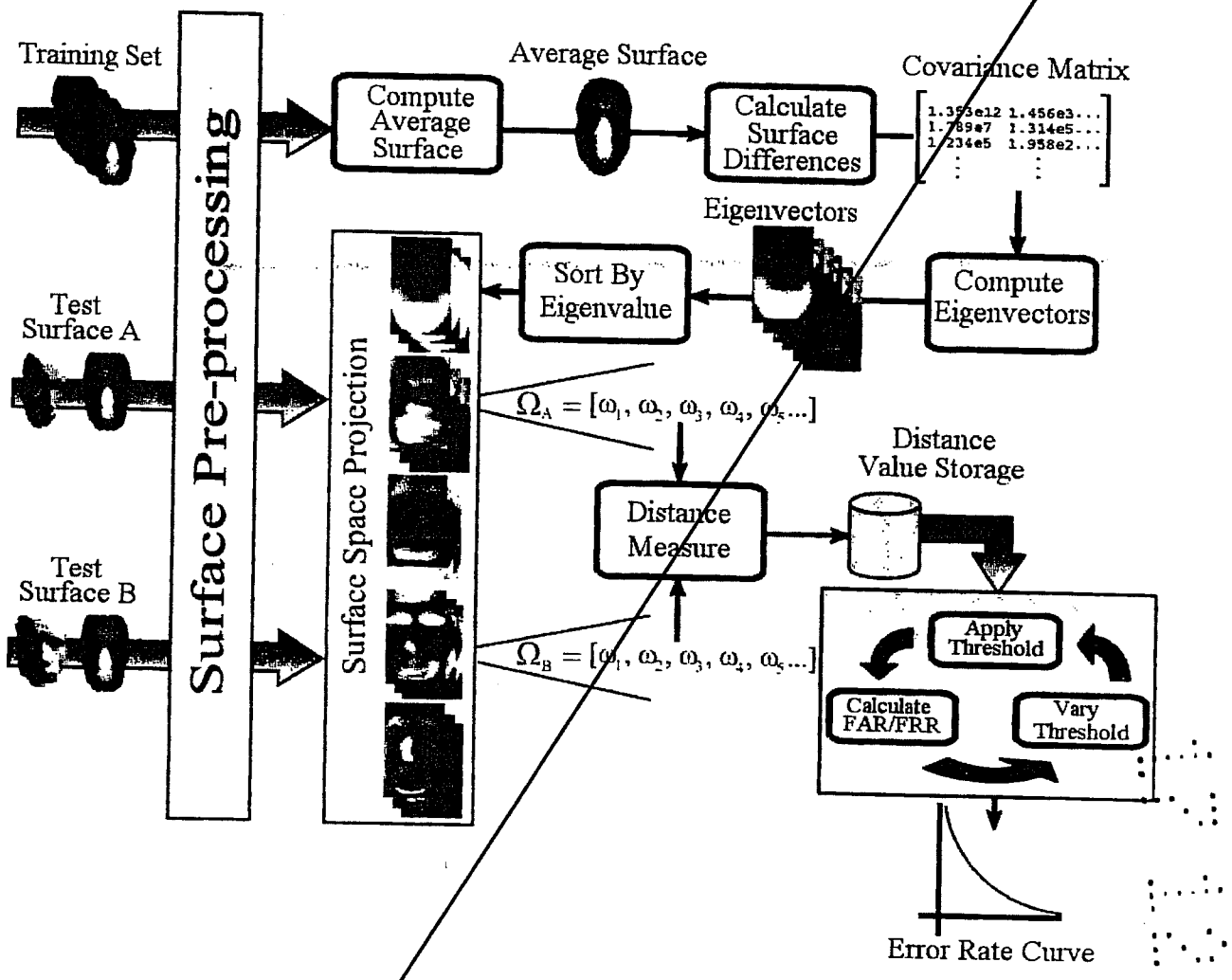


Fig. 9. Experimental framework for evaluating verification systems

Horizontal Gradient	Vertical Gradient	Horizontal Gradient Large	Vertical Gradient Large
 -1 1	 -1 1	 -1 0 0 0 1	 -1 0 0 0 1
Applies the 2x1 kernel to compute the horizontal derivative	Applies the 1x2 kernel to compute the vertical derivative	Horizontal gradient calculated over a greater horizontal distance	Vertical gradient calculated over a greater vertical distance
Laplacian	**Sobel X**	**Sobel Y**	**Sobel Magnitude**
 0 1 0 1 -4 1 0 1 0	 -1 0 1 -2 0 2 -1 0 1	 1 2 1 0 0 0 -1 -2 -1	
An isotropic measure of the second spatial derivative	Application of the sobel derivative filter in the horizontal direction	Application of the sobel derivative filter in the vertical direction	The magnitude of the X and Y sobel derivatives
Horizontal Curvature	**Vertical Curvature**	**Curvature Magnitude**	**Curve Type**
			
Applies the sobel X kernel twice to calculate the second horizontal derivative	Applies the sobel Y kernel twice to calculate the second vertical derivative	The magnitude of the vertical and horizontal curvatures	Segmentation of the surface into 8 discreet curvature types
Min Curvature	**Max Curvature**	**Abs Min Curvature**	**Abs Max Curvature**
			
The minimum of the horizontal and vertical curvature values	The maximum of the horizontal and vertical curvature values	The minimum of the absolute horizontal and vertical curvatures	The maximum of the absolute horizontal and vertical curvatures

Figure 12. Brief descriptions of surface representations with the convolution kernels used.

Horizontal Gradient	Vertical Gradient	Horizontal Gradient Large	Vertical Gradient Large
 -1 1	 -1 1	 -1 0 0 0 1	 -1 0 0 0 1
Applies the 2x1 kernel to compute the horizontal derivative	Applies the 1x2 kernel to compute the vertical derivative	Horizontal gradient calculated over a greater horizontal distance	Vertical gradient calculated over a greater vertical distance
Laplacian	Sobel X	Sobel Y	Sobel Magnitude
 0 1 0 1 -4 1 0 1 0	 -1 0 1 -2 0 2 -1 0 1	 1 2 1 0 0 0 -1 -2 -1	
An isotropic measure of the second spatial derivative	Application of the sobel derivative filter in the horizontal direction	Application of the sobel derivative filter in the vertical direction	The magnitude of the X and Y sobel derivatives
Horizontal Curvature	Vertical Curvature	Curvature Magnitude	Curve Type
			
Applies the sobel X kernel twice to calculate the second horizontal derivative	Applies the sobel Y kernel twice to calculate the second vertical derivative	The magnitude of the vertical and horizontal curvatures	Segmentation of the surface into 8 discrect curvature types
Min Curvature	Max Curvature	Abs Min Curvature	Abs Max Curvature
			
The minimum of the horizontal and vertical curvature values	The maximum of the horizontal and vertical curvature values	The minimum of the absolute horizontal and vertical curvatures	The maximum of the absolute horizontal and vertical curvatures

Figure 12. Brief descriptions of surface representations with the convolution kernels used.

Horizontal Derivative	Vertical Derivative	Horizontal Derivative 2	Vertical Derivative 2
 -1 1	 -1 1	 -1 0 0 0 1	 -1 0 0 0 1
Applies the 2x1 kernel to compute the horizontal derivative	Applies the 1x2 kernel to compute the vertical derivative	Horizontal gradient over a greater horizontal distance	Vertical gradient over a greater vertical distance
Laplacian	Sobel X	Sobel Y	Sobel Magnitude
 0 1 0 1 -4 1 0 1 0	 -1 0 1 -2 0 2 -1 0 1	 1 2 1 0 0 0 -1 -2 -1	
An isotropic measure of the second spatial derivative	Application of the horizontal sobel derivative filter	Application of the vertical sobel derivative filter	The magnitude of Sobel X and Y combined.
Horizontal Curvature	Vertical Curvature	Curvature Magnitude	Curve Type
			
Applies sobel X twice to calculate the second horizontal derivative	Applies sobel Y twice to calculate the second vertical derivative	The magnitude of the vertical and horizontal curvatures	Segmentation of the surface into 8 discreet curvature types
Min Curvature	Max Curvature	Abs Min Curvature	Abs Max Curvature
			
The minimum of the horizontal and vertical curvature values	The maximum of the horizontal and vertical curvature values	The minimum of the absolute horizontal and vertical curvatures	The maximum of the absolute horizontal and vertical curvatures

Fig. 13

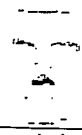
Horizontal Derivative	Vertical Derivative	Horizontal Derivative 2	Vertical Derivative 2
 -1 1	 -1 1	 -1 0 0 0 1	 -1 0 0 0 1
Applies the 2x1 kernel to compute the horizontal derivative	Applies the 1x2 kernel to compute the vertical derivative	Horizontal gradient over a greater horizontal distance	Vertical gradient over a greater vertical distance
Laplacian	Sobel X	Sobel Y	Sobel Magnitude
 0 1 0 1 -4 1 0 1 0	 -1 0 1 -2 0 2 -1 0 1	 1 2 1 0 0 0 -1 -2 -1	
An isotropic measure of the second spatial derivative	Application of the horizontal sobel derivative filter	Application of the vertical sobel derivative filter	The magnitude of Sobel X and Y combined.
Horizontal Curvature	Vertical Curvature	Curvature Magnitude	Curve Type
			
Applies sobel X twice to calculate the second horizontal derivative	Applies sobel Y twice to calculate the second vertical derivative	The magnitude of the vertical and horizontal curvatures	Segmentation of the surface into 8 discreet curvature types
Min Curvature	Max Curvature	Abs Min Curvature	Abs Max Curvature
			
The minimum of the horizontal and vertical curvature values	The maximum of the horizontal and vertical curvature values	The minimum of the absolute horizontal and vertical curvatures	The maximum of the absolute horizontal and vertical curvatures

Fig. 13

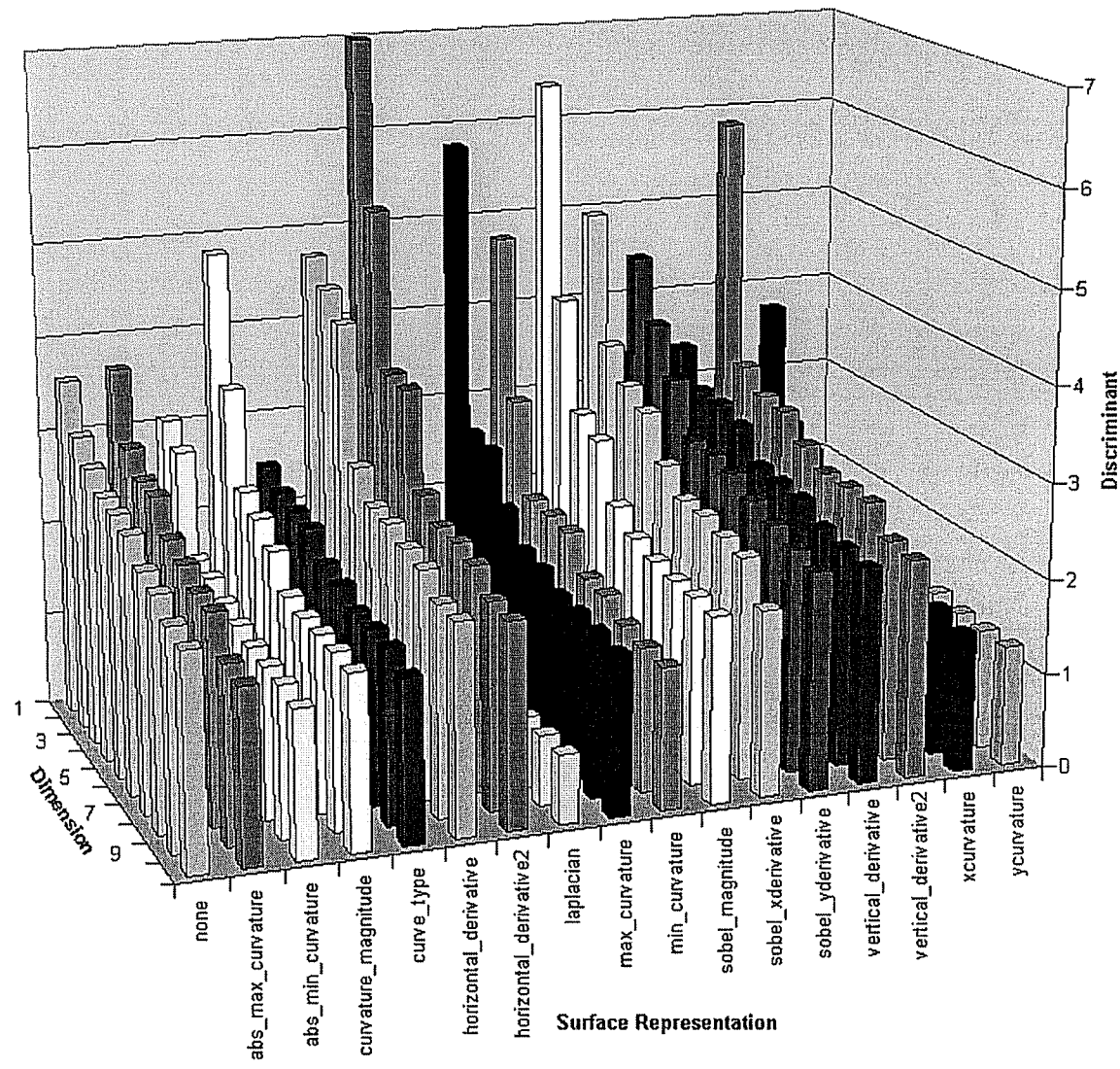

Discriminant
7
6
5
4
3
2
1
0
Dimension
1
3
5
7
9
none
abs_max_curvature
abs_min_curvature
curvature_magnitude
curve_type
horizontal_derivative
horizontal_derivative2
laplacian
max_curvature
min_curvature
sobel_magnitude
sobel_xderivative
sobel_yderivative
vertical_derivative
vertical_derivative2
xcurvature
ycurvature
Surface Representation

Fig. 15

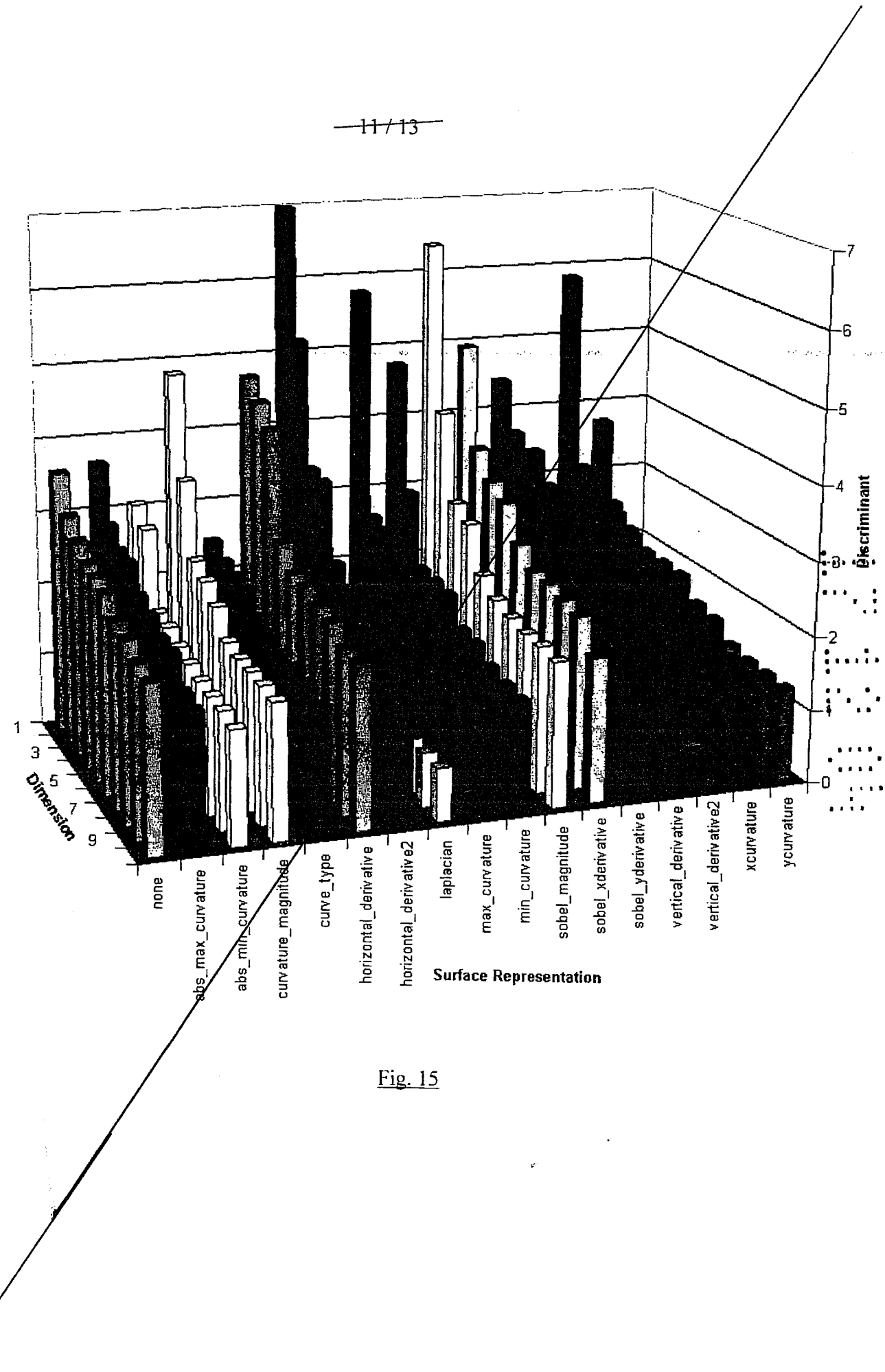

Discriminant
0
1
2
3
4
5
6
7
Dimension
1
3
5
7
9
Surface Representation
none
abs_max_curvature
abs_min_curvature
curvature_magnitude
curve_type
horizontal_derivative
horizontal_derivative2
laplacian
max_curvature
min_curvature
sobel_magnitude
sobel_xderivative
sobel_yderivative
vertical_derivative
vertical_derivative2
xcurvature
ycurvature

Fig. 15