

$$\rho = 0.9 \quad (1)$$

$$\sigma = 30 * \pi / 180 \quad (2)$$

$$\theta_r = \arccos((V \cdot N)) \quad (3)$$

$$\phi_{\text{diff}} = (\text{normalize}(V - N * ((V \cdot N))) \cdot \text{normalize}(L - N * ((L \cdot N)))) \quad (4)$$

$$N = \vec{n} \quad (5)$$

$$L = \vec{\omega}_i \quad (6)$$

$$V = \vec{\omega}_o \quad (7)$$

$$\theta_i = \arccos((L \cdot N)) \quad (8)$$

$$\alpha = \max(\theta_i, \theta_r) \quad (9)$$

$$\beta = \min(\theta_i, \theta_r) \quad (10)$$

$$C_1 = 1 - 0.5 * (\sigma^2) / ((\sigma^2) + 0.33) \quad (11)$$

$$C_2 = \frac{0.45 * (\sigma^2)}{((\sigma^2) + 0.09)} * (\text{step}(\phi_{\text{diff}}) * (\sin(\alpha)) + (1 - \text{step}(\phi_{\text{diff}})) * (\sin(\alpha) - \frac{2 * \beta^3}{\pi})) \quad (12)$$

$$C_3 = 0.125 * (\sigma^2) / ((\sigma^2) + 0.09) * ((4 * \alpha * \beta) / (\pi * \pi))^2 \quad (13)$$

$$L_1 = \rho / \pi * (C_1 + \phi_{\text{diff}} * C_2 * \tan(\beta) + (1 - \text{abs}(\phi_{\text{diff}})) * C_3 * \tan((\alpha + \beta) / 2)) \quad (14)$$

$$L_2 = 0.17 * \rho * \rho / \pi * (\sigma^2) / ((\sigma^2) + 0.13) * (1 - \phi_{\text{diff}} * (4 * \beta * \beta) / (\pi * \pi)) \quad (15)$$

$$f = L_1 + L_2 \quad (16)$$

$$\text{normalize}(\vec{u}) = \frac{\vec{u}}{\sqrt{\vec{u} \cdot \vec{u}}} \quad (17)$$

$$\text{abs}(v) = \max(v, -v) \quad (18)$$

Step function that returns 1 when  $x \geq 0$  and 0 when  $x < 0$

$$\text{step}(x) = \min(1, \max(0, x/(\text{abs}(x) + \epsilon))) \quad (19)$$