Chapter 8

Some Existing Ambulatory Devices

8.1 Introduction

In this chapter we present some of the existing devices using structured lighting. In order to stay in the field of interest of the thesis, we limited ourselves to applications taking place in an ambulatory environment.

The aim is not to be exhaustive, but we must say that we found relatively few remote applications using structured lighting. Four of them, described hereafter, have been chosen.

Note that even if this chapter presents structured lighting applications, it is not included in Part II, devoted to our own applications.

8.2 The Biris Range Sensor

The Biris range sensor has been developed at the National Reasearch Council of Canada at the end of the 1980's. The main objective was to obtain a low-cost, very compact, and robust, range sensor for robotic applications in difficult and severe environments. As far as we know, it was the first portable range sensor using structured lighting. A few tens of papers dealing with the Biris sensor have been published, proving the popularity of the device.

This 3-D measurement system derives its name ("bi-iris") from the fact that its functioning is based on a double-slit mask replacing the iris of a standard camera lens [33] [34].

Fig. 8.1 shows the principle of the sensor in a plane parallel to the optical axis of the camera and transversal to the two slits. A reference plane is set by a lens focusing adjustment. For every point P belonging to this plane, the mask in the lens has no effect and a point P' is imaged on the CCD sensor. On the other hand, a point Q closer to the lens will be imaged in Q', and the cross section of the image at the CCD plane will show two points q' and q'' for which the separation is a function of the distance between points P and Q along the optical axis (see [34] for mathematical details).

In order to identify the points to be measured, a laser pattern is projected on the object. The most usual one is a laser plane, which thus produces a double laser curve on the image because of the mask, allowing the reconstruction of the 2-D profile of an object's "slice". Distances up to 3 m can be measured, with a global accuracy of 0.5% [35].

One of the applications using this device is the volume measurement of wood processed by delimber machines [36]. Fig. 8.2 illustrates the method: three Biris sensors, projecting laser planes aligned with each other, are used to measure the cross section of the tree (each 2-D profile is supposed to cover at least 120 degrees of the circumference), which is moving along its axis in order to allow the measurement of the volume.

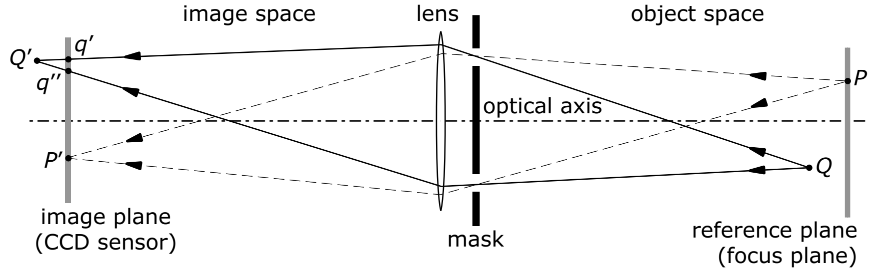

Fig. 8.1. Principle of the Biris sensor.

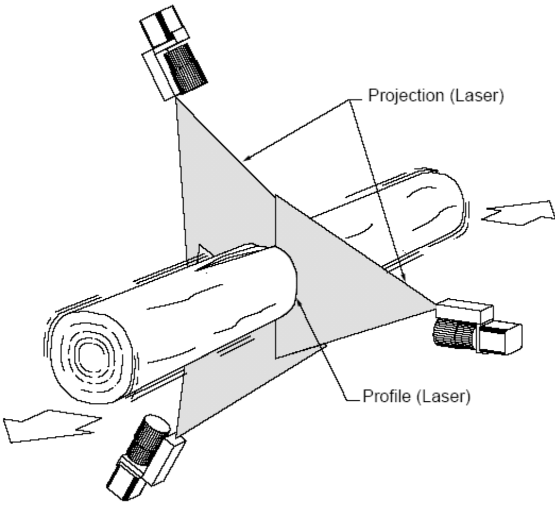

Fig. 8.2. Principle of cross section measurement for the wood volume estimation (taken from [36]).

Note that this technique differs from the one we use for the diameter measurement of cylinders (see Chapter 9) by the amount of sensors used (only one in our case) and by the fact that the object under study can have a random orientation with regard to the measuring head of the instrument (which is not the case in the present application).

Another application uses the same principle: four sensors similar to the Biris range sensor, mounted on a rigid mechanical structure, are used to acquire the 3-D model of a human body [37]. It can not be considered as ambulatory though.

8.3 An Instrument to Measure the Size of Skin Wounds

Many chronically ill people suffer from skin ulcers, which may develop e.g. from minor injuries or behavioral influences such as smoking [38].

The pattern of healing is poorly understood and clinicians need an instrument which will give an objective measure of the dimensions of a wound, so that changes in the short term can be detected. The risk of introducing infection should be minimized by ensuring that the instrument does not touch the patient.

The aim of the work presented in [38] is to produce such an instrument. The principle involved is structured lighting, but instead of using laser patterns, the authors use a data-projector, which has the advantage of letting the user create any desired pattern (via a computer).

This portable device—its dimensions are of 50x30x10 cm—is composed of a color CCD camera and a projector with a 24-V 250-W tungsten halogen bulb. The projected pattern is a slide of alternating red and blue stripes, with a single reference green stripe in the center. The fact that they are using the three primary colors is of course deliberate: the three types of stripes will—more or less—only appear in the corresponding color channel of the camera. The green stripe is used for detecting the center of the pattern while the red and blue stripes, once their central threads are detected, allow the 3-D reconstruction of the skin profile (by the superposition of all the 2-D profiles provided by each stripe). Note that the alternation of red and blue stripes is a mean of doubling the resolution of the device.

The volume of the ulcer is that enclosed by the former healthy surface, which is defined by a cubic spline interpolated between the surrounding areas of healthy skin, and the existing ulcer surface, whose position is defined by the 3-D profile. The perimeter of the ulcer is delimited by the operator who manually traces (after image acquisition) around the wound boundary, using the computer mouse. Note that the edge of the ulcer may be swollen and slightly raised: this leads to a negative volume. See Fig. 8.3 showing the cross section of a typical ulcer.

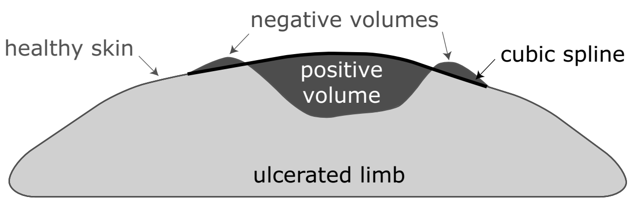

Fig. 8.3. Cross section of a typical ulcer showing the measured and reconstructed surfaces.

Along with the volume, the area is also calculated, the authors claiming an accuracy of 5% on both quantities (the figures have been validated on patients). The experiments helped to confirm the view of some physicians that wounds heal from the base first (and not from the boundary): volume decreases much faster than area at the first place, then area decreases while volume remains fairly steady (cf. Fig. 8.4).

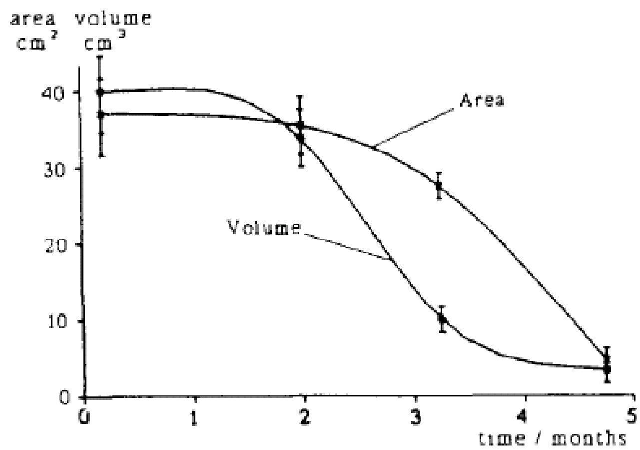

Fig. 8.4. Change in area and volume of an ulcer over a five-month period (taken from [38]).

For mathematical details, see [38].

8.4 A Mars Landing System Using Structured Lighting

A method of 3-D remote sensing relying on structured lighting is presented in [39]. The instrument is composed of a monochrome CCD camera and a laser diode crossing a holographic grating splitting the laser beam to form a grid of laser dots, which would be regularly spaced if projected on a strictly plane surface parallel to the grating.

The use of triangulation on each dot allows the 3-D coordinate calculation of a series of points, leading to a discrete 3-D map of the analyzed surface. Beside the "classical" subpixel center location of the laser dots (similar to that described in Section 5.7.1), the authors propose to rotate the laser pattern by an adequately-computed angle around the axis of the original laser beam. This permits to avoid the superimposition of some dots on the image: without this precaution, it would be possible that two dots in a given column of the pattern, belonging to two adjacent rows, occupy the same region on the image.

The proposed application is a safe landing system, e.g. for a Mars mission. As the authors say, large-scale hazards such as craters would be hard to detect with a structured lighting system, because it would require to work at very large distance from the surface, which would drastically deteriorate the accuracy of the range maps. However, local hazards, such as rocks or steep slopes, could be detected by a properly configured structured light system (see Fig. 8.5).

The authors could not test the system on Mars surface, but their experiments on a reduced model makes them claim that a device projecting a 30x30 grid of laser dots over a 12x12-meter landing site, 35 meters above the ground, with a distance of 2 meters between the optical center of the camera and the laser diode, could identify 75cm-radius rocks and 20-degree slopes (these figures being considered as critical for Mars landings). The full developments are in [39].

8.5 Pipe Inspection Using a Laser-Based Transducer

An original ambulatory application of structured lighting can be found in [40], dealing with in-situ pipe inspection. The aim is to detect defects like cracks and holes, e.g. in the public sewer network.

The proposed sensor system consists of a monochrome CCD camera, a 1-mW, 635-nm laser diode and a low-cost optical diffuser that widens the laser beam into a light ring (cf. Fig. 8.6). The device is mounted on a mobile platform which is moving inside the pipe, along its axis. During operation, the ring projections are continuously acquired by the camera.

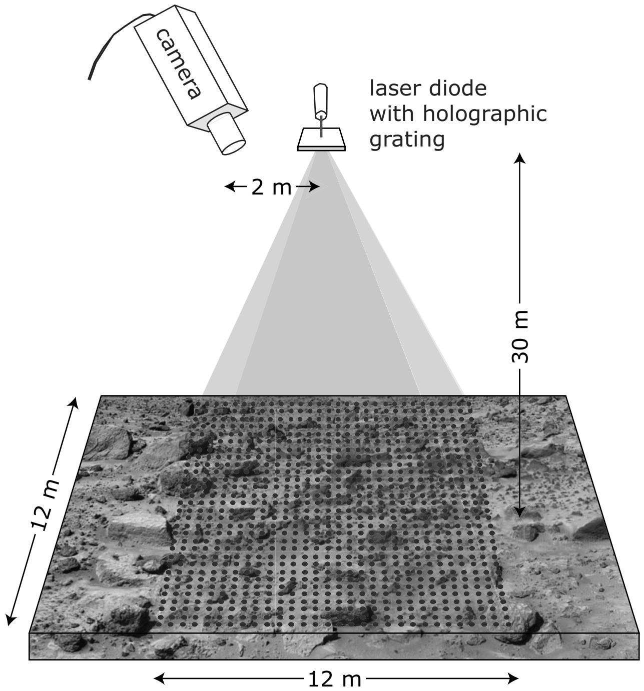

Fig. 8.5. Illustration of the safe landing system based on structured lighting.

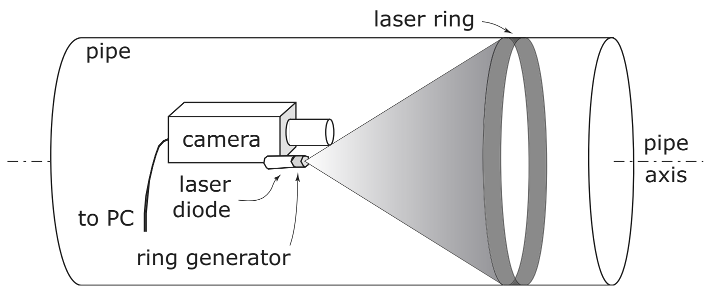

Fig. 8.6. 3-D view of the experimental device.

Considering that the light ring appears as a circle on the image, the location of the surface under investigation relative to the platform can be found by pure trigonometry (using the ring and pipe radii). If the laser is not perfectly aligned with the pipe axis (which will generally be the case), the circle on the image becomes an ellipse whose characteristics (orientation and length of the axes) are extracted by a robust algorithm during image processing, allowing the distance calculation.

The light intensity on pipe defects changes compared to non-defective areas. This phenomenon is due to the characteristics of the reflected light at discontinuities, which is scattered depending on the smoothness of the surface, and reflected according to the basic laws of reflection. Consequently, analyzing the light intensity values of the projected rings allows to detect the angular position of local cracks and holes (cf. Fig. 8.7).

A defect map is thus built knowing the position over time, of the platform and of the light ring referred to the latter. For mathematical details, see [40].

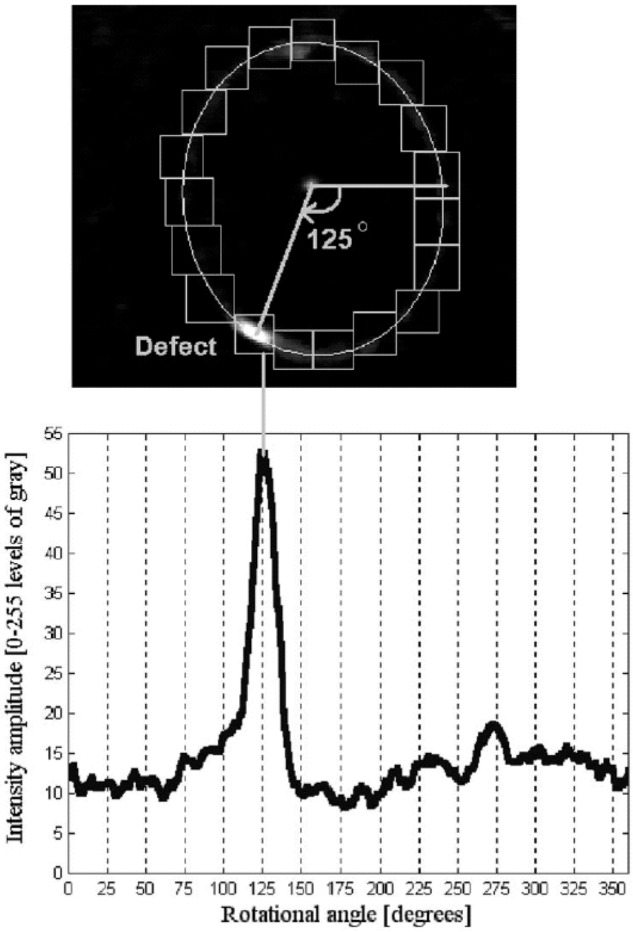

Fig. 8.7. Example of image showing a pipe defect, indicated by the peak in the intensity profile (taken from [40]).