Chapter 4

Hardware

4.1 Introduction

In this chapter we present the hardware used in the scope of the thesis.

At first we detail the CCD cameras and lenses (Section 4.2) and the laser diodes and optics (Section 4.3), i.e. the main components needed to apply the method.

A few words are then given about the interference filters placed in front of the camera sensor (Section 4.4).

Section 4.5 closes the chapter with a short description of the two different video capture boards used to interface the cameras.

4.2 CCD Cameras and Lenses

4.2.1 CCD cameras

One of the important components of a laser triangulation system is the detector, i.e. the CCD camera in our case (as announced in Chapters 2 and 3).

Two distinct models were used in the different applications presented in Part II. Both have similar characteristics in terms of resolution (i.e. the amount of pixels composing the CCD sensor) and sensitivity (i.e. the minimum illumination detected by the sensor), the major differences being in their dimensions and weights. TABLE 4.1 synthesizes their specifications, and Fig. 4.1 shows a picture of each model.

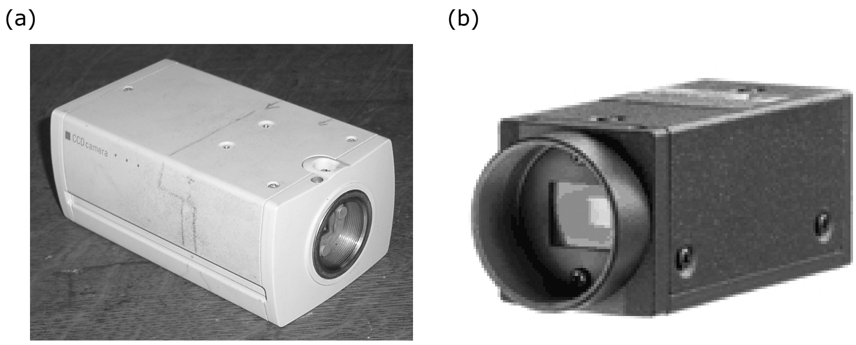

Fig. 4.1. Pictures of (a) the security (#1) and (b) the industrial (#2) cameras.

To summarize, we worked with monochrome 256-gray-level CCD cameras, with a resolution of 768 x 576 pixels, a pixel size of 1/160 mm and a high sensitivity.

TABLE 4.1. Specifications of the CCD Cameras

	Camera #1	Camera #2
Type	Security camera	Industrial camera
Used in Chapters	9–11	12
Color mode	monochrome	
Number of colors	256 gray levels	
Sensor format	1/3"	
Sensor size	4.8 x 3.6 mm	
Resolution	768 x 576 pixels	
Pixel size	1/160 mm	
Minimum sensitivity	0.1 lux	0.3 lux
Signal-to-noise ratio	$>$ 50 dB	$>$ 56 dB
Electronic shutter speed	1/60 – 1/100000 sec.	1/100 – 1/10000 sec.
Power requirement	12 VDC	
Power consumption	$<$ 2.5 W	$<$ 1.5 W
Dimensions	121 x 68 x 49 mm	29 x 29 x 62 mm
Weight	490 g	100 g

It is to be noted that both cameras could have been used for all the applications. The fact we worked with two different models has only to do with practical considerations (the application described in Chapter 12 involved a private partner who wanted his own camera).

4.2.2 Camera lenses

The next important component of our systems is the camera lens, which mainly defines:

- the working distance, i.e. the usual distance between the instrument and the target under study guaranteeing a correct focus;
- the field-of-view, noted FOV, fixing the maximal observable width of the measured object at the working distance, but also the dynamics of the triangulation system in terms of distance (remember that the vertical position of the laser line varies with the distance).

Even though it is a strongly application-dependent part of a vision machine device, we happened to use only two different models of lenses. They are presented on Table 4.2 and pictured on Fig. 4.2.

Table 4.2. Specifications of the Camera Lenses

	Lens #1	Lens #2
Type	fixed focal	
Used in Chapters	9–11	12
Focal length	8 mm	191 mm
Angular FOV (horizontal)	33°	1.5°
Working distance	100 cm	100 mm
FOV at working distance	60 cm	2.4 mm
Depth of field	40 cm – ∞	98–102 mm

The attentive reader will remark that the two lens models correspond to the two particular cases discussed in Chapter 7. We can indeed separate all the applications presented in Part II into two distinct groups: Lens #1 for mid-range applications (see Chapters 9–11) and Lens #2 for the unique close-range application (see Chapter 12).

(a) (b)

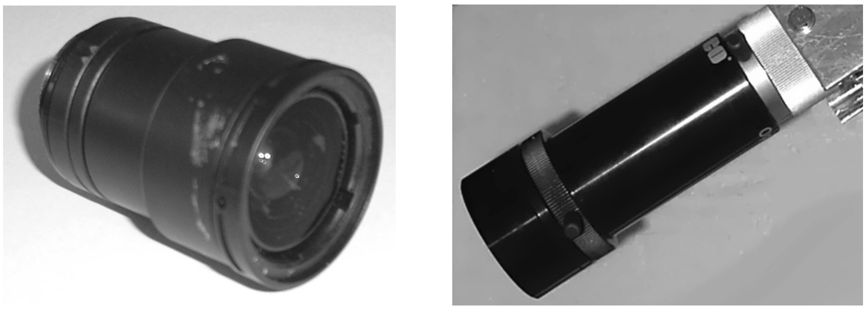

Fig. 4.2. Pictures of (a) the 8-mm (#1) and (b) the 200-mm (#2) fixed-focal lenses.

4.3 Laser Diodes and Optics

Laser diodes, along with their optics, distinguish themselves from each other by the:

- wavelength. We only worked with red lasers for evident cost reasons. Because of the spectral response of CCD sensors (made of silicon), this has the happy consequence of optimizing the sensitivity of the cameras to our lasers;
- output power. It could remain quite reasonable (a few mW) seen the high sensitivity of the cameras described earlier in this chapter;
- type of created laser pattern: single or multiple planes;
- working distance, i.e. the distance at which the laser pattern is best focused;
- fan angle, which is the angular aperture of the laser stripe in its longitudinal direction;
- pattern thickness at working distance;
- inter-beam angle in the case of multiple laser planes: it represents the angular distance between the laser planes, in their transversal direction.

The three different types of laser devices we used are presented on TABLE 4.3 and pictured on Fig. 4.3.

As mentioned in Section 3.2.2, our laser plane generators produce—at a given distance from the source—a uniform flux density along the stripe. Note that in the case of Laser #2, generating three stripes, additional lines of lower

Table 4.3. Specifications of the Laser Diodes and their Optics

	Laser #1	Laser #2	Laser #3
Pattern type	1 plane	3 planes	1 plane
Used in Chapters	9	9–11	12
Wavelength	656 nm	670 nm	638 nm
Output power	3 mW	10 mW	3 mW
Working distance	1 m	1 m	243 mm
Fan angle	40°	30°	constant beam width (25 mm)
Pattern thickness	2 mm	2 mm	16 μm
Inter-beam angle	–	1.5°	–

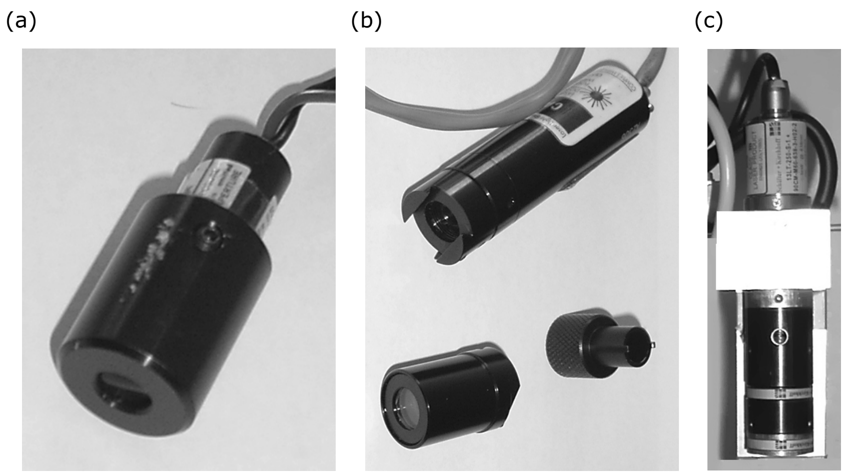

Fig. 4.3. Pictures of (a) the 3-mW 1-line (#1), (b) the 10-mW 3-line (#2) and the (c) the 3-mW micro-line (#3) lasers with their optics.

luminance are observed, because of a grating effect in the generating optics [see Fig. 4.5(b)].

4.4 Interference Filters

Although we have not yet mentioned interference filters, these are of primary importance in our applications.

Seen their extremely narrow bandwidth (typically 10 nm), they are particularly indicated when working with lasers, which produce coherent light emitted in one wavelength only. In each application, we will thus place the appropriate interference filter (i.e. whose bandwidth is centered on the laser diode's wavelength) between the CCD sensor and the lens of the camera. This way of doing ensures us that mostly only the laser pattern will be "seen" by the camera, making image processing easier (see Chapter 5).

In interference filters, discrimination of wavelengths derives from constructive and destructive interferences at partially reflecting boundaries within the filter. Wavelengths within the passband enjoy optimal transmittance, resulting from constructive interferences, while wavelengths beyond the passband are reflected through destructive interferences. The partially reflecting boundaries are formed by depositing films with alternating high and low refractive indexes. These films are of dielectric materials and are deposited on a glass substrate [24].

The main parameters of an interference filter are the:

- central wavelength. Typically used to denote the peak transmitting wavelength of a filter, it is however actually the midpoint determined by the passband wavelengths where the transmittance is 50% of the peak (for interference filters, the peak is usually not at the midpoint wavelength);
- bandwidth, i.e. the wavelength range that the filter passes. This width is defined at a specific transmission value, the standard being to define bandwidth as Full Width at Half Maximum (FWHM);
- peak transmittance, which is the percentage of incident energy transmitted at the peak wavelength;

All the interference filters that we used were the same, their central wavelength excepted, which was chosen appropriately for each laser diode. Their main characteristics are presented on Table 4.4, and Fig. 4.4 shows a picture of such a filter.

On Fig. 4.5 we see the impressive efficacy of such a filter. One can easily imagine how easier the image processing stage becomes with this type of filtering.

Table 4.4. Specifications of the Interference Filters

Central wavelength	638, 656 or 670 nm
FWHM	10 nm
Peak transmittance	> 50%

Fig. 4.4. Picture of an interference filter.

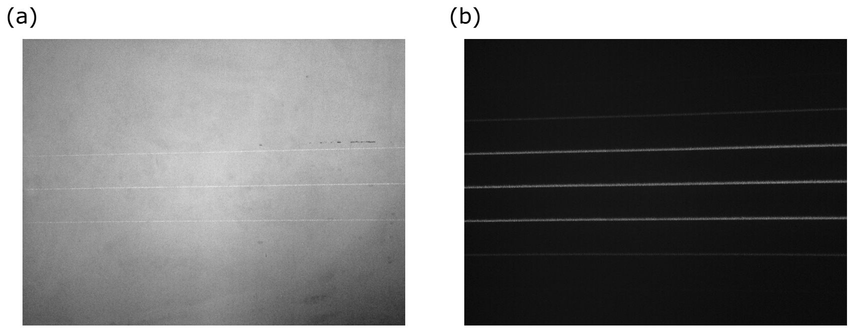

Fig. 4.5. Pictures of a white wall under natural lighting hit by 3 laser planes, (a) without and (b) with the interference filter between the CCD sensor and the lens of the camera. On (b), additional lines of lower luminance are observed, because of a grating effect in the laser generating optics.

4.5 Video Capture Boards

The last component of our devices is the video capture board, used to interface the CCD camera with the PC, in order to allow still image acquisition (our method does not require proper video acquisition).

We used two distinct models, represented on Fig. 4.6, distinguished by the connection mode with the computer: Video Board #1 is connected via the PCI bus, and Video Board #2 via a Firewire port. The latter was only used in the application described in Chapter 12, for which we used a laptop.

In both cases, the camera and the video board are linked with a BNC-to-RCA cable. They of course support the—identical—resolution of the two cameras.

(a) (b)

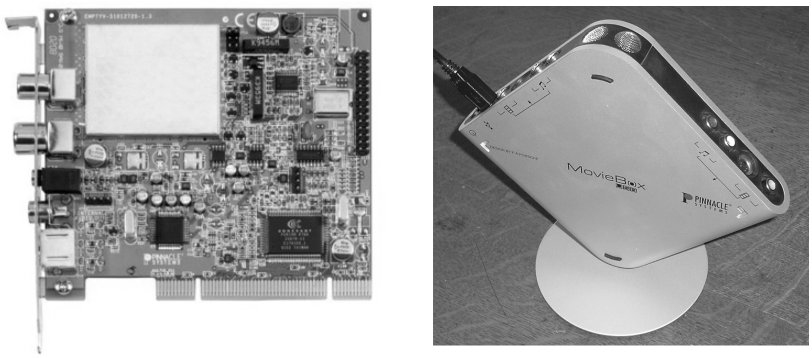

Fig. 4.6. Pictures of (a) the PCI (#1) and (b) the Firewire (#2) video boards.