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Determinar la magnitud y el módulo de los gradientes de pixeles de esta imagen utilizando las siguientes fórmulas.

1	2	6	4
3	7	5	3
9	5	8	6

Diferencia central

$$\delta f_x = \frac{f(x+1,y) - f(x-1,y)}{2} \qquad \delta f_y = \frac{f(x,y+1) - f(x,y-1)}{2}$$

Diferencia hacia delante

$$\Delta f_x = f(x+1,y) - f(x,y) \qquad \Delta f_y = f(x,y+1) - f(x,y)$$

Diferencia hacia atrás

$$\nabla f_x = f(x,y) - f(x-1,y) \qquad \nabla f_y = f(x,y) - f(x,y-1)$$

$$f(x_{1,1}) = 2 - 1 = 1 \qquad f(x_{1,2}) = \frac{6-1}{2} = 2.5 \qquad f(x_{1,3}) = \frac{4-2}{2} = 1 \qquad f(x_{1,4}) = 4 - 6 = -2$$

$$f(x_{2,1}) = 7 - 3 = 4 \qquad f(x_{2,2}) = \frac{5-3}{2} = 1 \qquad f(x_{2,3}) = \frac{6-1}{2} = 2.5 \qquad f(x_{2,4}) = 3 - 5 = -2$$

$$f(x_{3,1}) = 5 - 9 = -4 \qquad f(x_{3,2}) = \frac{8-9}{2} = -0.5 \qquad f(x_{3,3}) = \frac{6-1}{2} = 2.5 \qquad f(x_{3,4}) = 6 - 8 = -2$$

$$f(y_{1,1}) = 1 - 3 = -2 \qquad f(y_{1,2}) = 2 - 7 = -5 \qquad f(y_{1,3}) = 6 - 5 = 1 \qquad f(y_{1,4}) = 4 - 3 = 1$$

$$f(y_{2,1}) = \frac{1-9}{2} = -4 \qquad f(y_{2,2}) = \frac{2-5}{2} = -1.5 \qquad f(y_{2,3}) = \frac{6-8}{2} = -1 \qquad f(y_{2,4}) = \frac{4-6}{2} = -1$$

$$f(y_{3,1}) = 3 - 9 = -6 \qquad f(y_{3,2}) = 7 - 5 = 2 \qquad f(y_{3,3}) = 5 - 8 = -3 \qquad f(y_{3,4}) = 3 - 6 = -3$$

$$g_x = \begin{bmatrix} 1 & 2.5 & 1 & -2 \\ 4 & 1 & -2 & -2 \\ -4 & -0.5 & 0.5 & -2 \end{bmatrix} \qquad g_y = \begin{bmatrix} -2 & -5 & 1 & 1 \\ -4 & -1.5 & -1 & -1 \\ -6 & 2 & -3 & -3 \end{bmatrix}$$

Aplicando la siguiente fórmula, obtenemos la magnitud del vector de los gradientes de los pixeles:

$$g = \sqrt{g_x^2 + g_y^2}$$

$$g_{1,1} = \sqrt{1^2 + (-2)^2} = 2.236 \qquad g_{1,2} = \sqrt{2.5^2 + (-5)^2} = 5.59 \qquad g_{1,3} = \sqrt{1^2 + (-1)^2} = 1.414$$

$$g_{2,1} = \sqrt{4^2 + (-4)^2} = 5.657 \qquad g_{2,2} = \sqrt{1^2 + (-1.5)^2} = 1.803 \qquad g_{2,3} = \sqrt{(-2)^2 + (-1)^2} = 2.236$$

$$g_{3,1} = \sqrt{(-4)^2 + (-6)^2} = 7.211 \qquad g_{3,2} = \sqrt{(-0.5)^2 + 2^2} = 2.062 \qquad g_{3,3} = \sqrt{(-0.5)^2 + (-3)^2} = 3.041$$

$$g_{1,4} = \sqrt{(-2)^2 + 1^2} = 2.236$$

$$g_{2,4} = \sqrt{(-2)^2 + (-1)^2} = 2.236$$

$$g_{3,4} = \sqrt{(-2)^2 + (-3)^2} = 3.606$$

$$g = \begin{bmatrix} 2.236 & 5.59 & 1.414 & 2.236 \\ 5.657 & 1.803 & 2.236 & 2.236 \\ 7.211 & 2.062 & 3.041 & 3.606 \end{bmatrix}$$

Aplicando la siguiente fórmula, obtenemos el módulo del vector de los gradientes de los pixeles, el resultado en radianes lo pasamos a grados.

$$\theta = \arctan\left(\frac{g_y}{g_x}\right)$$

$$\theta_{1,1} = \arctan\left(\frac{-2}{1}\right) = -1.1071487177941 \qquad \theta_{1,2} = \arctan\left(\frac{-5}{2.5}\right) = -1.1071487177941$$

$$\theta_{2,1} = \arctan\left(\frac{-4}{4}\right) = -0.78539816339745 \qquad \theta_{2,2} = \arctan\left(\frac{-1.5}{1}\right) = -0.98279372324733$$

$$\theta_{3,1} = \arctan\left(\frac{-6}{-4}\right) = 0.98279372324733 \qquad \theta_{3,2} = \arctan\left(\frac{2}{-0.5}\right) = -1.325817663668$$

$$\theta_{1,3} = \arctan\left(\frac{1}{1}\right) = 0.78539816339745 \qquad \theta_{1,4} = \arctan\left(\frac{-1}{-2}\right) = 0.46364760900081$$

$$\theta_{2,3} = \arctan\left(\frac{-1}{-2}\right) = 0.46364760900081 \qquad \theta_{2,4} = \arctan\left(\frac{-1}{-2}\right) = 0.46364760900081$$

$$\theta_{3,3} = \arctan\left(\frac{-3}{0.5}\right) = -1.4056476493803 \qquad \theta_{3,4} = \arctan\left(\frac{-3}{-2}\right) = 0.98279372324733$$

Pasando a grados los valores anteriores, tenemos el siguiente resultado:

$$\theta = \begin{bmatrix} -63.435° & -63.435 & 45° & 26.565° \\ -45° & -56.31° & 26.565° & 26.565° \\ 56.31° & -75.964° & -80.538° & 56.31° \end{bmatrix}$$