The visual system

In the previous chapter, we have already mentioned the **visual system**. Now we pay more attention to it. The visual system consists of the eyes and everything directly related to them. How does it work? And what principles should we use when designing displays for it? That's what this chapter is about.

1 Setting up visual displays

1.1 The build-up of the visual system

Vision can be split up into foveal and peripheral vision. In your **fovea**, you have a lot of **cones**. (Cones detect color.) Your acuity is large, and you can thus see a lot of detail. In your periphery, you don't have cones. Instead, there are only **rods**. (Rods can't detect color, but can detect brightness and motion.) Although the acuity of the periphery is small, it is very good at detecting motion.

Let's examine the foveal vision a bit closer. This type of vision concerns the focussing of the eye. The eye can try to follow a certain moving object. We then have **pursuit eye movements**. Alternatively, the eye can jump from one place to another place. We are then dealing with **saccadic eye movements**. Important parameters are now the **location** of the focus, as well as the **dwell time**, which is the amount of time which the eye focusses on a certain point.

1.2 The eye focus of the pilot

Examine a pilot in a cockpit. When an emergency occurs, the pilot needs to be notified. Visual cues can be used for this. But these visual cues will quite probably not be in the foveal vision of the pilot, but in the peripheral vision. So to make sure that the pilot sees it, motion needs to be involved. A good way to warn the pilot is thus to use blinking lights.

Of course, the pilot also needs to check on all his indicators regularly. This is done by **visual sampling**: checking one indicator, then checking another one, and so on. But how often does the pilot check each indicator? Research has shown that this depends on the **risk** involved with not checking the indicator. This risk is the **expected cost** of not checking the indicator. Subconsciously, the pilot tries to minimize it.

Basically, this means that people create a **mental model** of the statistical properties of events in the environment. They use this model to guide their visual sampling. We can use this idea when designing the cockpit. Displays that are frequently sampled must be placed centrally and close together. Alternatively, we can also condense data in one display or minimize the data which needs to be displayed.

Examples of displays that minimize data are the **primary flight display** and the **navigation display**. They are both used by the flight director. The **flight director** uses these two displays to tell the pilot what he needs to do to keep for example the right heading. The pilot first defines the control task. (e.g. maintain heading.) The automatic controller then uses the available information to generate a control signal FD. This control signal is presented to the pilot, who then tries to follow it using his control stick. (This is called '**follow the needle**'.)

1.3 Having multiple displays

There are a lot of displays in the cockpit. How does the brain process this? The first phase is the **preattentive phase**. The brain then organizes the visual world into objects and groups of objects. Objects are often grouped together when they are close together, when they lie in a line/curve and/or when they look alike. In the second phase, called **focal attention**, we then limit our attention to a certain (group of) objects.

A pilot can also process multiple data next to each other. We call this **parallel processing**. Parallel processing can be achieved in multiple ways. In **multi-modality**, information is provided by multiple systems, like the visual system, the vestibular system, the auditory system and such. In **visual modality**, information comes from both the foveal and the peripheral vision. Finally, when only using the **foveal vision**, we can process several items within the useful field together.

When using multiple stimuli (like multiple displays), **emergent features** might occur. This is the case when the displays have a global property that is not evident when one looks at the displays individually. (For example, if all displays suddenly get a background color, this might seem like an interesting feature. But if these colors then happen to write a message on the complete dashboard, we have emergent features.)

1.4 Principles of display design

When designing the dashboard in an aircraft, it is wise to take into account several principles. We'll list a few.

- The **proximity compatibility principle** (PCP) states that, if information sources need to be integrated, it will be benificial to present the information in an integrated format. So, displaying related information close to eachother is positive.
- The **principle of pictorial realism** states that, when information is mentally represented in an analog fashion, it should also be displayed in an analog format. Also, the orientation and ordering of these displays should be compatible. (In an altimeter, high altitudes should be displayed up, not down.)
- The **principle of the moving part** states that the direction of movement of an indicator on a display should be compatible with the direction of movement of an operator's mental model of the variable. For example, it doesn't make sense if a pitch-up motion is displayed by an indicator going downward.

When setting up a display, another very important thing to decide is which reference frame to use. In an **ego-centered (ego-centric) frame of reference**, the pilot's perspective is used. (An example is the tunnel-in-the-sky display.) However, in the **world-centered (exo-centric) frame of reference**, a moving map is displayed. The camera now provides a top-down view of the aircraft. When displaying information about the motion of the aircraft, an ego-centric frame of reference is generally preferred.

2 Perceiving a three-dimensional situation

2.1 Perceiving depth

In the old conventional cockpit instruments, the information about the location and motion of the aircraft was divided over at least four separate instruments. Mentally integrating this information is difficult. A solution was offered by the **electronic flight instrument system** (EFIS). This integrated all the data in two displays: the PFD and the ND.

However, the EFIS displays also have a downside: they are planar (i.e. two-dimensional). However, the pilot needs to get a three-dimensional image of the situation. So this could be a cause of a lack of situational awareness. It would be better if a new version of the PFD presents data in a spatio-temporal way. One such example is using an **ecological display**. Such a display tries to provide visual cues which humans naturally would also use to perceive their motion in the environment.

There are several ways to add depth in an image. Examples are using tricks like linear perspective lines, light and shadow or the relative sizes of objects. If the eyes are 'fooled' in this way, we are talking about **indirect perception**. The opposite is **direct perception**. Here, the depth information is contained in the way the light enters the eyes.

2.2 Perceiving motion

Next to depth, we should also add motion to an image. A motion perspective causes **optical flow**. The **gradients** of this optical flow (i.e. how fast objects appear to move) determines the magnitude of the relative velocity of the observer. On the other hand, the **pattern** of the optical flow is an indication of the direction of the relative motion. (That is, if all object appear to be moving to the right, you are moving to the left. But if all objects appear to be going away from each other, you are moving towards them.)

How do we perceive motion? Let's suppose that we are flying over a ground with a lot of straight parallel lines. First, let's say we're flying parallel to these lines on a height z. The horizontal distance between our airplane and a certain line is y. The so-called **optical splay angle** Ω is the angle which this line appears to make with our longitudinal axis. (Though in reality these lines are parallel.) This angle, and the **splay angle rate** $\dot{\Omega}$, can be found using

$$\Omega = \arctan\left(\frac{y}{z}\right) \qquad \text{and} \qquad \dot{\Omega} = -\left(\frac{\dot{z}}{z}\right)\cos\Omega\sin\Omega + \left(\frac{\dot{y}}{z}\right)\cos^2\Omega. \tag{2.1}$$

It is interesting to note that Ω does not depend on x or $\dot{x}$ and is only scaled by z.

Now examine the case where we are flying perpendicular to all the horizontal lines on the ground. This time our distance towards a line is denoted by x. The **optical depression angle** and the **depression rate** are now given by

$$\delta = \arctan\left(\frac{z}{x}\right) \qquad \text{and} \qquad \dot{\delta} = \left(\frac{\dot{z}}{z}\right)\cos\delta\sin\delta - \left(\frac{\dot{x}}{z}\right)\sin^2\delta. \tag{2.2}$$

This time, δ does not depend on y or $\dot{y}$. But z still does scale δ.

When we're in a rectilinear motion, there are two important parameters which determine our perception of velocity. First, there is the **optical edge rate** (OER). This is the rate at which local discontinuities cross a fixed point of reference in the observer's view. It depends on the texture and the velocity, but not on the height above the surface. Second, there is the **global optical flow rate** (GOFR), defined as $\dot{x}/z = V/h$. It depends on the velocity and the height, but not on the texture.

Another important parameter is the **time-to-contact** (TTC) $\tau(t)$. Let's suppose that an object is a distance $Z(t)$ away, but travelling towards us with a velocity V. On our retina, this object has a size $r(t)$, but this size is growing with a velocity $v(t)$. It can now be shown that

$$\frac{Z(t)}{V} = \frac{r(t)}{v(t)} = \tau(t). \tag{2.3}$$

So, by using the speed with which an object grows on our retina, we can calculate the time-to-contact. This is another way of acquiring a feeling for three-dimensional depth.