Cooperating Robots
Lecture Notes

Locomotion Strategy of the House Fly

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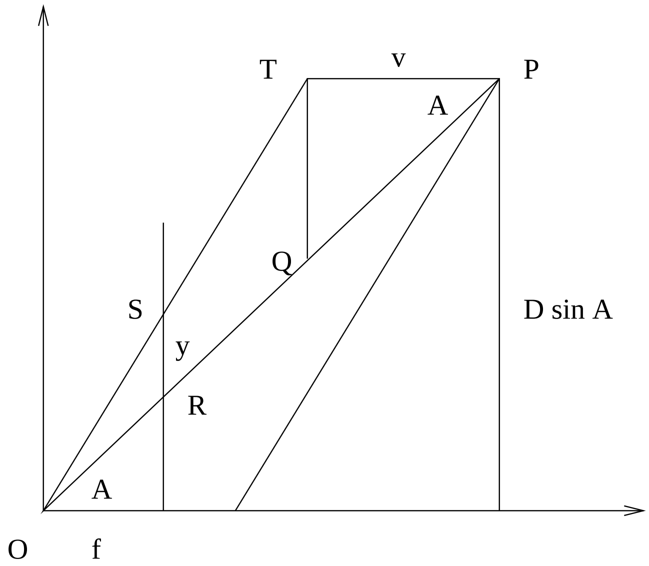
The common first module of both proposed designs are to implement a "vision" module for a robot. The word vision is quoted, since I suggest 1-dimensional and not 2-dimensional vision. This simply for engineering feasability. The module can be based on data from the on-board camera and the infrared sensors. The approach is based upon the locomotion strategy of the house fly. The principle is explained briefly in Pfeiffer's book [1], page 438 and more fully in this note.

The idea is that our idealized house fly (the robot) should move straight ahead with constant velocity when feasable. We assume that features are projections of vertical lines in the environment upon the retina. We want to understand the relation between the retinal motion of the projection and the distance to the environmental feature. Assume first that the fly moves in an environment where no other objects move. Then a nearby object has a larger retinal velocity than a far away object in the same direction. One can use different models of the retina. One model is a flat image plane as in an image sensor. Another is a circular image more similar to a biological retina. Here the flat model is presented.

We can measure the displacement y in the image. See figure 1

$$
\begin{aligned}
\frac{y}{v \tan A} &= \frac{\frac{f}{\cos A}}{D - \frac{v}{\cos A}} \\
D - \frac{v}{\cos A} &= \frac{vf}{y}\frac{\tan A}{\cos A} \\
D &= \frac{vf}{y}\frac{\tan A}{\cos A} + \frac{v}{\cos A} \\
&= v\,\frac{f \sin A + y \cos A}{y \cos^2 A}
\end{aligned}
$$

$$
\frac{D}{v} = \left(\frac{f}{y}\frac{\sin A}{\cos^2 A} + \frac{1}{\cos A}\right) \qquad (1)
$$



Figur 1: House fly geometry. $|PO| = D \quad \frac{|SR|}{|TQ|} = \frac{|OR|}{|OQ|}. \quad \frac{y}{v \tan A} = \frac{\frac{f}{\cos A}}{D - \frac{v}{\cos A}}$

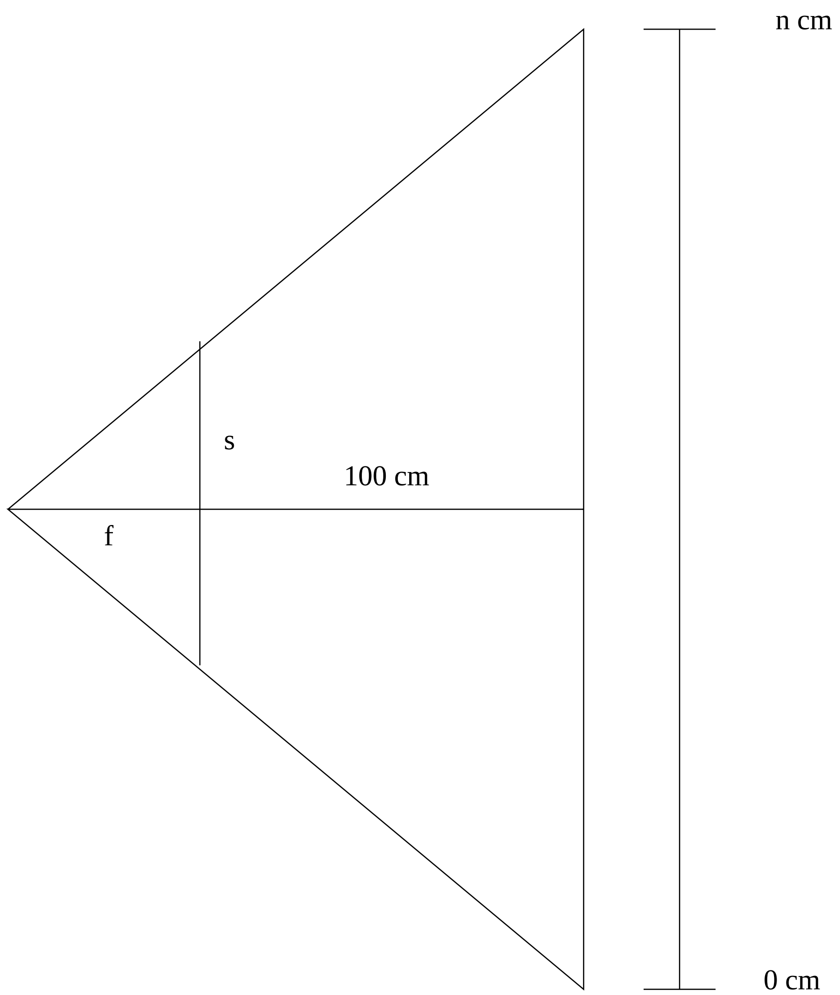
The fly (robot) can choose its speed by choosing how far it moves between time frames. y is distance moved on chip. The physical size of the chip is 3.0 cm $\times$ 3.4 cm. The size of the image is 60×80 pixels and the size of a pixel is $3.4/80\,\mathrm{cm} = 42\,\mu$ since we talk columns.

f and y must be measured in equal unis, either pixels or cm. We know the size of the CCD chip, hence can measure the focal length f by an experiment. See figure 2. We let the robot take an image of a measuring stick at known distance (100 cm).

Precision

During a straight flight the fly can compute relative distance to objects. Several questions present themselves: The expression for the distance shows that the precision of the distance computation depends upon the speed and the angle at which the features are visible. The angle must be as small as possible and at the same time y must be as large as possible. Which is the optimal angle under which the fly should view a feature? The fly may choose its direction to optimize the precision by which the distance is measured. The fly may reasonably focus on the features which relocate fastest, and choose its direction to optimize computation of that distance.

We shall discuss equation 1 using the quantities $d = \frac{D}{v}$ and $a = \frac{f}{y}$. Given a measurement y (or $\frac{f}{y}$) for a feature, which is the optimal angle for the fly to view



Figur 2: Focal length measuring experiment. $\frac{s}{n} = \frac{f}{100}$ $f = 100\,\frac{s}{n}$

the feature? The answer can be found by minimizing the relative uncertainty. I use the notation $g_x(x)$ for $\frac{\partial g(x)}{\partial x}$. The relative uncertainty of $g(x)$ with respect to x is

$$x \frac{g_x(x)}{g(x)}$$

In our case we get

$$\begin{aligned} A\frac{d_A}{d} &= A\frac{\partial\left(\frac{f}{y}\frac{\sin A}{\cos^2 A}+\frac{1}{\cos A}\right)/\partial A}{\left(\frac{f}{y}\frac{\sin A}{\cos^2 A}+\frac{1}{\cos A}\right)} \\ &= A\frac{\frac{a}{\cos(A)^2}+\tan(A)+A\,\tan(a)^2}{1+a\tan(A)} \end{aligned}$$

The denominator is always positive, since the angle is less than 90°. The function graph tells us that the angle should be as large as possible to obtain the best precision. From figure 1 it seems reasonable since increasing the angle is seen to increase y.

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(* mathematica program to graph A D[d, A])/d as function of a and A *)
d = a Sin[A]/((Cos[A])^2) + 1/Cos[A]
relerr =(A D[d, A])/d
Plot3D[relerr,{A,\[Pi]/10,\[Pi]/3},{a,1,30},AxesLabel->{A,a,reler}]
```

On one robot it is possible to pan the camera. From the figure one can see, that the fly can obtain better determination of relative distance by tilting the image plane toward the direction to the feature. It should estimate the speed of a feature out of the corner of its eye.

Moving Objects

The fly can measure the relative distances to features at each time step. It can keep a table of features and their positions. It follows that it can detect when the distance to a feature changes, which again means that it can determine the motion of other objects. In order to keep a table of features and their position it must be able to track the features, that is to determine which features in two time frames are identical. Features may appear and disappear behind other objects or appear into or disappear from the view field of the camera. Continually changing positions of objects in the environment requires fast processing.

Exploratory Behavior

The bottom line is that it is possible for a moving robot to map its environment. We have available a candidate for a strategy for exploratory behavior. The robot can decide to change direction either when the distence is less than a certain threshold or when its infrared sensors tell it is time to turn. Different decision rules can be used for choosing direction. Random change is one, and getting information about a badly explored feature is another. It remains to be seen how precise and fast it can be done.

Litteratur

[1] Rolf Pfeiffer and Christian Scheier. *Understanding Intelligence.* MIT Press, 1999.