Time-to-Contact from Image Intensity

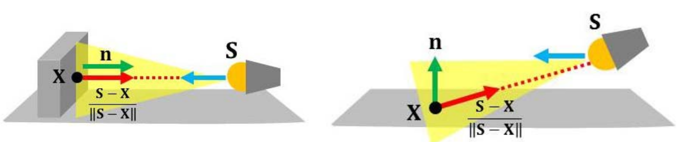
Yukitoshi Watanabe[1], Fumihiko Sakaue[1], Jun Sato[1]
[1]Department of Computer Science, Nagoya Institute of Technology

The time-to-contact is very useful for measuring the danger of collision of objects [1], and has been studied extensively. It is invariant under camera parameters and camera motions, and thus we do not need to estimate camera parameters and camera motions for computing the time-to-contact. However, the existing methods for measuring the time-to-contact are based on geometric image features, such as corners and edge lines, and thus they cannot be used when there are no geometric features in images. In this paper, we propose a new method for computing the time-to-contact from photometric information in images. When a light source moves in the 3D scene, an observed intensity changes according to the motion of the light source. In this paper, we analyze the change in photometric information in images, and show that the time-to-contact can be estimated just from the changes in intensity in images. Our method does not need any additional information, such as radiance of light source, reflectance of object and orientation of object surface.

Let us consider the case where a light source exists in a scene. In this case, observed intensity i can be described by a light source position $\mathbf{S}$, surface normal $\mathbf{n}$ and observed point $\mathbf{X}$ as follows:

$$i = \frac{1}{||\mathbf{S}-\mathbf{X}||^2} E\rho \frac{\mathbf{n}^\top(\mathbf{S}-\mathbf{X})}{||\mathbf{S}-\mathbf{X}||} \tag{1}$$

where E and ρ denote the radiance of the light source and the reflectance of the surface respectively.



(a) move toward observation point (b) move toward non-observation point

Figure 1: Two different cases for estimating time-to-contact. In case (a), the light source moves toward the observed point. In case (b), the light source moves not in the direction of the observed point

Under this reflection model, we propose a method for estimating time-to-contact from image intensity. For this objective, we first consider the case where the light source moves toward the observation point X as shown in Fig.1 (a). In this case, the relative angle between the surface normal $\mathbf{n}$ and the orientation of the light source $\frac{\mathbf{S}-\mathbf{X}}{||\mathbf{S}-\mathbf{X}||}$ is constant during the light source motion, and thus Eq (1) can be rewritten as follows:

$$i = \frac{k}{||\mathbf{S}-\mathbf{X}||^2} = \frac{k}{d^2} \tag{2}$$

where, d denotes the distance between $\mathbf{X}$ and $\mathbf{S}$, and k is a constant, since it depends only on the reflectance of surface and the radiance of a light source. Thus, square root of intensity can be computed as follows:

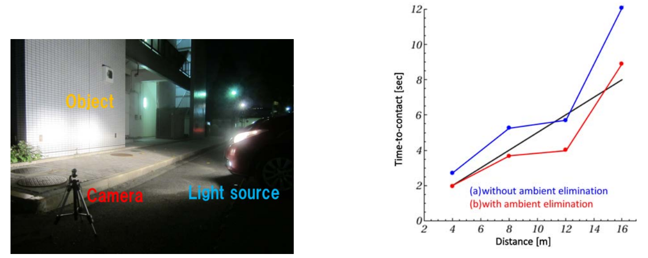
$$\sqrt{i} = \frac{\sqrt{k}}{||\mathbf{S}-\mathbf{X}||} = \frac{\sqrt{k}}{d} \tag{3}$$

Since $\sqrt{i}$ is inversely proportional to distance d, we can estimate time-to-contact TC from image intensity as follows:

$$TC = \frac{\sqrt{i}}{\sqrt{i'} - \sqrt{i}} \tag{4}$$

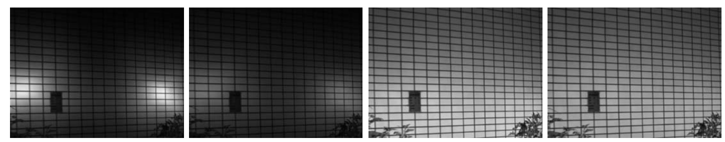
where i' indicates the observed intensity at time $t+1$.

This is an extended abstract. The full paper is available at the Computer Vision Foundation webpage.



(a) Experimental environment (b) Estimated time-to-contact

Figure 2: Experimental environment and estimated time-to-contact



(a) 4m (b) 6m (c) 16m (d) 18m

Figure 3: Examples of observed images.

We next generalize the problem and consider the case where the light source does not move toward the observation point $\mathbf{X}$ as shown in Fig.1(b). In this case, not only the distance but also the angle between the surface normal and the light source orientation changes according to the motion of the light source. For analyzing the change in angle, we rewrite the distance $||\mathbf{S}-\mathbf{X}||$ by using its horizontal distance d and vertical distance h as $\sqrt{d^2+h^2}$. Since the light source moves only in the horizontal direction, the vertical distance h is constant. Thus, by taking the derivative of the intensity i with respect to the time t, we have:

$$j = \frac{di}{dt} = \frac{di}{dd}\frac{dd}{dt} = \frac{-3sE\rho hd}{(d^2+h^2)^{\frac{5}{2}}} \tag{5}$$

where, $s = \frac{dd}{dt}$ is a speed of the light source, and we assume that it is constant. Note that, the denominator of the derivative is an exponentiation of the denominator of intensity i. Thus, we can eliminate the term by computing I as follows:

$$I = \frac{i^{\frac{5}{3}}}{j} = -\frac{(E\rho h)^{\frac{2}{3}}}{3s} \cdot \frac{1}{d} = \frac{k''}{d} \tag{6}$$

Finally, we can estimate time-to-contact by using I as follows:

$$TC = \frac{I}{I' - I} \tag{7}$$

where I' is computed from Eq.(6) at time $t+1$.

In this abstract, we explained the simplest case when there is a single light source in the scene. The extended method under the existence of ambient light is also described in our main conference paper.

Finally, we show experimental results from the head light of a vehicle in an outdoor scene as shown in Fig.2 (a). In this experiment, the vehicle moved toward the wall shown in Fig. (a). Figure3 (a), (b) and (c), (d) show two examples of pairs of consecutive images. The estimated time-to-contact from these images is shown in Fig.2 (b). The estimated time-to-contact from the proposed method is very close to the ground truth, and we find that the proposed method can estimate time-to-contact reliably, even if the light source is not exactly a point light and the observed surface is not exactly Lambertian.

[1] A. Guillem, A. Negre, and J.L. Crowley. time to contact for obstacle avoidance. In *European Conference on Mobile Robotics*, pages 19–24, 2009.